t&UC®
Tunneling & Underground Construction
The Official Publication of UCA of SME
www.TUCmagazine.com
Volume 15 NO. 1 March 2021

Current and future developments
Emerging data-processing technologies
Benefits of digitalization in tunnel construction

Special Editorial Supplement from the publisher of Mining engineering

Access Professional Development on Your Schedule.

Catch up on missed conference opportunities and keep current with industry information.

Purchase individual program recordings or the entire conference.

- NATWeek
- Cutting Edge Conference
- George A. Fox Webinar

Plus, search the extensive UCA library of on-demand content and select a topic of interest, including Young Member Webinars and UCA Webinars.

Visit ucaofsme.org to learn more

UCA Underground Construction Association
A Division of SME

Inspiring tunneling professionals worldwide.

ucaofsme.org

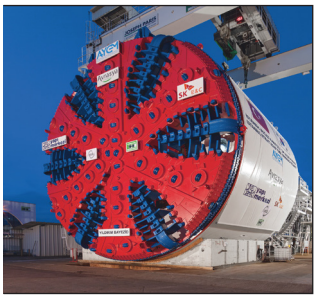
March Contents

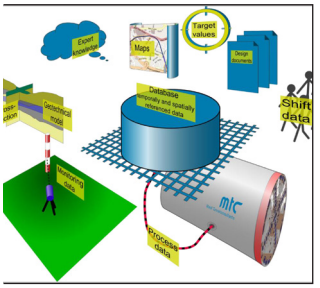
Cover Story

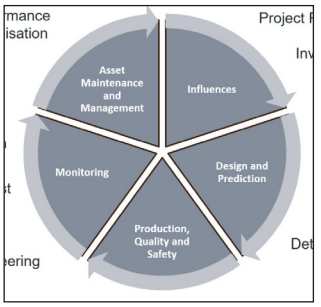
In This Issue

In this issue two of the world's leading manufacturers of tunnel boring machines talk about the future of the industry on page 9. Starting on page 13, Ulf Gwildis, Ulrich Maidl and Jamal Rostami write about emerging technologies and technology transfers to mechanized tunneling projects that have the potential of impacting the tunneling practice and being a disruptive force in the industry. On page 20, Angus Maxwell and Jacob Grasmick write about the various implementations of digitalization and describe efforts to combine all data types to analyze the relationships between influences, predictions and performance in a single digital platform.

Feature Articles







tucmagazine.com

AN OFFICIAL PUBLICATION OF UCA OF SME | WWW.SMENET.ORG | VOLUME 15 NO. 1 | MARCH 2021

UCA forms new strategic plan as a guide for the next five to 10 years

In mid-2020, UCA began a strategic-planning process. At the executive committee meeting in late January, we voted to adopt the main tenets of a new strategic plan for UCA. What does this mean to you as a UCA member? This strategic plan describes the areas of emphasis that UCA, a Division of SME, will pursue over the coming five to 10 years.

The process was extremely beneficial. We began by surveying industry leaders for their feedback on what UCA does well and not so well. The "warts and all" feedback was important and instructive for our deliberations. The executive committee then spent two half-day sessions to:

1. Describe the organizational ideology and vision of the UCA.
2. Identify goals that we will strive to achieve.

The core ideology of UCA is to promote the responsible development and use of underground space. In addition, we retain and promote the SME core values, namely: safety, stewardship, excellence, inclusion, ethics, innovation and collaboration.

The envisioned future we developed for UCA is an unrealized but definite vision for our association. UCA's vision is building a better world through underground construction as a superior, long-term solution.

After this process was completed, we worked to select three strategic goals for UCA to pursue so that we can achieve our vision while upholding our core values and ideology. This exercise is always interesting as it requires us to choose what we want to do from myriad possibilities. These goals are a blend of our aspirations as well as building upon our current work and what we have already achieved. The three goals chosen for our strategic direction are described below, along with objectives to help us get there:

Industry education: UCA is recognized as the preferred forum for exchanging information for the advancement of the U.S. tunneling industry.

Objectives: Enhance relationships around the industry and between industry stakeholders; improve the education of students and young members to ensure a robust industry pipeline of talent and promote publications that educate and provide guidelines for the industry.

Stakeholder awareness: External stakeholders understand the value and support the use of underground space.

Objectives: Increase the positive perception of underground space as a viable solution; investigate a more concerted legislative outreach program and enhance the UCA awards program to increase both industry and external visibility.

Association growth: UCA is valued by members and is experiencing growth.

Objectives: Enhance the value received by each member; increase member diversity at all levels of the association; partner strategically with other associations to expand opportunities for UCA members; enhance financial sustainability and expand individual and corporate memberships.

The most important takeaway is that UCA is your professional association with an overarching purpose to help you meet your career objectives by promoting the industry. As always, I urge you to get involved with UCA and you will reap the benefits. ■

Robert JF Goodfellow,
UCA of SME Chair

EDITORIAL STAFF

Editor
William Gleason
gleason@smenet.org

Associate Editor
Margo Ellis
ellis@smenet.org

Production Graphic Artist
Ted Robertson
robertson@smenet.org

BUSINESS STAFF

Media Manager
Advertising
Gary Garvey
garvey@smenet.org

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

Internet www.smenet.org

ALWAYS ADVANCING

www.terratec.co

TOTAL TUNNELLING SOLUTIONS

TERRATEC offers full range of equipment from pipe jacking machines to open TBMs, from soft ground to 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.

TUNNELLING SOLUTIONS

TERRATEC

Gateway Tunnel could get support from incoming Biden administration

U.S. Transportation Secretary Pete Buttigieg told the U.S. Senate Commerce Committee during a confirmation hearing that the Biden administration plans to move forward on a new $11.6 billion Gateway Tunnel under the Hudson River, connecting New York and New Jersey.

The new tunnel would be built alongside an existing tunnel that is more than 100 years old and in desperate need of repair or replacement. The tunnels were to be part of a $30 billion infrastructure overall to modernize the Northeast Corridor rail line in New York City and New Jersey. That overhaul was largely stalled by the Trump administration.

The comments from Buttigieg contrasted with those of his predecessor, Elaine Chao, who complained to the same panel in March 2018 about what she said was a public campaign "to bully the department, to pressure the federal government" to fund the new train tunnel under the Hudson River.

NJ.com reported that former President Trump at one point threatened to shut down the government rather than approve any federal funding for Gateway.

Buttigieg was answering a question from U.S. Sen. Richard Blumenthal, D-CT, who talked about the need to repair the 111-year-old tunnels that were damaged by Hurricane Sandy. Blumenthal also questioned Chao at that earlier hearing.

"The tunnels are decrepit, degrading and about to potentially collapse," Blumenthal told Buttigieg. "I'd like your commitment that you will move this project, which is essential to all rail traffic and indeed all transportation in the Northeast."

"I've heard this loud and clear from you and your colleagues and counterparts in the region," Buttigieg responded, "and look forward to working with you on this to move forward."

Biden, who as a U.S. senator from Delaware was a frequent Amtrak user, supported Gateway during the campaign.

His infrastructure plan called for "putting the Northeast Corridor on higher speeds and shrinking the travel time from DC to New York by half — and build in conjunction with it a new, safer Hudson River Tunnel."

The Trump administration lowered Gateway's rating, making the tunnel ineligible for federal funding, even as it supported construction of a new Portal

(continued on page 5)

Thames Tideway breaks new ground as super sewer moves one step closer to completion

Tunnel boring of the final 7.6-km (4.7-mile) central section of the main tunnel of the Tideway Project in London, England was completed on Nov. 30 when the tunnel boring machine (Ursula) broke through on the Battersea to Bermondsey Drive at the deep shaft at Tideway's Chambers Wharf site.

The drive is part of the 25-km (15.5 -mile) £4.2 billion Thames Tideway Tunnel (as the super sewer is formally known) project. With the completion of the drive, TBMs working on the project have now successfully passed beneath 21 Thames crossings, including Tower, Waterloo and Westminster bridges and 19 km (11.8 miles) of tunnel boring has been completed.

Mark Sneesby, Tideway's chief operating officer, said: "This is an important day for everyone on the Tideway project, as well as for Londoners and the River Thames.

"With around four-fifths of the tunneling now complete, everyone on Tideway is focused on getting this job done safely and delivering a cleaner Thames for the city."

London News Online reported that the work on the remaining 5.5-km (3.4-mile) section was due to begin soon.

Viv Jones, project director for the central section, said, "The hard work from our teams on site and below ground has enabled us to safely continue tunneling despite COVID-19 — and continue work on this vital piece of infrastructure.

"Ferrovial and Laing O'Rourke, the contractors on the central section, have done a fantastic job, and I thank the teams involved for their efforts to clean up London's iconic river."

As part of its drive, the TBM excavated more than 1 Mt (1.1 million st) of spoil, all of which was removed from site using barges on the Thames — preventing more than 250,000 HGV trips.

Around 240 barges were also used to transport concrete segments to site. These segments slot together underground to form the rings which make up the tunnel. This section of tunnel is formed of 4,227 rings.

Tim Newman, Tideway's project geologist, added, "Completing the longest single drive on the Tideway project is a wonderful milestone, and our teams have made great progress through a challenging year.

"TBM Ursula has tunneled at incredible depths, encountering a real mix of geology — through clay, sand, gravel and chalk. The expertise required for such a task is immense and allowed us to quickly and safely adapt the tools on the cutterhead as needed." ■

Two Central Subway Program projects win awards from International Tunnelling Association

Each year since 2015, the International Tunnelling and Underground Space Association (ITA-AITES) has recognized the best tunneling and underground construction projects from around the world with its ITA Tunnelling and Underground Space Awards.

This year, two projects associated with the Central Subway Program in San Francisco, CA — the Chinatown Station of the Central Subway Program and the Union Square Market Street Station — were honored by the ITA as Project of the Year (between €50 million and €500 million) and as the Innovative and Contributing Underground Spaces winner, respectively.

Chinatown Station is one of three stations for the Central Subway Project, a north-south LRT extension. Chinatown is a vibrant commercial and residential district with the city's highest population density.

Chinatown Station project was one of the most challenging engineering and underground construction projects in the United States due to its setting in narrow streets, historic buildings, numerous utilities and poor ground conditions. The station's main elements are the Station Platform and Crossover caverns combined. The overall main cavern dimensions are 192 m (630 ft) long by 16.7 m (54.7 ft) wide and 13.1 m (43 ft) high with an excavated cross section of 202 m^2 (2174 sq ft), making it one of the largest conventional tunneling excavations in poor ground and soil-like materials in the United States. The main station entrance and service facility are located off-street and connected to the platform cavern via a cross-cut cavern. This enables the construction of the station cavern in two directions simultaneously, running as many as four operations. Due to ground variability and the risk of conventional tunneling, a pre-support system comprised of grouted steel pipe arch canopies were provided and face bolts were used in the center drift. To protect adjoining buildings, including the Mandarin Tower and the historic Presbyterian Church, an instrumentation and monitoring plan was developed using multipoint extensometers, inclinometers and total stationing. Compensation grouting was implemented to maintain the settlement in impacted structures to less than 12 mm (0.47 in.).

Also part of the Central Subway Program is the Union Square Market Street Station where battered drilled shafts were used as permanent ground support, earning this section of the project the award from ITA for Innovative and Contributing Underground Spaces.

The Central Subway Project in San Francisco, CA is a 2.7-km (1.7-mile) long subway extension with three underground stations and one surface station. The project will improve public transportation by extending the Muni Metro T Third Line through South of Market District, Union Square and Chinatown. The south entrance will be integrated with the existing BART/MUNI Powell Street Station, providing a direct connection between the two transit lines. To the north, the main entrance will be at the southeast corner of Union Square on Geary Street. A portion of the famous Union Square Garage and Plaza will be repurposed to house the main points of egress as well as two emergency ventilation shafts. The station is approximately 289 m (950 ft) long. Its overall configuration is divided into three areas: the North Concourse, the Platform and the South Concourse. The North Concourse is about 61 m (200 ft) long and 16 m (55 ft) below the roadway. The Platform is approximately 122 m (400 ft) long and ranges in depth from 27 to 30 m (90 to 100 ft). The South Concourse is about 76 m (250 ft) long along Stockton Street and another 31 m (100 ft) as it wraps along Ellis Street. The depth ranges from about 6 to 9 m (20 to 30 ft) as it ascends north. ■

Gateway: Tunnel could be on track for 2028 completion

(continued from page 4)

Bridge over the Hackensack River. That agreement was signed during the final days of his administration.

The Gateway Program Development Corp. hopes to have a new tunnel completed by 2028.

As reported by *Bloomberg*, New York Sen. Chuck Schumer hinted at the favorable prospects of the tunnel project receiving funding in a recent video call with reporters and members of The Riders Alliance, a grassroots organization fighting for improved — read: affordable and more reliable — public transit in New York.

During the call, Schumer said that he was working with the Biden administration and Buttigieg to "unleash" $12 billion that would be made available to the Gateway Program. Per *Bloomberg*, Schumer also relayed during the call that he has implored Buttigieg to give the Metropolitan Transit Authority federal guidance on moving forward with a Manhattan congestion pricing scheme that will help to foot the bills of billions of dollars in other transit-related projects.

The Senate secured $1 billion in federal funding for the Gateway Program in 2015. However, the Gateway Program Development Corp. has been waiting for further funding to tap into it and begin the various necessary federal review processes per the *Gothamist*. ■

Melbourne Metro project part of huge infrastructure spending in Australia

Tunneling projects such as the Melbourne Metro project in Victoria, Australia are part of larger infrastructure investment plans in Australia that authorities are turning to as a means to boost the economy following the COVID-19 pandemic.

Infrastructure Partnerships Australia Chief Executive Adrian Dwyer said administrations across the country were planning to spend a combined $225 billion on general infrastructure over the next four years, with the growth in expenditure outstripping that of other public spending.

The *Sydney Morning Herald* reported that governments across the country will inject an extra $46 billion into the economy through roads, school upgrades and social housing.

Analysis compiled by Infrastructure Partnerships Australia shows the response by federal, state and territory governments will be worth almost $17 billion extra in spending on infrastructure in the current financial year before stepping up even further in 2021 and 2022.

The Melbourne Metro project, due for completion in 2025, is a 90 km (55 mile) long suburban rail loop. The Victorian Budget 2020/21 invested $2.2 billion to kickstart this procurement process, buy the land required for the tunnel boring machine (TBM) launches and facilitate construction of the six new underground stations.

The Suburban Rail Loop is a critical investment in Victoria's long-term liveability, and will support Melbourne's continued growth to a global city of up to nine million people by 2050.

Prior to the global pandemic $53.3 billion was expected to be spent on infrastructure in the 2020-21 financial year in Australia, but this has grown to $66.9 billion with the biggest individual spend by New South Wales.

The federal government will double its infrastructure spend this year to $10.9 billion before increasing to $13.7 billion by 2023-2024 while the government in Victoria will almost double its spending to $18.1 billion by the same year.

Rail projects at the state level have contributed heavily to the large increase in expenditure. NSW is sinking $28 billion into the Sydney Metro program while Victoria is spending $19 billion on the Melbourne airport rail link, the suburban rail loop and Geelong fast rail.

Infrastructure Partnerships estimates governments have committed to spending the equivalent of the planned Western Sydney Airport every month for the next 48 months on new infrastructure.

Spending will peak at $71 billion in 2021-2022 but will remain elevated in the years after. In 2023-2024, governments still expect to be spending more than $66 billion on infrastructure. ■

AMT, Brown and Caldwell selected for water quality project in Virginia

The Virginia Department of Transportation (VDOT) has selected a team of A. Morton Thomas and Associates Inc. (AMT) supported by team partner Brown and Caldwell to assist in implementing its municipal separate storm sewer system (MS4) program.

Encompassing more than 80,000 km (50,000 miles) of roadways, more than 1,000 stormwater management facilities and more than 15,000 regulated outfalls, VDOT's MS4 is authorized to collect and safely discharge excess stormwater into bodies of water within urbanized areas of the Commonwealth in adherence with Virginia Pollutant Discharge Elimination System (VPDES) permit limits. VDOT's MS4 program addresses control measures and special conditions to monitor and reduce pollutants discharging from its sewers, ensuring permitted total maximum daily load requirements are met to protect the water quality of streams, rivers, wetlands and bays. VDOT's storm sewer system is unique in that it is integrated with municipal systems across the Commonwealth. The AMT/Brown and Caldwell team will assist VDOT in working with these municipalities to address issues related to interconnectivity statewide.

The team will work alongside VDOT's MS4 and stormwater management leadership to review and enhance stormwater management guidelines, policies, standards and specifications, and manuals to ensure ongoing VPDES permit compliance. Additionally, the team will provide inventory, inspection and data-management solutions to identify, catalog, assess and monitor assets through enhanced data analytics and establish as-needed maintenance strategies. A thorough training curriculum associated with MS4 program requirements including design, construction, maintenance, and pollution prevention will also be developed.

"We are honored to be selected and our vastly experienced local team is committed to helping Virginia continue to meet its water quality regulatory requirements," said AMT project manager Ginny Snead, PE, CFM. ■

HNTB selected to develop first-of-its-kind tunnel to Ontario Airport in San Bernardino, CA

The San Bernardino County Transportation Authority (SBCTA) recently selected HNTB for the project and construction management services contract for its first-of-a-kind, emerging-technology tunnel mobility solution to Ontario Airport in San Bernardino, CA.

HNTB will work with SBCTA to procure, select and oversee a design, build, operate and maintain — known as DBOM — developer for the project. This unique project will connect the airport with the Rancho Cucamonga station area via a 6.6 km (4 mile) long tunnel that moves passengers using autonomous-vehicle technology.

The project is expected to get underway in the third quarter of this year. Completion is expected within 48 months.

"The Ontario Airport Loop project is a transformational project for our region that will improve mobility, reduce traffic congestion and have a significant positive impact on the environment for our residents as ONT continues to grow," said Carrie Schindler, SBCTA director of transit and rail. "Total cost will be about $85 million when adding an operations center, management services and paying operators prevailing wages."

"This is 15 times less than a $1 billion to $1.5 billion surface rail extension from the Metrolink San Bernardino Line, or other alternatives considered, and could be built in four years rather than the 10 years it would take to fund and extend a more traditional connection," added Schindler.

Implementation of this project will transform the station into a multimodal regional hub. It will connect the future Brightline passenger rail service to Las Vegas via Metrolink from the City of Los Angeles, while offering services for travelers to get to Ontario Airport as well.

"The concept of moving people in more efficient and cost-effective ways — while optimizing fixed infrastructure costs and deploying emerging technologies such as autonomous vehicles — is the future of mobility services in the United States," said Ian Choudri, HNTB project manager and senior vice president. "When completed, the project will transform the San Bernardino region by reducing congestion, improving the environment and attracting more businesses and airline traffic to Ontario Airport. At the same time, this project will set a gold standard for the country to refer to and deploy similar systems to improve quality of life for residents." ■

Sandvik to acquire DSI Underground

Sandvik has signed an agreement to acquire DSI Underground, the global leader in ground support and reinforcement products, systems and solutions for the underground mining and tunneling industries. The company will be park of Sandvik Mining and Rock Solutions.

"This acquisition is an important step in our growth ambition. DSI Underground's track record of driving progress and safety in underground operations and its global reach will further strengthen our world-leading market position within mining and rock solutions," said Stefan Widing, president and CEO of Sandvik.

DSI Underground is present in 70 countries, with 22 production units situated close to end customers. The product offering includes bolting systems, injection chemicals and resin capsules.

"With the world's most extensive choice of ground support products and systems, the DSI Underground's offering is highly complementary and enables us to deliver greater value and safety to our customers. The deal gives DSI Underground access to Sandvik's substantial research and development, global service and sales network, complements our growing aftermarket business and strengthens our leadership in underground mining and tunneling," said Henrik Ager, president of Sandvik Mining and Rock Solutions.

DSI Underground has approximately 2,000 employees. DSI Underground's revenue for 2020 is expected to be about €518 million (excluding the four joint ventures that are part of the acquisition) and it has an EBIT margin that to a certain extent will be dilutive to Sandvik Mining and Rock Solutions' margin. The purchase price is approximately €943 million on a cash and debt-free basis. Impact on Sandvik's earnings per share will be slightly positive.

The transaction is expected to close by mid-2021 and is subject to relevant regulatory approvals. ■

Robbins enters a new chapter as Global TBM Company

Global TBM Company, newly established by industry veteran Lok Home, announced the recent purchase of substantially all the assets of The Robbins Company. The company will operate as Robbins and with Home as the president and CEO. The acquisition will result in a seamless transition for a number of ongoing projects throughout the world, as Robbins renews its commitment to service, quality underground equipment and top-notch support that its customers have come to expect.

Home said the company has a bright future as a result of the transaction. "We are starting off the new year with a respectable backlog of orders," he noted. "In 2021 and beyond, our clients can depend on Robbins to deliver high-quality machines, and technically superior machines for very difficult projects," said Home. "That's where Robbins really stands out."

Home went on to say that Robbins is starting 2021 with no significant bank or institutional debt. "We have many projects to look forward to," he continued. "Robbins is currently delivering Crossover machines and TBMs equipped for challenging geological conditions in many countries including the United States, Norway, India, China and Canada." The company's conveyor and small boring machine divisions will also continue to deliver equipment worldwide.

Home emphasized that Robbins has always been focused on building the best and strongest machines. He pledged that the company will continue to do that. "We still have our strong engineering team and we plan to continue our many industry involvements including the International Tunneling Association (ITA) and its associate member organizations. We're glad to be a part of this community and this industry," Home added.

Robbins tunnel boring machine.

The company expects to continue with exciting new developments as well, including a soon-to-be-unveiled noncircular rock boring machine. Robbins remains focused on creativity and innovation to solve the industry's greatest challenges. ■

High-speed rail line receives renewed interest

A decades-old plan to build a high-speed railroad connecting New York, NY and Boston, MA that could include a 16-mile tunnel under Long Island Sound has received renewed interest in part from President Joe Biden's promise to invest $2 trillion clean energy infrastructure.

The *Associated Press* reported that the new North Atlantic Rail plan was developed at University of Pennsylvania planning studios. It calls for improving existing lines and building new infrastructure, including boring the 25-km (16-mile) tunnel, to create an electric high-speed line that would allow travel at well over 321 kph (200 mph) and cut the current train trip of about 3.5 hours between the two cities to just over 1.5 hours, officials said.

Amtrak's current trains can go as fast as 241 kph (150 mph) but travel much slower than that on much of the current aging track.

The price tag for the project is estimated to be more than $100 billion.

"This probably should have been done decades ago," said Hartford Mayor Luke Bronin, who is a co-chair of the coalition of interests pushing the plan.

Robert Yaro, a planner at the University of Pennsylvania and the former president of the Regional Plan Association, developed the latest model. Because of recent improvements in tunneling technology, he said, it's not as far-fetched as it sounds.

"There are 36 tunnels of this length or longer that have been built or are under construction around the world in the last 10 years alone — over 100 in the last 20 years," he said. "This is what the world is doing."

Critics have noted that officials have failed to get local and environmental approvals for much smaller transportation ideas, such as an expressway that would link Hartford and Providence, RI, or even an expansion of state Route 11 in eastern Connecticut, a highway meant to finish a link between Hartford and New London, that currently dead-ends after 11 km (7 miles).

U.S. Sen. Richard Blumenthal, a Connecticut Democrat, said that with the commitment of Biden and Transportation Secretary Pete Buttigieg to improving transportation infrastructure, he is among those who believe the time is right to start thinking about improving train travel in the Northeast.

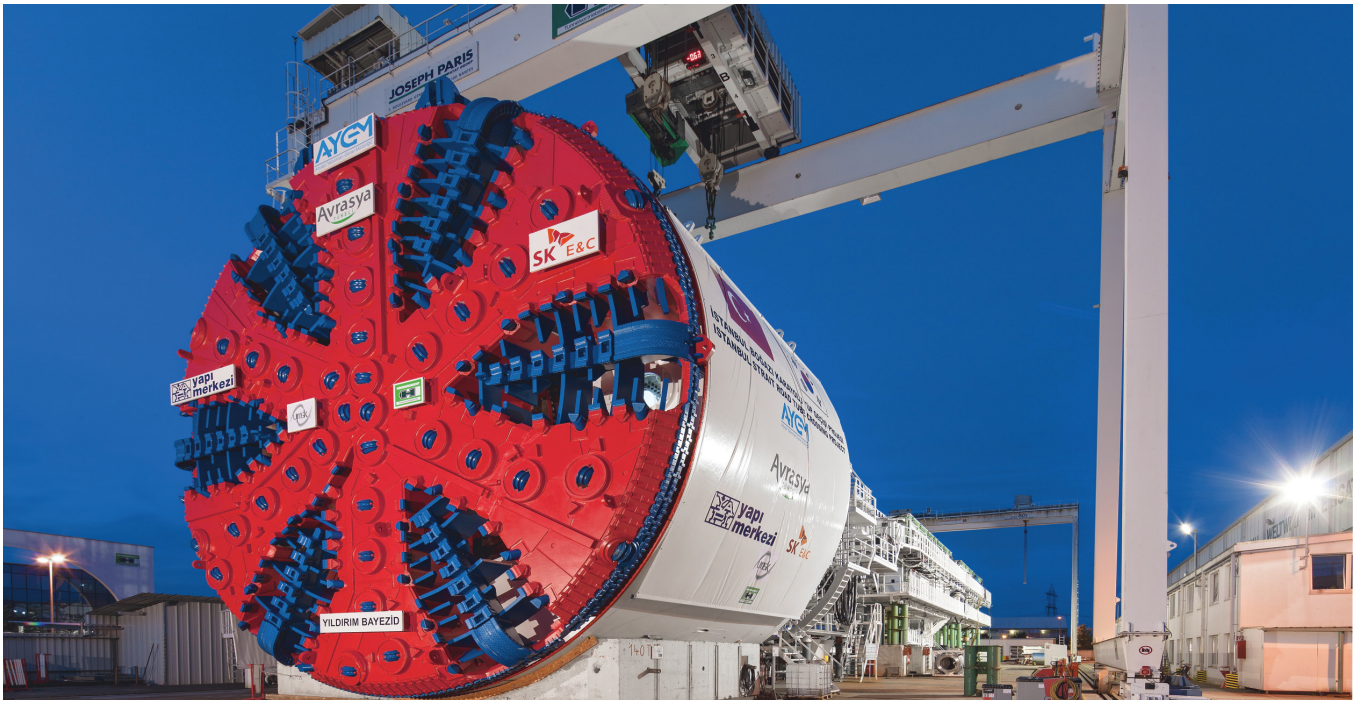
But Blumenthal said the focus should be on rebuilding the Hudson Tunnel in New York and the existing tracks between that city and New Haven. ■

Current and future developments;

Insight from two of the world's leading TBM manufacturers

by William Gleason, Editor

The 3.34-km (2-mile) crossing under the Bosphorus for a two-story road tunnel was completed in about 16 months. The large-diameter Mixshield (13.6 m or 45 ft) tunneled to the deepest point of 106 m (350 ft), with a prevailing water pressure of 11 bar.



A number of factors and influences including environmental and societal changes have increased the demand for more tunnels in cities around the world. There are many large-scale transit and water tunneling projects currently underway and more are on the horizon.

Tunnel boring machines (TBM) are the primary means of building the tunnels. The editors of *T&UC* reached out to two of the world's largest manufacturers of TBMs, Herrenknect and Robbins, to get insight into the future developments in the industry.

The following is the response from each company.

Steffen Dubé, president and general manager of Herrenknecht Tunnelling Systems USA Inc. and Jack Brockway, consultant, former president and general manager of Herrenknecht Tunnelling Systems USA Inc. spoke on behalf of Herrenknect.

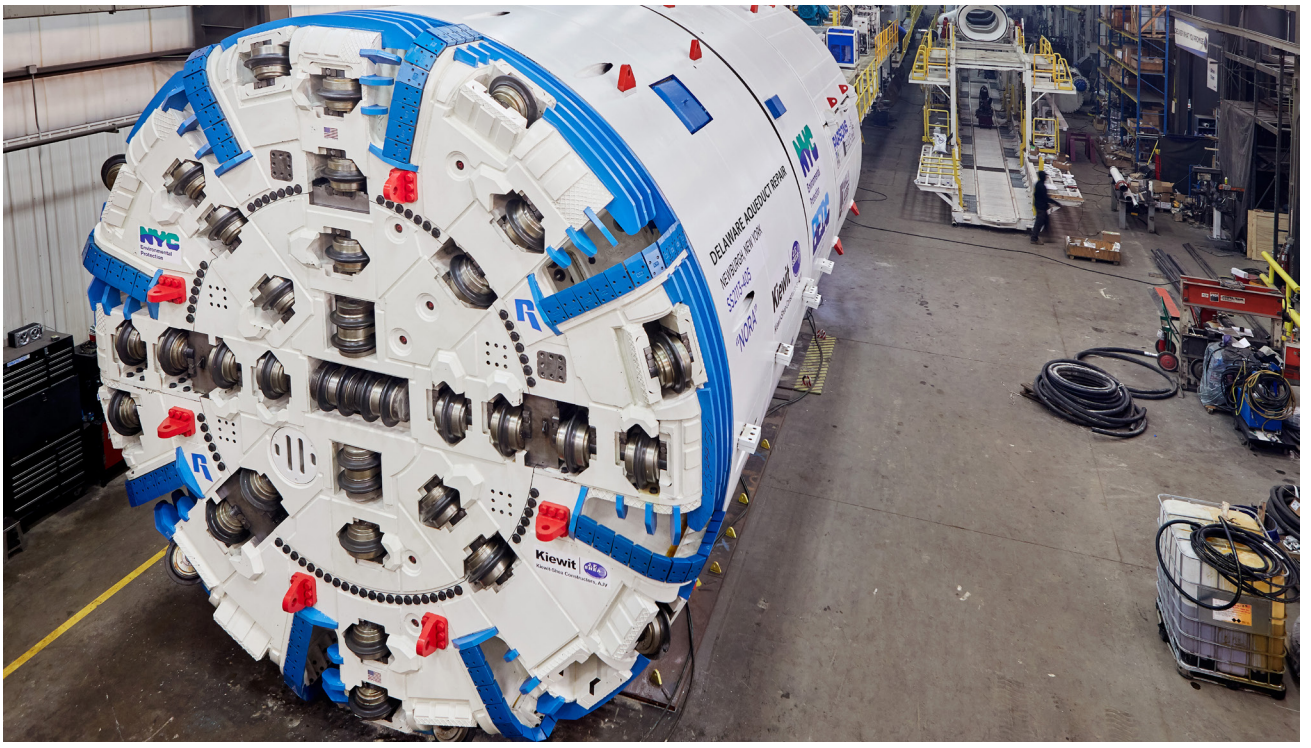
Robbins was represented by Doug Harding, Robbins vice president, and Brad Grothen, Robbins technical director.

T&UC: Society has embraced the idea of underground infrastructure in modernizing and developing towns and cities across the world. Globally there is currently a significant demand for new TBMs that seems to be increasing well into the future. How do you see the few premier TBM manufacturers meeting this challenge?

Herrenknecht: Even with a further increase of the demand, based on the current market situation, we would not spot manufacturing capacity issues. Herrenknecht sees itself as a recognized, trusted partner for contractors in mechanized tunnel and pipeline construction in the United States. With our innovative machines we are involved in very complex infrastructure projects and customer-oriented services. We regularly find that our project partners greatly appreciate targeted and project-specific support of their construction activities. Quality and service are generally highly valued, especially for projects with complex challenges or multilayered parameters. We can count on a top team in the United States that works closely and very successfully with our headquarters in Schwanau, Germany. As a family business, we want to continue to provide lasting impetus to the market well into the future.

Brad Grothen, Robbins: Robbins is looking forward to the new challenges that come with improving our cities and infrastructure in geology. While there are fewer

A Robbins TBM used for the Delaware Aqueduct Bypass Tunnel. The tunnel is the largest repair project in the 177-year history of New York City's water supply system. Its centerpiece is a 4 km (2.5 mile) long bypass tunnel that DEP is a 180-m (600-ft) tunnel under the Hudson River.



manufacturers, there is not a shortage of manufacturing capacity to meet this demand. As in the past, the biggest challenges for those looking to build tunnels will be making sure that contractors have the necessary skills and that the correct machine is employed to build their tunnel.

Doug Harding, Robbins: We see that there is adequate capacity to manufacture the machines; however, the supply chain for the components has been challenged due to the COVID-19 pandemic. We do see as the vaccine is distributed and the number of positive cases starts to reduce, this will bring back confidence in the supply chain.

T&UC: TBMs have been pushing the envelope on what has previously been attempted for the last several decades. What do you see as the greatest challenges for TBM tunneling in the next five to 10 years?

Brad Grothen, Robbins: There have been significant advances in excavation rates, tool performance and reliability in the past and there will continue to be incremental progress in these areas moving forward. Robbins sees the primary areas for development being associated with the efficiency of machines designed to excavate in the most difficult geology, and their ability to do so in a safe manner in a very cost-competitive environment.

Herrenknecht: In recent decades, diameter, face pressure and variable ground have been the development targets. While such factors will continue to be important drivers for development we expect to see additional ones in digital development, automation, sustainability and of course — as has always been — ensuring the highest safety and quality standards must never be at stake.

Looking at the small diameters the demand for increasingly long drives in smaller diameters leads to new technical solutions to install tunnel systems and pipelines exactly where they are needed without harming the environment while protecting aboveground structures.

Our niche in civil engineering is an engineering business for real specialists and pioneers. It profits from technological innovative strength and the enormous diversity of highly specialized companies. Machine technology and customer-specific services optimized for projects and market requirements are not a series or platform business. Technological progress at Herrenknecht is therefore always carried out in well-balanced steps, backed up by expertise, and in partnership.

Doug Harding, Robbins: The challenges will be for TBMs that can cope with a wide range of geology along the same alignment. Machines need to be able to efficiently operate in varying conditions, high pressure, and faulted and fractured geology and tunnels that are deemed to be gassy.

T&UC: What new features and innovation for TBMs are realistic and how much can future project challenges be met with this technology?

Herrenknecht: Technology trends such as digitalization and remanufacturing for an optimized ecological footprint of the projects as well as the further development of established technologies and methods open up interesting opportunities. A major driver for equipment development might also become a future shortage of skilled personnel willing to work underground.

Innovative infrastructure solutions can become additional drivers — on both a large and a smaller scale: the proven mechanized shaft-sinking technology (VSM), for example, can help relieve the tense inner-city parking situation in many places as property prices continue to rise. On a small footprint, with the U-Park system, there is room for many parking spaces in underground shafts with automatically operated parking towers.

The potential of innovations for future project challenges we also see in mining. Due to the constantly growing demand for ores, it is becoming more and more attractive to extract raw materials underground at increasingly greater depths. Whether and when deposits are profitable also depends on the efficiency of the technology used to extract ore deposits. We have therefore used our expertise in mechanized tunneling to develop innovative machine concepts for a variety of applications in mining to make the construction of underground infrastructure in mines safer and more efficient. For example, the first projects with shaft boring roadheaders (realizing shafts 8 m (26 ft) in diameter) demonstrates the potential: twice as fast and safer.

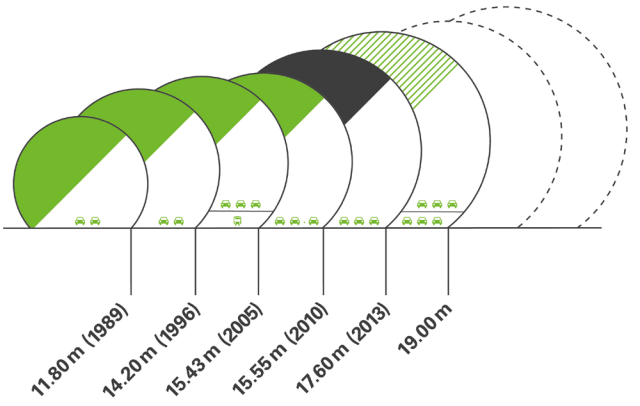
Doug Harding, Robbins: Developments in technology related to ground prediction along the alignment and ahead of the boring information can be invaluable and allow the TBM to be prepared to minimize risk as the geology changes. We also see the technology of data collection on TBM operations to be valuable to detect early failures or improve efficiency of the tunneling operations. Advances in robotics also have a place to allow remote entry into the muck chamber for cutter inspection and changing, which creates a safer environment for the operating crews.

Brad Grothen, Robbins: In some ways the better question is "how do we make our future projects open to new features and innovation?" Since most projects are bid on lowest price with very risk-averse clients, how do we bring innovation into this market?

T&UC: What areas will further automation and digital development enhance TBM operations?

Brad Grothen, Robbins: Digital development, such as data-collection systems that are installed on the machines, now allow contractors to analyze and identify areas in their operation for further improvements. They also allow the owners to better understand how the tunnel was built and better track how it will perform in the future. Care should be taken that these systems are used to enhance operation and the betterment of the industry and not as a legal tool.

High-capacity infrastructure is needed to cope with the demands of mobility and flexibility of people living in metropolises. The bigger they are, the more road lanes can be integrated — parallel or on two levels, sometimes with a metro in the lower section. Moving from one record to the next calls for proven expertise and trustworthy partnership between all parties involved. The latest supersize benchmark with a diameter of 17.6 m (58 ft) was set in Hong Kong. A machine and tunnel concept already has been developed for 19 m (62.3 ft) in diameter.



Herrenknecht: In addition to the mentioned factors and areas, the integration of performance-related elements of the jobsite is ongoing. The interlinking of jobsite systems in order to achieve best possible results will continue. For example, the monitoring and reporting system going along with Herrenknecht slurry treatment plants (STP) that are operating today not only provide information for the STP operator, it combines datas of the slurry treatment plant and the tunnel boring machine. With this information, the STP operator is able to react proactively in terms of important changes in the TBM drive and it also enables the TBM crew to react promptly to bentonite or separation matters.

Contractors are currently using virtual simulations for training purposes. This can improve the safety and performance of projects significantly as steep learning curves can often be achieved and errors avoided during the operation of the machine. Herrenknecht supports the development of training centers with know-how, hardware and software. A highlight is the erector simulator. It is a virtual learning system for efficient ring-building training and in consequence for decreasing ring building times during operation (latest version with 3D glasses).

Herrenknecht Remanufacturing, reduced eco-footprint, 100 percent warranty. Compared to the production of a new machine, the energy savings can reach around 80 percent, and the material consumption reduces up to 99 percent. The Herrenknecht remanufacturing process complies with the strict ITA guidelines and consists of six steps. Remanufacturing involves directing the product to an entirely new life cycle. The remanufactured systems and components can be regarded at least "as good as new." Variety of test and inspection methods to determine the condition of components, for example, ultrasonic testing is used to detect internal damage.

T&UC: Regarding artificial intelligence (AI), what are the biggest advancements in regard to tunneling and underground construction? For example, could this lead to automated operation with a real-time understanding of ground; prediction capability in conjunction with TBM operating parameters and what other areas can be developed?

Brad Grothen, Robbins: There is certainly potential for the application of AI in the tunneling industry and it is already being utilized in areas like prediction of ground behavior, such as squeezing ground. One of the strengths of AI is its ability to form algorithms between variables that are not well understood. To do this it takes a lot of clean data where the right decisions and variables are presented. In the coming years AI will certainly be used as a tool to assist operators in making better decisions, especially in areas that have significant economic impact that make the development of the algorithms a worthwhile investment. An example of this would be the relationship between subsidence monitoring sensors and pressure sensors to more accurately model the geology reaction to the machine's operating parameters, allowing adjustment in near real time. A fully automated machine utilizing ground prediction is still some time off, but the industry and TBM operations will certainly be benefiting in ever-increasing amounts.

Herrenknecht: Yes, these topics named in the question are the key elements regarding AI in the area of tunneling and underground construction.

T&UC: Are there developments in material technology that will have an impact in the next decade?

Herrenknecht: For the predominant material of a TBM, the steel, we would not expect step changes. However ongoing developments in special materials, for bearings, excavation tools and seals will bring continuous improvements there. New manufacturing methods like 3D printing however could trigger further developments. New developments on the tunnel-lining side may, in reverse, have influence on TBM technology.

Doug Harding, Robbins: This will come, in particular for higher abrasion resistant materials for wear areas on the machine. Advances and developments in chemicals to treat the ground and grout technology to support the ground are also advancing and need to be adapted to TBMs.

T&UC: Will we see a maintenance-free TBM with high TBM availability in the next 10 to 20 years?

Herrenknecht: We expect to see far more industrialized processes on TBMs, though probably not a fully maintenance-free TBM. In addition to the tunneling technology for successful tunneling projects, excellent operational service support is a decisive factor to prevent downtimes on the jobsite and enable optimal advance rates. In the future, web-based digital service solutions will also play an important role for smooth tunnel missions. As part of a digital service platform, Herrenknecht is therefore currently developing an e-maintenance tool and an e-shop for spare and wear parts.

Doug Harding, Robbins: The TBMs themselves have been shown to be very reliable along with the muck-handling systems. What we need to focus on in regard to improvements in tunnel availability should be ground conditioning and monitoring along with logistics throughout the complete operation cycle. This will help to improve the overall availability of the tunneling operations. ■

Emerging data-processing technologies for TBM projects — state of the art and outlook

The old miner's saying 'All is dark ahead of the pick' captures the uncertainty of geology and geotechnical conditions in mining as well as modern-day tunneling. Rapid technological advances in machine manufacturing allow tunnel boring machines (TBM) to be used in ever more challenging ground conditions. The new generations of TBMs have a significant level of sensory systems built in with the collected data available for analysis in near real-time. Data collection and processing provides increasing opportunities for analyzing the tunneling process, inferring face conditions encountered during tunneling, optimizing performance and providing and maintaining building information modeling (BIM) models for use over the design life of the underground structure. This article offers a snapshot of the current state of data collection and processing in tunneling for a variety of end uses and offers some thoughts on emerging technologies and technology transfers to mechanized tunneling projects that have the potential of impacting the tunneling practice and being a disruptive force in the industry. The discussion will provide a brief background on how the big data is changing tunneling and how these emerging technologies are being implemented in different projects.

Data sources

The basic requirement for success in any tunneling project is sufficient data on the geological and geotechnical conditions along the alignment. Geotechnical exploration provides this data by characterization and testing of a limited amount of sampled material and from field testing and monitoring of instrumentation, specifically installed for the project. Existing geological maps and geotechnical archive data supplement the data base used for predicting the subsoil conditions that will be encountered during tunneling. The design objectives and boundary conditions that are to be considered, including estimating the interaction of geotechnical conditions, tunnel and existing structures go into the planning and design process and result in the documents that become the basis for the bid process, selection of the tunneling contractor and execution of construction.

The construction process itself is the source of huge amounts of data from various sources that provide the opportunity to add to the project data base more detailed information on subsoil conditions within and beyond the tunnel envelope, the behavior of the various geotechnical units in response to tunneling and the interaction of the tunnel and surrounding ground. This data can serve to add to the understanding of the subsoil condition(s), thereby either verifying the contractually defined subsurface conditions or identifying differing site conditions (DSC), the latter allowing the contractor to consider a DSC claim and request for modifications of the cost and time schedule if material impact on the tunneling process is determined. Ideally, the data collected during the construction phase is used by all project stakeholders to advance the project in the most effective and efficient way. However, shielded tunneling methods do not allow direct observation of the tunnel walls and in the case of pressurized face units, limited to no access to observe the face, and thereby require some interpretation of ground conditions. This offers the opportunity for correct or misinterpretation of the actual tunnel face conditions encountered.

Construction process monitoring data, TBM operational parameters, instrumentation data on subsurface deformation and hydrostatic head variations, and survey data including INSAR satellite data on ground surface movement add to the data base for analyzing cause-effect relationships. Sharing the data between the project parties constitutes the commonly available set of information and increases the probability of establishing the facts and perhaps achieving an agreement regarding impacts on cost and schedule.

The collection of data does not end with completion of the tunneling process. Data collection on post-construction displacement trends of surface structures, or those in close proximity of the tunnel, changes of ground water table, and — last but not least — tunnel liner conditions over the service life of the structure provides information that adds to the overall project database. This includes any rehabilitation work on the tunnel during the service life.

An overview of the various sources of relevant data during planning and design, construction and service life of a tunnel is provided in Fig. 1.

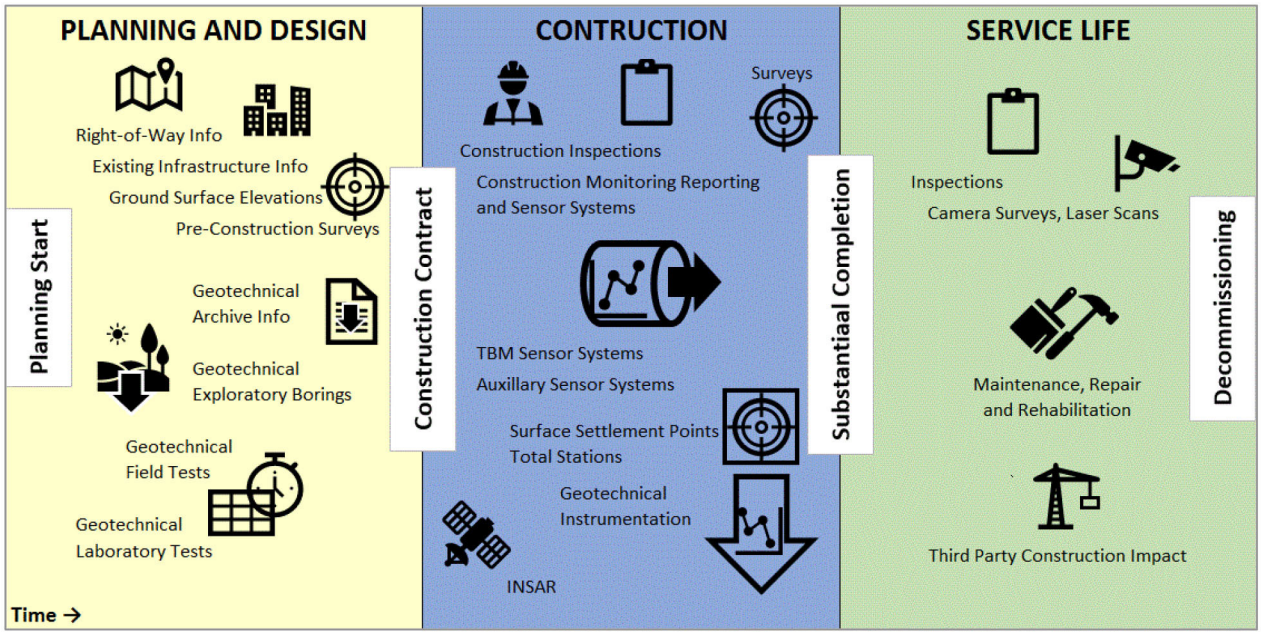
Data is increasingly acquired in digital form e.g., with the use of sensors or input values on the observations

Ulf Gwildis, Ulrich Maidl and Jamal Rostami

Ulf Gwildis, Ulrich Maidl and Jamal Rostami, members UCA, are senior engineering geologist, CDM Smith, Bellevue, WA, founder and managing director, MTC, Munich, Germany and Associate Professor, Alacer Gold/Haddon Endowed Chair, Colorado School of Mines, Golden, CO, email gwildisug@cdmsmith.com.

FIG. 1

Diagram of data sources.



made by field crews during geotechnical exploration and during construction monitoring using tablets. The resulting electronic databases can be easily shared among project parties with process controls determining when a file reaches the revision level at which sharing is permitted. These can be, for instance, geotechnical logs being shared after validation of field observations by a certain amount of geotechnical laboratory index testing, or tunnel inspectors' reports being shared after review by the resident engineer. Instrumentation data are often acquired digitally and automatically by total stations that are monitoring survey points on existing infrastructure within the zone of influence of the tunnel construction. The data from these sources are typically displayed in graphic information system (GIS) software with time and spatial references relatable to one another and made accessible to users online.

For tunneling projects in larger metropolitan areas such as Seattle, WA, where government agencies make archives of geotechnical reports and exploration logs linked to a GIS system available to the public via an online geologic information portal, these archives may gain in importance as a data source, especially where past projects, tunneling or otherwise, required deep explorations and methodical characterization of subsoil conditions. This is an invaluable source of information on the preliminary stages of a site investigation and can result in substantial cost savings for the owners.

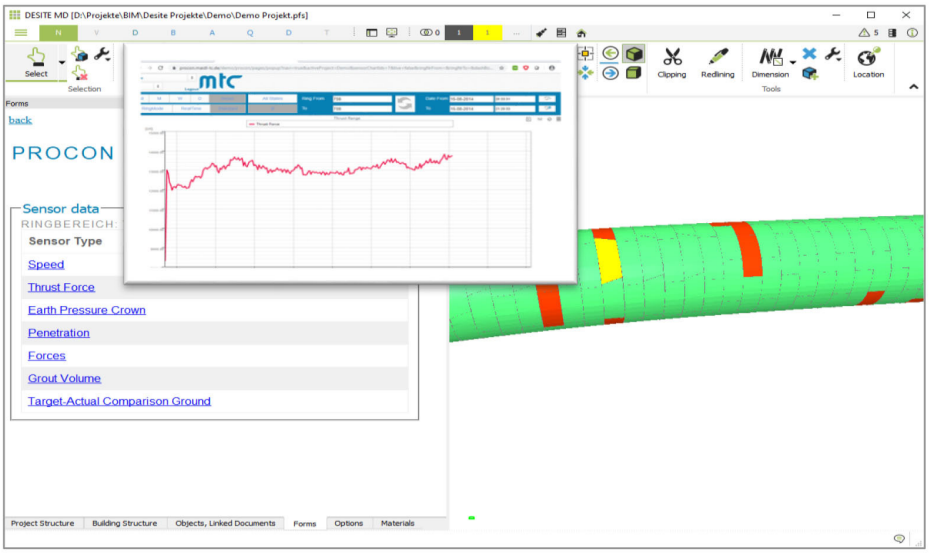
Data processing (2020)

The design phase of a TBM tunneling project provides a representation of the planned tunnel structure using computer-aided design (CAD) tools and a model of the subsoil conditions the TBM will need to be operated in to excavate the tunnel and build the tunnel liner while minimizing deformations that could impact third parties. These are the basic requirements for conforming to the limits specified in the construction contract. The main components of the geotechnical data in the design and bidding process are compiled in a geotechnical data report (GDR) and the summary interpretation, which allows for a risk sharing program, is contractually described in a geotechnical baseline report (GBR). The GBR is based on analytical evaluations or perhaps numerical modeling to develop the design of tunnel structure and shafts, cross passages and other subsystems and functional components, and combined with the specifications, defines the limits for deformations and surface settlement. Ideally, the geological and geotechnical data are consolidated in a ground model using 3D geologic modeling software.

Although not yet common in mechanized tunneling, a BIM model can already be generated during the design phase with the CAD data imported to BIM software such as Autodesk Revit and others. The basis for BIM is typically a 3D geometrical representation of the tunnel system with various levels of detail. As an example, the segmental liner of a TBM tunnel can be shown as a surface with no thickness dimension at a low level of detail and can be shown with an accurate three-dimensional depiction of individual liner segments and their relation to each other at a higher level of detail. The model can be visualized at any angle in 3D, which can be useful for a better understanding of complex geometries of building elements. However, the actual value of

FIG. 2

BIM representation of segmental liner and TBM thrust forces



BIM consists of linking the geometrically depicted building elements with information specific to a given element. To use tunnel-liner segments as an example again, this information may include structural reinforcement per design, the as-built position and TBM operational parameters, such as thrust forces, exerted on the liner ring as recorded during construction, and any damage features observed during tunnel inspections conducted over the service life to the tunnel. Figure 2 shows an example of a BIM representation of a tunnel built by a TBM and lined using concrete segments with thrust forces exerted on individual elements during the ring-building process depicted using color coding.

After the tunnel design and the ground model developed based on the geotechnical data gathered during the exploration phase are set, the data collected from the TBM as the tool for tunnel construction is the next key component to be considered for further detailing the BIM model during the construction phase. With modern TBMs generating 200 to 1,000 sensor readings every two to 10 seconds, the large data volume requires filtering out data to make it manageable. Only relevant data for the specific evaluation at hand and visualization are used to allow easy recognition of relevant values and trends for quick decision making as the construction processes proceed.

Most modern-day TBM projects utilize process-control software such as PROCON for providing graphic presentations of TBM data in user-configurable diagrams combined in dashboards to the project parties — contractor, owner, engineer — in real time at any location with internet-connectivity. A dashboard example of process-controlling software is presented in Fig. 3.

In addition to the automatically recorded data generated by the TBM, the process-control software integrates relevant project documents such as the CAD drawings and the ground model, which requires using a project-wide uniform space and time reference system. Other sources providing relevant data of the interaction between the ground, the tunneling process and the completed structure during and after the construction

FIG. 3

Dashboard example of TBM operational data visualization.

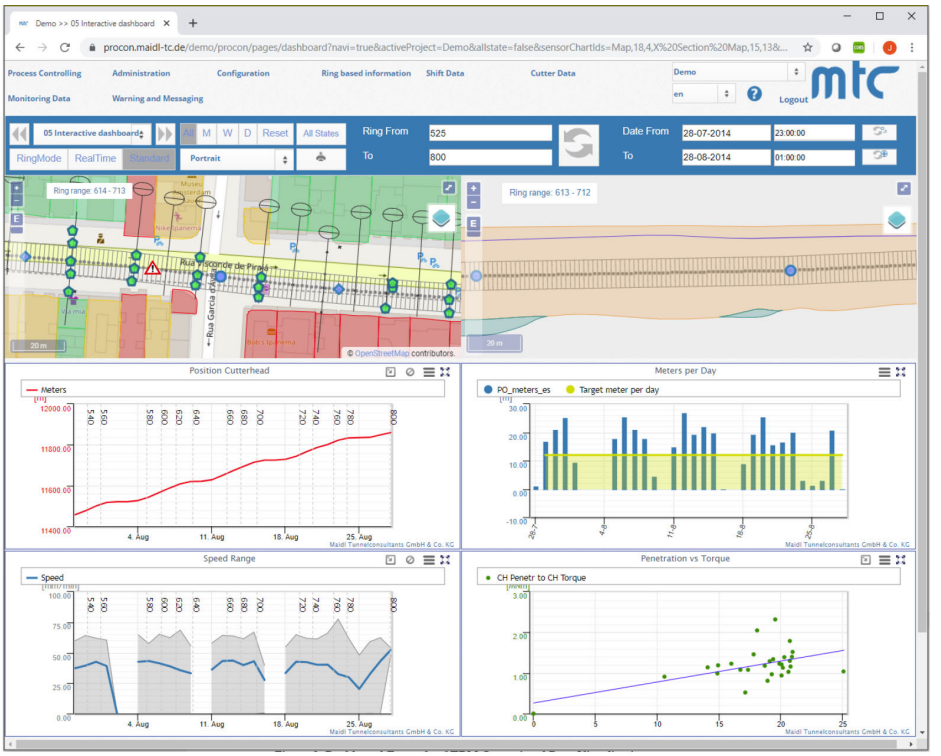
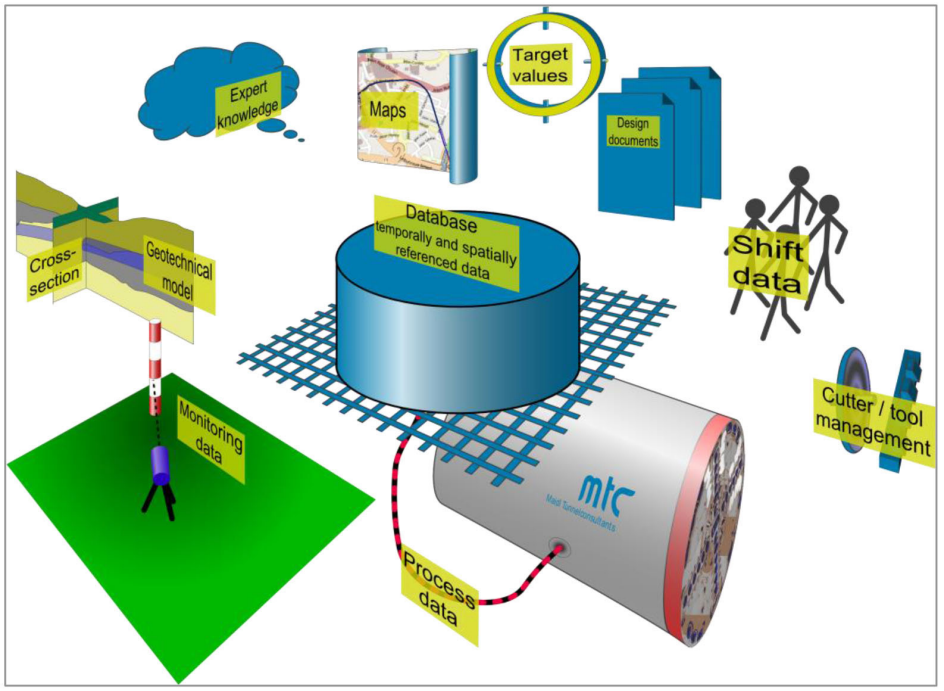


FIG. 4

Data sources for process-control software integrated information management system.



phase are integrated as well. These data sources include survey data and geotechnical instrumentation data (e.g., surface deformations above the tunnel alignment). These measurements are often digitally acquired and processed and are typically displayed in a GIS environment, where users can easily locate instrument or survey point locations and access the associated measurement data. Additional data sources are interventions for cutterhead maintenance (tool wear), shift reports and other construction reporting generated by user interface or by other form of data compilation. A presentation of the various data sources integrated into PROCON used here as an example for process-controlling software is provided in Fig. 4.

The integrated database allows evaluating TBM performance and identifying inefficiencies, to detect deviations from the predicted ground conditions, to conduct downtime analysis, to evaluate tool wear cause-effect relationships and generally to analyze the influence of ground conditions on TBM operational aspects (Maidl and Stascheit, 2014).

With completion of the tunneling process, BIM databases — if maintained — will support asset management over the service life of the tunnel.

Emerging and disruptive technologies

The impact that technological developments in data collection and processing may have on a specific industry such as tunneling is difficult to predict; however, the following basic trends seem to be evident:

- Technological advances in sensor technology including image sensors and digital image processing software have resulted in increased data collection options over time at lower cost for monitoring systems and physical processes. This includes the use of hyper-spectral cameras that can track many other features that are not readily visible such as thermal patterns, gas/liquid traces and surface finishes.
- Commercial use of advanced surveying and remote sensing technologies (laser scanning, laser tracking, LIDAR, INSAR) has increased as new infrastructure projects in dense urban environments require increasing focus on the impact on existing infrastructure.
- Computing power increases exponentially over time as proven to date by the continuing validity of the observation that the number of transistors on integrated circuits doubles approximately every two years (known as Moore's law). Although Moore's law cannot continue forever and most semiconductor industry experts expect it to reach its physical limit at some point in this decade (2020s), other technological developments may sustain the general trend of increasing computing power (e.g., a breakthrough in quantum computing and its application).
- The decrease of data storage cost per gigabyte of data over time has in the past been exponential. This includes hardware as well as web services introduced in recent years that offer cloud data storage as a secure and scalable form of data storage on a flexible and accessible platform.
- Similarly, data transfer speeds have increased over time and more diversity in network topologies (star, tree, mesh networking) generally increases the ability to share data.
- Over the past decade, powerful analytics engines for big data-processing emerged. Among them, Apache Spark, a general-purpose cluster-computing framework developed in 2009 by University of California Berkeley's AMPLab and open-sourced in 2010, has become the basis for a multitude of commercial applications and will continue to be so with its key use case being based on the ability of processing streaming data and data analytics in real time, in conjunction with machine learning (ML) capabilities. ML, a branch of artificial intelligence (AI), is a data-analysis

method that automates analytical model building based on the idea that systems can learn from data, identify patterns and make decisions with no or minimal human intervention.

- Internet connectivity, open-source databases and computing tools/frameworks, and commoditized services are great equalizers for innovators. Historically, innovation has been driven by high-cost, high-risk processes involving substantial organizational infrastructure. Now, small experiments can be created resulting in innovative and marketable solutions by individuals and small-scale enterprises.

These trends have resulted in a number of emerging technologies that have disrupted certain industries and have changed our daily routines. Prominent examples at this time (2020) are the Internet of Things, autonomously operating (a.k.a. self-driving) cars; virtual, augmented, mixed and enhanced reality (Microsoft's HoloLens 2 becoming a commodity for industrial processes); use of AI-enabled cameras for face recognition, site surveillance and inspection works; use of unmanned aerial vehicles (UAVs, or drones) for photogrammetric survey, LIDAR survey, geologic mapping (e.g., rock face mapping using Structure from Motion (SfM) photogrammetric range imaging technique). Recently combining drones with AI-enabled cameras was used for inspecting mine tailings dams in Brazil in the wake of such a dam's breach that resulted in hundreds of fatalities.

On the individual level, products such as AI-enabled cameras and UAVs have become toys for the amateur tinkerer. At the Ignite Seattle 2019 short-form speaking event, an Amazon product engineer presented the problem of his housecat bringing half-dead prey into the house in the middle of the night and also presented the solution he engineered: a cat-flap lock controlled by an AI-enabled camera. After installing the AI-enabled camera at the cat-flap entry path, taking 23,000 photos of his cat in the various states of advancing and leaving with and without prey in its mouth, using a platform for developing and deploying machine learning algorithms named SageMaker and services for AI-powered transcription and translation, he constructed an Arduino-powered locking mechanism keeping the cat-flap locked for 15 minutes once the camera identified a scenario in which the cat approached the entry with prey in its mouth. The presentation illustrated the everyday utility of AI. These examples are scalable for a variety of industries and can be equally used in tunneling where monitoring of the muck can be used to identify issues at the face and monitoring of the personnel and equipment can be used to improve work safety at the jobsites.

Considerations for future TBM projects — an outlook

Big data analytics can find actionable insights from data. A simple example from grocery shopping — if cereal and bananas appear in the same customer's shopping basket, then milk is also likely to appear in that basket with a confidence level determined from the dataset used for training — this can obviously be transferred to the mechanized tunneling process for detecting patterns between TBM operation, ground conditions and surface deformations.

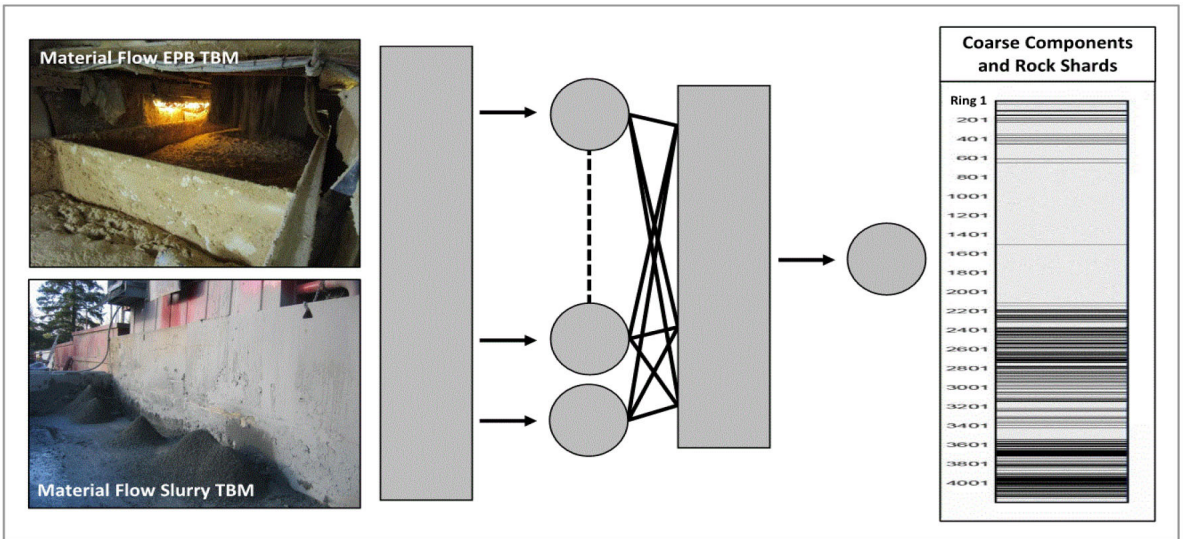
Machine learning has been applied before in tunneling, however, mostly in hard-rock tunneling with a smaller number of parameters describing face conditions and tunnel excavation processes compared to pressurized-face soft-ground TBM tunneling, resulting in simpler models. Prediction of hard rock TBM penetration rates based on parameters describing rock strength and joint systems is one example (Benardos, 2008; Martins and Miranda, 2013; Salimi et al., 2015). Use of a trained model to better forecast rock quality based on probe holes and historical probe hole data in drill-and-blast tunneling is another example (Allende Valdes et al. 2019). Several approaches have been conducted using trained models to predict TBM tunneling-induced surface settlements and research is ongoing using numerical simulation models for training and for settlement prognosis in near-real time as the TBM is advancing (Stascheit et al., 2018). Recently, machine learning has also been applied for earth pressure balance (EPB) TBM performance analytics of the Northgate Link tunnel drives in Seattle's complex and variable glacial geology (Mooney et al., 2018). The data evaluation reportedly identified or confirmed the TBM driving strategy, adjusted after a first drive to use less thrust at lower advance rate in a second drive for minimizing tool wear and improving overall performance by having to perform fewer tool maintenance stops.

Building on these applications and assuming the continuing validity of the aforementioned trends, it seems relatively safe to predict an increase of AI applications in mechanized tunneling. The near-future goals may be an improved performance forecast and to determine TBM driving strategies to optimize overall performance assisting the TBM operator in the decision-making process. This would shift this process more and more to the automated system based on AI data analysis driving the TBM, or a hybrid system where the data is analyzed and prepared by an expert system for the end user or operator to make a final decision relative to the implementation of the recommendations. New sensor technology provides additional valuable data sources (e.g., recent developments in tool wear monitoring such as recording disc cutter rotation speed and tool temperature sensor data (Mosavat, 2017)).

The earlier reference to new product innovation such as the AI-controlled cat-flap lock by individuals would indicate that AI applications may be developed for individual TBM projects tailored to the specific boundary conditions and needs. A possible application of an AI-enabled camera could be for monitoring muck flows —

FIG. 5

ML application for face condition tracking.



either at conveyor belts of EPB TBM operations or at separation plants of slurry TBM operations — with the objective of inferring face conditions in highly variable geology for comparison with the baselined conditions per GBR (Gwildis et al., 2009). Low-hanging fruit in this regard would be identifying rock shards as indicators for encountering coarse components such as cobbles and boulders, during a TBM drive through glacial and interglacial deposits. A conceptual sketch is provided in Fig. 5.

Each BIM database of a completed tunnel may be of value for a future tunneling project (e.g. one in similar ground conditions). After all, the computer does not forget as long as the data access is maintained. Cloud-based data storage services seem to provide the infrastructure to do so. And these data bases may even become a commodity. The value for asset management seems obvious. Maintenance inspection data can be added to the design and construction phase data and performance of the structure can be evaluated if as per design, unexpected system behavior or deterioration can be linked to relevant information for cause-effect-evaluation, and questions, concerns or claims by third parties, such as unanticipated settlement of structures within the area of influence of the tunnel alignment, can be addressed based on data.

TBM projects in urban areas with a high density of existing infrastructure have in the past included involvement of infrastructure owners as third parties to the project in monitoring the operation and its effects. Data were collected and analyzed by the third party to protect its assets. The results of material flow reconciliation such as the ratio of theoretical weight of the excavated soil volume versus the combined weight of spoils, conditioners and grout measured during the tunneling and later ring-building processes at a specific ring location have been mapped for identifying lower risk versus higher risk areas of possible future settlement (Fig. 6).

With further densification of urban areas, the focus on data from both old and new construction will only increase.

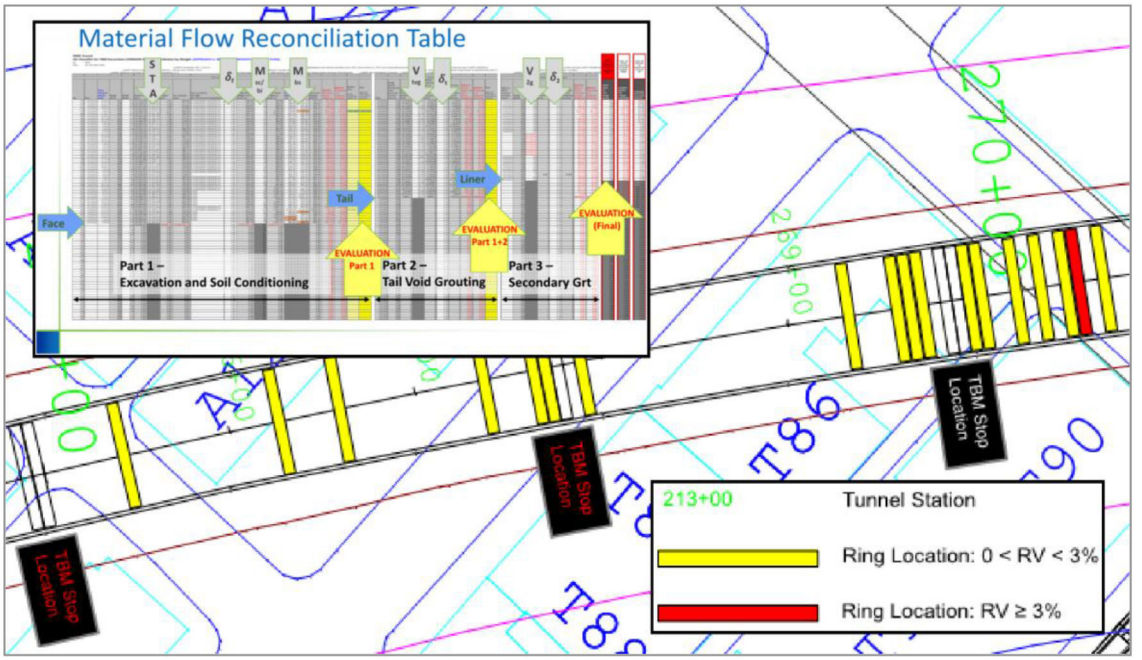
Discussion of implications

An increasing amount of data will be generated and processed during all phases of future TBM projects, from the early-planning-phase cradle to the post-service-life grave. The current trend seems to be that all this data will be integrated in a BIM database of the specific tunnel project. Assuming that machine learning will be increasingly used for big data analytics to detect patterns and trends and derive actionable insights from the data base, what will be the implications? The following statements are meant to start the thought process and discussion on disruptive impact on the tunneling industry and do not claim to predict the future.

- Use of geotechnical archive data in metropolitan areas will increase and may result in a reduction of project-specific geotechnical exploration over time. This is especially true as the manufacturers get closer to designing the "Universal TBM" that is a more flexible system with ample capabilities to identify the issues ahead of the face and adapt to the upcoming ground conditions. This does not negate the need for understanding the ground conditions, just that it could be the result of the actual tunneling operation and not relying only on the site investigations.
- The accuracy of tracking face conditions during pressurized-face TBM drives may increase, but the transparency and traceability by the human mind of the underlying analytics may not.

FIG. 6

Material flow reconciliation results (RV) overlain onto as-built liner ring locations.



- TBM project databases may become commodities similar to research papers.
- Data analytics of past TBM drives may be increasingly used for pre-bid decisions on TBM selection, drive strategy and operational target parameters.
- Real-time data analytics by AI processes may result in TBM operation assistance and ultimately in autonomously driven TBMs.
- Future tunnel construction contracts may require submission of the contractor's tunneling plan to include TBM driving strategy and performance modeling results, which may then be compared to independent modeling.
- DSC claims may be based on the difference of TBM performance compared to pre-drive modeling considering the ground conditions along the tunnel derived from the interpretation of site-related data during TBM advance.
- In densely built metropolitan areas, the focus on the extent to which existing infrastructure is impacted by a new TBM project will increase, hence the need for a better understanding of the ground conditions and impact of machine operation on the surrounding structures. Improved TBM performance as reflected in more efficient operations with minimum impact on the surrounding environment will be the ultimate goal of applying the data analytics in the tunneling industry. ■

References

Allende Valdes, M., Merello, J.P., Cofre, P., 2019. Artificial Intelligence Technique for Geomechanical Forecasting. RETC Proceedings. Chicago, IL, June 2019.

Benardos, A., 2008. Artificial Intelligence in Underground Development: A Study of TBM Performance. Underground Spaces, WITPress, 2008.

Gwildis, U.G., Maday, L.E., Newby, J.E., 2009. Actual vs. Baseline Tracking during TBM Tunneling in highly variable Glacial Geology. RETC Proceedings. Las Vegas, NV, June 2009.

Hamm, B., 2019. Cats, Rats, AI, Oh My. Ignite Seattle, June 6, 2019.

Maidl, U., Stascheit, J., 2014. Real Time Process Controlling for EPB Shields – Echtzeit-Prozesscontrolling bei Erddruckschilden, Geomechanics and Tunneling 7, 2014.

Martins, F.F., Miranda, T.F.S., 2013. Prediction of Hard Rock TBM Penetration Rate based on Data Mining Techniques. 18th International Conference on Soil Mechanics and Geotechnical Engineering Proceedings. Paris, September 2013.

Mooney, M., Yu, H., Mokhtari, S., Zhang, X., Zhou, X., Alavi, E., Smiley, L., Hodder, W., 2018. EPB TBM Performance on the University Link U230 Project. NAT Proceedings. Washington, D.C., June 2018.

Mosavat, K, 2017. A Smart Disc Cutter Monitoring System Using Cutter Instrumentation Technology. RETC Proceedings. San Diego, CA, June 2017.

Salimi, A., Moormann, C., Singh, T.N., Jain, P., 2015. TBM Performance Prediction in Rock Tunneling Using Various Artificial Intelligence Algorithms. 11th Iranian and 2nd Regional Tunnelling Conference Proceedings, November 2015.

Stascheit, J., Ninic, J., Meschke, G., Hegemann, F., Maidl, U., 2018. Building Information Modelling in Mechanised Shield Tunnelling – A Practitioner's Outlook to the Near Future / Building Information Modelling im maschinellen Schildvortrieb – Ein praxisorientierter Blick in die naehere Zukunft, Geomechanics and Tunneling 11, 2018.

Quantification of tangible and intangible benefits of digitalization in tunnel construction

Angus Maxwell and Jacob Grasmick

Angus Maxwell and Jacob Grasmick, members SME, are chief executive and geotechnical engineer, respectively with Maxwell GeoSystems, email asm@maxwellgeosystems.com.

As the tunneling industry continues to adopt Tunnel 4.0, digital twins of the tunnel construction site are becoming standard requirements for tunneling projects. However, the benefits of these remain unproven to many practitioners. This article discusses the various implementations of digitalization and describes efforts to combine all data types to analyze the relationships between influences, predictions and performance in a single digital platform. This includes data pertaining to investigations, design, construction, monitoring and post-construction asset performance and management. Based on 16 years of global tunneling projects this article aims to quantify the tangible and intangible benefits of such systems. Using a number of real examples, this article describes where opportunities were taken and where they went unrealized. Challenges and considerations for both procuring and developing these digital twins are also discussed.

Digitalization is the use of digital tools during the entire life cycle of tunnel construction from concept, design and planning, construction and commissioning, operation, maintenance, expansion and reconstruction. These tools can enable automation of manual tasks and active data management, leading to time/cost savings and increased accessibility/transparency, thus promoting risk reduction and enhanced collaboration and communication. Ultimately, the proper management of data on a business level utilizing the advancements in cloud data storage and processes provides numerous opportunities for improved business as they evolve.

McKinsey & Company claimed that construction lags other engineering disciplines in research and development (R&D) expenditure and has a poor level of productivity with frequent cost and time overruns (Dobbs et al., 2013; Agarwal et al., 2016). In 2017, McKinsey & Company reported that five key areas will revolutionize the industry over the coming years (Barbosa et al., 2017):

- Higher-definition surveying and geolocation.
- 5D building information modeling.
- Digital collaboration and mobility.
- The Internet of Things and advanced analytics.
- Future proof design and construction.

Barbosa et al. suggested that when coupled with four key principles — transparency and risk sharing in contracts, return on investment orientation, simplicity and intuitiveness in the design of new solutions, and change management these technologies — will deliver productivity increases to close the gap with manufacturing and the general economy currently standing at 50 and 80 percent, respectively.

Foundations of digitalization

What is required in order to apply digital tools to tunnel construction?

Spreadsheets and word processors have replaced pen-and-paper methods with digital tools and have resulted in an explosion of documentation, which in some cases has been more hindrance than help. What digitalization is looking for is standardization of nomenclature and agreement of a common data model; what shall we record and how shall we record it? Furthermore, an agreement on communication protocols is needed:

- Means of 'moving' data — do systems communicate with other systems directly or is an agreed communication standard required?
- Data access — who can access and use the data? How to ensure data is kept accessible to engineers so that creativity is not stifled while ensuring that it is not used improperly?
- Data use and edit tracking — is record-keeping on both the use of, and modifications made to the data to track what has happened to the data since the raw information was recorded?

One could be forgiven for thinking that digitalization in tunnel construction is a recent development. In reality, digital developments have been progressing gradually since the late 1980s and early 1990s, which saw the rise of word processing, spreadsheets, numerical analysis, mail programs and the transition from hand-drawing production to computer-aided design (CAD).

Early days

Even in the late 1980s engineers recognized the need to standardize the way in which production was recorded. On the Channel Tunnel, a coding system nicknamed the "Black Ball" charts defined two-part codes for how time would be classified on shift reports. This classification agreed early in the project enabled the production manager to evaluate

time and identify objectively where time was being lost and where there may be opportunity to increase productivity on the project.

At the same time, engineering geologists of the Association for Geotechnical and Geo-environmental Specialists met to agree on a standard for communication of ground investigation data digitally and avoid the need to painfully digitize paper boreholes. This became highly effective and contributed to a shortening of the time between drilling and data analysis, a key requirement on many tunnel jobs where alignments would change during design. The proliferation of this standard, first in the United Kingdom and later in Australia and Asia, met the need for ground investigation databases.

Original databases consisted of simple GIS applications to host paper-based historical records on a map interface and often made use of a number of simple map products. More extensive database applications focused on geological data, including logging, in situ and laboratory tests. The author helped to create one of the first large borehole databases on the Channel Tunnel Rail Link (HS1 in the UK) hosting more than 3,000 boreholes. In an industry first, this database resource was made available to tenderers. To the authors' knowledge, this has not since been repeated.

Many of these early systems had extensive graphing capabilities but little in the way of geological interpretation. On both HS1 and the Thames Water Ring Main between 1993 and 1995, engineers made computer connections between the borehole databases and other applications, including geostatistical analysis software and CAD. Before the advent of any application, programming interface (API), these connections involved generation of scripts that could be run with the associated application to automate the production of drawings and sections, or to automate the entry of data into the geostatistical analysis. The repeatability of this semi automation enabled up-to-date geological sections and layers to be created at any time with minimum additional work.

Benefit 1: Data standards and ease of communication, analysis and updating of data.

Equivalent central systems did not exist for instrumentation and in the early 1990s instruments were regularly downloaded to spreadsheets and manually processed. This was often a laborious task and the constant oversight meant that it had to be repeated thousands of times during a project. Even at the time of London Docklands Light Rail and Limehouse Link & Heathrow Express in the early to mid-1990s, most data was processed manually. Only on the Boston Central Artery (Vaghar et al., 1997) did central systems with automatic processing start to get employed, in this case a response to the sheer scale of the monitoring required.

The Strategic Sewage Disposal Scheme tunnel data management system

In the mid-1990s one project did more than most to accelerate the move to digital systems. The Strategic Sewage Disposal Scheme (SSDS) was a fast-track hard rock tunneling project in Hong Kong under the harbor that was later renamed Harbour Area Treatment Scheme or HATS 1 (Endicott, 2014). The job comprised 25 km (15 miles) of tunneling east-west across Kowloon with a spur toward the east end of Hong Kong Island. The system was connected by 15 shafts with depths up 140 m (450 ft) which were awarded to two advanced works contracts. Six tunnels were let a year later in four contracts and were to be driven using open-gripper TBMs with probe and grout drilling capabilities with either a segment erector (but no tail shield) or a secondary cast in situ concrete lining. The majority of the tunnel contracts were awarded to a single joint venture.

The initial advanced works contracts suffered delays due to ground water and poor ground and put the tunnel contracts into immediate delay. Even with acceleration measures implemented, further tunneling difficulties made it clear the contract was heading for dispute, particularly as the program was fast-tracked.

The client's engineering team recognized the importance of maintaining auditable real-time records across a complex team, so efforts were made to create a common data environment (CDE) for tunneling that would standardize the way in which data was being collected across the many site teams. These were the early days of the internet and many different methods were being used (Lotus Notes, Quattro Pro, Excel, Word, various email systems but mostly just paper). This tunnel data management system (TDMS) was implemented with the backing of the project team using a system built on Visual Foxpro, an early database environment.

The aim of the system was to collate as much information from the various project stages and bring it all together into a single digital environment. This covered all the known influences on the job from ground conditions to environmental constraints, predictions or progress rates, geology and inflows to the recording of activity time and associated records (Fig. 1).

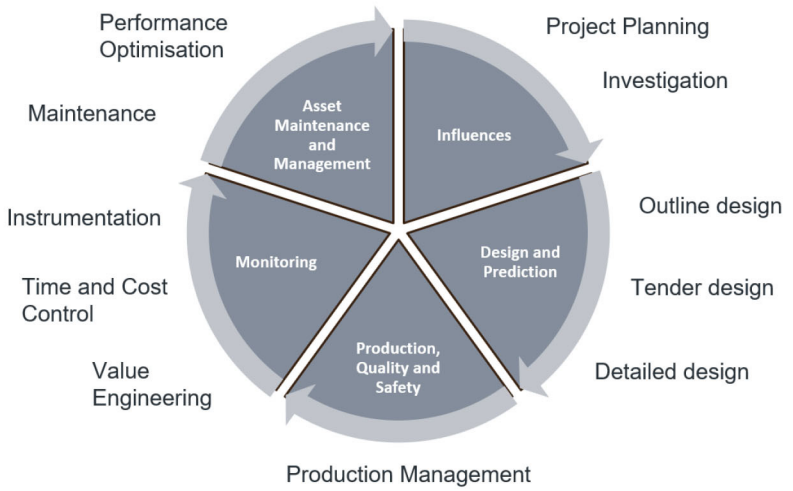
Monitoring of instrumentation was important to ensure that there was no damage to adjacent infrastructure and this was all housed in the same system as the production data. This defined the project information cycle.

In 1997, the contractor ceased work claiming impossibility and ultimately the joint venture (JV) was terminated. The shaft contractor was granted a change order to look after the sites and existing tunnels. Both the client and JV engaged lawyers and the client tendered for replacement contractors.

The TDMS system that was implemented built on the Channel Tunnel (Black Ball Code System) and tracked every 10 minutes on all the main tunneling activities through to the end of the project. Qualitative and quantitative records were linked to these activities covering all drilling and grouting, excavation, mapping, water inflow measurements and instrumentation and some

FIG.1

The project information cycle.



50,000 photographic records throughout the course of the job all perfectly audited and cross referenced as the job proceeded.

With the specter of arbitration hanging over the project and both sets of lawyers scrutinizing every action of the engineer and client on the replacement contracts, it was critical that all the records were faultless and instantly available such that any need to evaluate extensions of times and claims were backed by evidence that could not be disputed. The data from the systems was used to close out claims on the replacement contracts quickly. With data agreed to at the time and digitized in the end, there was no disputing the records and only the need to agree that the method of evaluation and quantification that would need to be defended in the arbitration with the original contractor.

The arbitration took place in 2000 in the International Arbitration Centre, presided over by an arbitrator from the United Kingdom. One tennis playing member of the legal team described the comprehensive nature of the win as being equivalent to 6-0, 6-0, 6-1.

Benefit 2: Save time and money arguing about the data. Successful litigants are often those with the best data.

Data to build on

The SSDS was just one part of a larger scheme to clean up Hong Kong waters. The HATS phase 2 was designed between 2002 and 2008 and comprised a further 25 km (15.5 miles) of tunnels built around Hong Kong Island at depths of 140 to 170 m (450 to 560 ft) below sea level. Water inflow and grouting as well as ground support requirements were a key factor in the planning and the client drilled several guided boreholes to follow the alignment at depth. Lugeon tests were done in places but these were difficult given the length of the boreholes.

The designers were provided all the information in the phase 1 TDMS and relied on this more than 80 precent for their estimates for probe and grout hole drilling and grout quantities (Endicott, 2014). Ultimately provisional quantities were reported to have come in at within 5 percent of the predicted amounts.

The availability of reliable, accurate and detailed records from the previous works helped to de-risk the project for both the client and contractor (Fig. 2).

Benefit 3: The data has value. Look after it and use it on future projects to reduce business risk.

Response to risk

The 2004 collapse of the Nicoll Highway, added to other tunnel-related events, led the International Insurers to demand an overhaul of the tunneling community's approach to tunnel risk. The Joint Code of Practice published with the British Tunneling Society and later the ITA laid out requirements for active risk management of tunnel projects and for constant review of risks as tunneling proceeded. By 2005, the Hong Kong government, recognizing the value of the TDMS, implemented a requirement for a TDMS system in all future tunneling works in Hong Kong as part of its response to the global joint code of practice.

This was later followed by the Mass Transit Railway Corp. (MTRC) in its projects from 2009-2016 (Maxwell, 2014). The merger between the Kowloon and Canton Railway (KCR) and the MTRC into a single private railway developer meant that politically some independent oversight was required to ensure that the public railway was constructed within acceptable financial, environmental and technical criteria. Maxwell GeoSystems was tasked with providing an independent monitoring and provision of a central database for the presentation and analysis of monitoring results. For the first time, response to alarm events could be made via online blogs (a very recent development at the time), which significantly reduced the time to action and close events on the project. As well as being a time-saving tool at the engineer level, confidence among senior management increased as a result of this transparency.

One welcome consequence of the implementation of the independent consultant was the ability to negotiate more favorable project-wide insurance at an owner level. The exact reduction is not known since many factors were conflated, however this is understood to be 0.1-0.2 percent of the construction value (pers comm A. Morris).

Benefit 4: Demonstrate machine-assisted active risk management that is data driven with less reliance on human systems and potentially benefit from cheaper insurance.

Early adopters

With monitoring playing a more important role, instrumentation providers rolled out a number of data-management applications. Often these were downloadable desktop programs linking to web databases or local databases with web portals. By 2010, most were moving fully to the web.

Monitoring was not just focused on the geotechnical and structural. Production staff started focusing on the machines themselves with dataloggers being applied to TBMs, drill jumbos and probe drills, and feeds sent back to engineers for review.

Everyone had their own excellent data, but accessibility across disciplines was limited. Engineers were operating in silos. A TBM pilot was still highly likely to be tunneling based on a printout of a geological section on the wall of his/her cabin that had not been updated since the start of the job. A geotechnical engineer looking to predict settlement could not easily get access to TBM face pressure or muck balance details. Sinkholes and blowouts remained common.

The rise of GIS helped communicate at least the positions of the machine to users, but GIS functionality at the time was not well-suited to the input of streaming data.

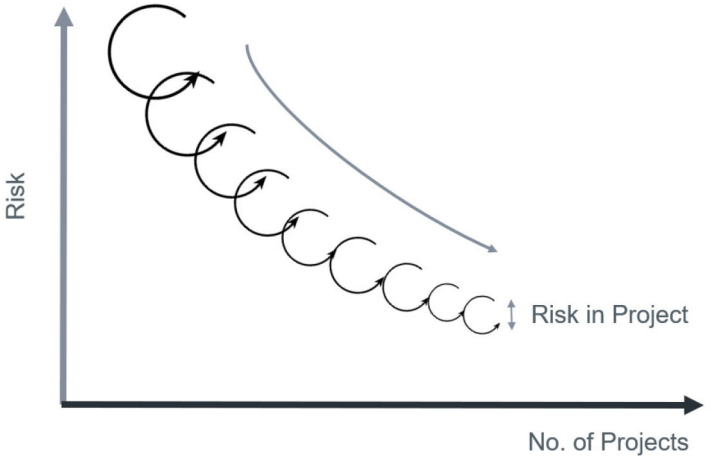
Aspirational phase

Around this time, tunneling started to push the boundaries of what could be achieved and larger machines started to be designed. Reflecting the increase in data volumes and connectivity, there was a proliferation of systems to cover all parts of tunneling from segment design and manufacture, TBM monitoring, robotic total stations, automatic monitoring both wired and wireless and the advent of remote monitoring from satellite to tunnel laser scanning. The data was hugely useful, but each system was different, segregated and with no means of interoperability and intercommunication. Silos continued.

A big change in the approach to data during the construction phase occurred during a large tunnel project in Singapore. As always, issues on prior projects are great motivators and Phase 1 of the Singapore Cable tunnels had suffered a delay due to settlement of a highway bridge. By this time, the TDMS platforms in Hong Kong were connecting production and instrumentation monitoring in a single platform (Maxwell et al., 2015b). Singapore Power Assets took the unusual approach to implement a project-spanning digital platform as part of a partnering for risk approach. Each contractor was asked to contribute to the cost of the platform and manage through a joint steering committee of both contractor and client personnel.

FIG.2

Business risk reduction with project information cycles.



The system covered prediction, progress and real-time tunneling parameters, hazard and risk and monitoring, and was fundamental to the daily tunneling review meetings. Importantly, the client was extremely forceful in insisted that there was a single source of truth on the project and that all meetings used the system as a basis for assessment. The highly transparent and complete review of all data at all times was reflected when comparing the rate of occurrence of sinkholes to historical projects (Table 1).

Similar combined systems were implemented on the Kuala Lumpur Metro Phase 1 and 2 and can be compared to the earlier tunneling of the Stormwater Management and Road Tunnel (SMART) tunnel (Siow, 2006) (Table 2). Much of this is owed to the use of the variable density slurry machine technology. However, advanced warning of approaching conditions and the immediate information

TABLE 1

Singapore Tunnel sinkhole rate 1997-2016.

	North East Line 1997-2001 Shirlaw, et al. (2016)	Circle Line Stage IV Osborne et al. (2016) and MGS (2007)	DTSS Phase 1 2000-2005 Shirlaw (2016)	Singapore Power 2011-2016 MGS (2015)
Number of sinkholes reported	20 in 20 km double tube		> 5 in 40 km	1 in 32.65 km single tube
Rate of sinkhole (> 150 mm) per km	1	0.1-1	0.1-0.5	0.03

TABLE 2

Kuala Lumpur Tunnel sinkhole rate, 2000-2020.

	SMART Tunnel (Slow, 2006)	KVMRT 1 (Maxwell et al.)	KVMRT2 (Mawxell, et al. 2021)
Number of sinkhole reported	41 in 9.7 km single tube	3 in 16 km twin tube	6 in 26 km twin tube
Rate of sinkhole (> 150 mm) per km	4.2	0.19	0.23

of ground response assisted the control process (Maxwell et al, 2015a).

Benefit 5: Consolidating systems and linking data together for better communication and rapid response to tunneling events reduces the risk or damage and stoppage.

The Singapore project was notable for the reduction in the costs of the client and engineer teams. Only two technicians and one engineer were required to oversee the management of data for the entire 35 km of the works. The streamlined teams were highly effective with shorter focused meetings and rapid closeout of actions.

Benefit 6: Reduction in organization size and increased organizational effectiveness.

Competing drivers

Up to this point, tunnels were almost exclusively designed using standard CAD methods with 2D plans and sections. The attributes for objects were held in the drawing notes or in the specifications. Most CAD platforms were already spatial databases and it made sense for these systems to start to store the attributes of the objects as well as the spatial characteristics. Unfortunately, the main driver for this building information modeling (BIM) approach was architecture and many of the standards for the structure of data within drawing systems adheres to the concept of objects that are prescribed such as a door or a window. Most large civil construction including tunnels are built of linear progress where the final dimension or design is not determined until the ground is proven.

As such we have seen the use of CAD-based BIM in tunnels to show complex geometries of the final built works, but seldom examples of BIM applied successfully to the active construction. On Crossrail, the key BIM successes according to Taylor (2018) were not related to the tunneling or heavy civil processes, but rather:

- Use of 3D & 4D modeling to manage construction fit-out of MEP&A.
- Linking asset data through a geographical information system (GIS).
- Augmented reality.
- Handover of information to maintenance and operation.

The difficulty transitioning CAD BIM from the permanent works design phase into construction management phase remains one of the biggest challenges in the digitalization journey.

The costs of digitalization versus the benefits

Construction companies are already spending large amounts on software. This is significant for businesses in construction and particularly in tunneling where margins below 5 percent are common. These investments in software and digitalization must make real returns otherwise, they are likely to be unsustainable. According to research by the McKinsey Global Institute, digital transformation in engineering and construction can result in up to 15 percent in productivity improvement, and reduce cost by 4-6 percent (Barbosa et al., 2017). Potential ways these returns can be realized include:

- Reduce the size of organizations.
- Better management of risk:
  - Increase the quality of the bidders with less gambling.
  - Remove uncertainty (use of accumulated data).
- More active sites and nimble processes.
- Reduce the design claims.
- Reduce ground-related claims.
- Optimize methods and use the data to improve.
- Control on expenditure of time and money. Data-driven forecasting and updating of project risk profiles.

2020 and beyond

As with any new initiative, BIM and digitalization attracts a huge number of innovators to design tools for a variety of applications. The engineer is overwhelmed with areas to invest, and many early adopters find themselves with a toolbox full of applications, few of which can talk to each other. To make them work together requires additional investment in teams of people to manage the digital investment, canceling out any cost benefit there may have been.

In recent years there has been the rise of the integrator. a platform built to connect tools together and manage the flow of data from one to the other. Such systems can also combine many tools in one platform and consolidate many separate investments in one.

The integrator may solve the issue of BIM transitioning from design phase to construction phase with the integrator taking object progress and production

details from the sites and providing regular feeds to BIM, Corporate GIS and program.

Benefit 7: Consolidate and reduce software costs.

Conclusion

This article presents a chronological summary of the evolution of digitization in tunneling and the benefits realized. These benefits include:

1. Data standards and ease of communication, analysis and updating of data.
2. Save time and money arguing about the data. Successful litigants are often those with the best data.
3. The data has value. Look after it and use it on future projects to reduce business risk.
4. Demonstrate machine-assisted active risk management that is data-driven with less reliance on human systems and benefit from cheaper insurance.
5. Consolidating systems and linking data together for better communication and rapid response to tunneling events reduces the risk or damage and stoppage.
6. Reduction in organization size and increased organizational effectiveness.
7. Consolidate and reduce software costs.

These tangible and intangible benefits often advertised are seldomly quantified in a manner that provides business with meaningful measures of these benefits. While it is frequently challenging to quantify the benefits directly, this paper provides examples of quantified benefits.

As digitization continues to become an increasing initiative in the tunneling industry, it is imperative that benefits are well documented and quantified to encourage adaptation. Furthermore, standardization will lead to more universal acceptance within the industry. Lastly, it is imperative that integrative tools are implemented to link data and software systems together to properly manage the digitization of all project data. ■

References

Agarwal, R., Chandrasekaran, S. and Sridhar, M. 2016. "Imagining construction's digital future." McKinsey & Company. 24 June, 2016.

Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M.J., Sridhar, M., Parsons, M., Bertram, N., Brown, S. 2017. Reinventing Construction: A route to higher productivity. McKinsey & Company. February 2017.

Dobbs, R., Pohl, H., Lin, D., Mischke, J., Garemo, N., Hexter, J., Matzinger, S., Palter, R. and Nanavatty, R. 2013. Infrastructure productivity: How to save $1 trillion a year. McKinsey & Company. January 2013.

Endicott, L.J., Ng, A.K.L., Chau, H.K.M. 2014. Hydrogeological Assessment for Tunnels in the Harbour Area Treatment Scheme Stage 2A Sewage Conveyance System. Trueventures, Singapore.

Maxwell A. Vasagavijayan S,, Satkunaseelan S. (2015a) The Contribution of Computer Systems to the Management of Geotechnical and Construction Risk on the Klang Valley MRT SBK Line Underground Works International Conference and Exhibition of Tunnelling and Underground Space IEM Kuala Lumpur

Maxwell A., Chong P.T., Chin Y.K. 2015(b). Client-Contractor Collaboration for Integrated TBM Process and Geotechnical Control – Power Grid Cable Tunnels Singapore. International Conference and Exhibition of Tunnelling and Underground Space (ICETUS2015) IEM Kuala Lumpur 3-5 March 2016.

Maxwell A, 2014 Management of Data for Underground Infrastructure Development in Asia, 2nd International Conference on Information Technology in Geo-Engineering ICITG, Durham

Maxwell Geosystems Pte Ltd 2007 Provision of INSITE data management system for the Circle Line Stage IV Contract C855. Who Hup/Shanghai Tunnel/Alpine Mayreder.

Maxwell Geosystems Pte Ltd 2015 Provision of MissionOS IDMS system for the NS-EW Cable Tunnels Project Singapore, Singapore Power Assets Pte Ltd.

McLearie D.D, Foreman,W, Hansmire, W and E Tong. 2001. Hong Kong Strategic Sewage Disposal Scheme Stage I Deep Tunnels. Proceedings of the Rapid Excavations and Tunnelling Conference (RETC). Edwin K.H. Tong

Shirlaw, N. 2016. Singapore tunneling: Challenges and innovations in complex mixed ground conditions. Tunneling Fundamentals, Practice, and Innovations Short Course. Colorado School of Mines, Golden, Colorado, USA. 20-23 June, 2016

Siow, M. T. 2006. Geotechnical aspects of the SMART tunnel. International Conference and Exhibition on Trenchless Technology and Tunnelling, 7-9 March 2006, Malaysia.

Taylor. 2018. Crossrail Project: Application Of BIM (Building Information Modelling) And Lessons Learned. Crossrail learning legacy.

Vaghar, S., Bobrow, D.J. and Marcotte, T.A., 1997. Instrumentation for Monitoring Ground Movements: Central Artery/Tunnel Project, Boston, Massachusetts. In Proceedings of the Rapid Excavation and Tunneling Conference (pp. 405-420). Society for Mining, Metallurgy & Exploration, Inc.

George A. Fox Conference moves to webinar format

by William Gleason, Editor

The 2021 George A. Fox Conference was supposed to be a celebration of its 20th anniversary on Jan. 26 at City University of New York. However, the ongoing COVID-19 pandemic made an in-person meeting impossible, and while the celebration will be delayed until 2022, the Fox Conference committee adapted and created a two-hour webinar in place of the conference.

For those who missed the presentation in January, the recording is available at http://www.georgefoxconference.com/.

Ed Plotkin opened the webinar with a talk about why and how the conference came into existence. Plotkin explained that the conference honors George A. Fox who, during his 50-year career, played lead roles in the planning, design and management of 70 major public works projects valued in excess of $61 billion. While millions of New York City's residents have benefited from his projects, few have ever seen Fox's work, which mainly consists of elaborate underground tunneling.

For those who missed the presentation in January, the recording is available at: http://www.georgefoxconference.com/

Fox's crowning achievement was his engineering and construction work for New York City's Third Water Tunnel — the largest capital construction project in New York City's history and the largest tunneling project in North America. The project was widely hailed as a modern engineering marvel when the first stage was opened in 1998. It is still considered one of the most complex and intricate engineering projects in the world. Construction of the 96-km (60-mile) water tunnel 180 m (600 ft) below New York City began in 1970 and completion is expected in 2021.

The total cost of the project is expected to be about $5 billion.

Plotkin explained that Fox also earned praise as an educator. He was a former chairman of The Cooper Union for the Advancement of Science and Art where he graduated in 1940. For more than a decade, he taught a course for seniors there that focused on the realities of being a civil engineer. In 1996, The Cooper Union honored him with its first "Builder of the City Award" for lifetime contributions to the construction of New York City's infrastructure.

One of the most popular an-

(continued on page 28)

Mike Rispin to lead Strata Tunneling

Strata Worldwide has announced the appointment of Mike Rispin to lead the launch of Strata's new global division, Strata Tunneling. Rispin brings more than 36 years of international tunneling and mining expertise to the position, having spent decades working in upper management for companies such as BASF, Normet and Dyno Nobel. He will be joining the company as vice president – tunneling.

Rispin is a professional engineer with memberships in both the American Society of Civil Engineers (ASCE) and The Moles organization. He is currently the vice chairman of the Underground Construction Association, a Division of SME.

"Mike Rispin has had an unprecedented career developing new markets for existing companies. His wide range of experience in underground industries will allow Strata Worldwide to excel in becoming a key supplier to the global tunneling industry. Mike is an excellent addition to our global team," said Alan Henderson, vice president Americas.

Mike Rispin

Historically Strata has sold multiple products into tunneling operations, such as emergency refuge chambers, proximity detection, collision avoidance systems, Internet of Things (IoT) networking, automated environmental monitoring and specialty chemicals. The company is now looking to establish a stronger market presence in tunneling, and offer a dedicated global product range, with technical support from Strata technicians and international distributors.

"Strata has been a leader in underground mining products and systems for nearly three decades, it is a natural progression for us to look to support the tunneling industry in the same way. We will continue to invest in industry resources to support Mike and allocate R&D funds to grow our product line," said Mike Berube, President and CEO of Strata Worldwide. ■

Dr. Ronald E. Heuer

In memoriam

Ronald Eugene Heuer passed away Dec. 22, 2020, at age 80. No stranger in the industry, Heuer was directly or indirectly involved in more than 1,000 tunneling projects over the course of his career. He was known internationally as a top geotechnical consultant for underground construction.

Heuer was born in Pontiac, IL in 1940, the son of a building contractor operating in Central Illinois. His father had just a few employees in his business building homes and farm structures, so Heuer's construction career really began in grade school, working with his father on weekends and summers. He earned degrees in civil engineering (B.S. in 1963) and geology (M.S. in 1965) from the University of Illinois. Ralph Peck (Golden Beaver Award for Engineering 1983), recognized as one of the top geotechnical consultants in the world at the time, set the tone of the program and believed strongly that both he and his students should be involved in engineering design and construction on actual projects. This ensured that Heuer received practical experience and exposure to real-world application of his studies.

Ronald Eugene Heuer

Heuer worked his way through graduate school helping Don Deere (Golden Beaver Award for Engineering 1990) on his consulting projects, many of which were pre-bid geology studies for tunnel jobs Perini Corporation was bidding.

In 1969, Heuer joined A. A. Mathews, Inc. of Arcadia, CA as a geotechnical assistant on projects and pre-bid studies in both California and Maryland. After five valuable years of experience working for Al Mathews (1976 Golden Beaver Award for Engineering), including earning his Ph.D. in civil engineering with a geotechnical emphasis, Heuer

(continued on page 28)

Alfred M. "Pete" Petrofsky

In memoriam

Alfred M. "Pete" Petrofsky, former CFO and chairman of McMillen Jacobs Associates, passed away on Dec.11, 2020. He was 92 years old.

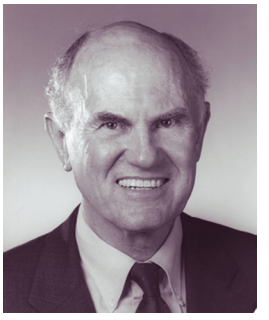
Hailing from Connecticut, Petrofsky received his B.S. in civil engineering from MIT in 1950. He started his tunneling career at Morrison-Knudsen (M-K), where his first projects included Boston's City Tunnel Extension (water) and the Boston Main Drains Tunnel (sewer). While at M-K he also worked on California Central Valley's San Luis Dam Project, which included an earthfill dam and four power tunnels driven under difficult conditions that included shale, sandstone and conglomerate.

Petrofsky joined McMillen Jacobs Associates (Jacobs Associates at the time) in 1966, served as chief financial officer and then Chairman of the Board from 1986 to 1995. He received the ASCE Thomas Fitch Rowland Prize in 1983 and the Golden Beaver Award for Engineering in 1998.

Responsible for some of McMillen Jacobs' most significant projects, he was recognized and respected worldwide as a tunnel, chamber and shaft design consultant. He was the chief construction engineer for the technically complex Melbourne Underground Rail Loop Authority (MURLA) project. With three underground stations and four tunnels, it completely encircles Melbourne's central business district.

Starting in the late 1980s and continuing through the 1990s, Petrofsky led the McMillen Jacobs' efforts on two large projects for the Massachusetts Water Resources Authority (MWRA): Boston's Inter-Island tunnel project and the Metrowest Water Supply tunnel. The Inter-Island tunnel project involved more than 7,620 m (25,000 ft) of sewer tunnels, and Metrowest consisted of 29 km (18 miles) of tunnel passing through six towns.

One of Petrofsky's additional achievements was helping what is now the San Francisco Public Utilities Commission advance the state of practice by bringing the first earth pressure balance (EPB) tunnel boring machine to the United States, changing forever the way soft ground tunnels are built in North America.



Alfred M. Petrofsky

By the time he retired in 2002, Petrofsky had amassed an extensive legacy in the tunneling industry with more than 50 tunneling assignments in 10 different countries — but his influence on McMillen Jacobs goes deeper than just his technical accomplishments. His philosophy of being honest with clients and employees, communicating openly and directly, and offering advice on a better solution to colleagues, even if they are not your clients or employees, helped establish the culture the firm embodies today. His legacy is at the core of McMillen Jacobs' culture, and we will continue to follow his example in the years to come. ■

Heuer

(continued from page 27)

returned to the University of Illinois as an associate professor of civil engineering. He taught undergraduate and graduate courses in geotechnical engineering while maintaining a part-time consulting practice. Heuer looked back at his opportunities to be mentored by Peck, Deere and Mathews as forming the basis of his career.

In 1978, Heuer left teaching to launch a full-time practice as an individual consultant specializing in tunnel projects. His work broke down into three-quarters pre-bid studies and geotechnical consulting for contractors, with the remainder of his work design studies and geotechnical consulting for owners and engineers and legal counsel in claim evaluation. Heuer's involvement ranged from single-day pre-bid studies on small jobs, such as a sewer crossing under a road or railroad, to multiple months of work on some large projects. Along the way, he authored or co-authored more than 20 professional papers on various aspects of tunneling and geotechnical issues. His efforts did not go unnoticed by his peers, earning him the Golden Beaver Engineering Award (2008), The Moles Non-Member Award (2014) and the UCA of SME Lifetime Achievement Award (2014).

Heuer's personal goal was to be "realistic" in anticipation of tunnel ground behavior, not overly conservative. Some special memories include the Straight Creek Tunnel in 1970 (Eisenhower Tunnel First Bore), where, under Mathews' guidance, he developed concept drawings and geotechnical analysis for multiple drift methods used to complete the tunnel excavation through the Loveland Fault Zone at a depth of 305 m (1,000 ft). These were later used as the basis of the second bore design. Other projects he looked back on as high points of his career were: the Point Lepreau Cooling Water Intake Shafts in New Brunswick, Canada in 1977, where a 6.4-m (21-ft) diameter shaft was raised within 4.2 m (14 ft) of the ocean bottom in the Bay of Fundy; the Mt. Baker Ridge Tunnel in Seattle in 1978; the Crosstown Tunnel in Milwaukee in 1986, where Dillingham used a 9.7-m (32-ft) diameter TBM with only 5.4 m (18 ft) of poor rock cover, below water bearing sand and gravel under 76-m (250-ft) head; and the BWARI Tunnel in Columbus, OH in 1999, where an EPB tunnel excavation was successfully completed despite the presence of many boulders.

Heuer devoted time to different hobbies over the years but enjoyed long-distance bicycle riding his entire life. He calculated that he had ridden more than 289,500 km (180,000 miles) in the last 40 years, including three tours across the United States. When not riding or working, he could be found reading with his beloved cat, Gabby, spending time with family, and observing nature in the woods and fields around his home.

Heuer is survived by his children, Janna (Edward Schell) and Garrick (Courtenay Carr) Heuer, and his first wife, Jeanne Zinser-Mandala, his ex-wife and friend Debra Virgens, and siblings Ruth Ann (Ray) Sipe and Robert (Barbara) Heuer. He has four grandchildren, Bronwyn and Tristan (Marissa Flores) Schell, and Brooklyn and Taylor Carr-Heuer, and a great-grandchild, Amelia. ■

George A. Fox Conference is the latest conference to go virtual

(continued from page 26)

nual presentations during the Fox Conference is the Industry Update in which attendees hear updates on projects large and small around the United States and beyond. Jim Rush, editor/publisher of *Tunnel Business Magazine*, provides the update in the webinar.

Rush notes that while the underground construction and tunneling market in the United States remains strong with a number of large projects in the construction or planning phases across the country, there are some significant challenges presented by the COVID-19 pandemic.

Tunnel work and other construction work was deemed essential which allowed work to continue, however, COVID protocols such as social distancing measures as well as increased illness and mandatory quarantines have stressed an already thin workforce.

During his presentation, Rush highlights the many tunneling projects that are currently underway in the United States. He also said some of the largest challenges from the pandemic might not present themselves for some time.

Metro transit agencies around the world have taken hard economic hits from decreased ridership and this loss of revenue could have significant impact on future projects and planning. Rush said the Hudson River and Second Ave. Subway projects are among those that face uncertain futures.

COVID, an owner's perspective

David Corkum, principal, McMillen Jacobs Associates moderated the session that focused on the impact of the COVID-19 pandemic on the procurement process. The discussion includes lessons learned to prevent delaying projects, and what contractual changes have been implemented to current and future projects.

Panelists include Lauren D'Attile, NY DEP; Justin Carl, advisor; Alex Renew and Doug Gabriel, Deputy Director of Engineering and Construction, Northeast Ohio Regional Sewer District. ■

UCA Working Groups provide new volunteer opportunities

The UCA has launched 15 working groups on key technical focus areas. These subcommittees mirror the subject areas established by the International Tunnelling Association (ITA) and aim to maximize benefit for UCA members by providing clear input on U.S. needs and perspectives. In this issue, and future issues of *T&UC*, ITA and UCA Working Groups will be featured.

Working Group 3:

Contractual Practices. This group is working on a series of ITA contractual pronouncements addressing the greatest opportunities for improvement in underground construction and the appropriate contract responses.

Leaders of ITA Working Group 3 (WG 3) are:

- Animateur: Matthias Neunschwander
- Vice-Animateur: Martin Smith
- Tutor: Randall Essex

Since its inception, WG 3 has published a number of documents. These documents are available on the ITA website: https://about.ita-aites.org/publications/wg-publications/content/8-working-group-3-contractual-practicesites.org) and include:

- "*Contractual Sharing of Risk in Underground Construction*," Versions published in 1988, 1990, 1992 and 1995.
- "*ITA Position Paper on Types of Contract,*" 1996.

Over the past several years, the WG has been preparing an updated version of "ITA Contractual Framework Checklist for Subsurface Construction Contracts," which was published in 2011. Thanks to the efforts and support of Randy Essex and Arnold Dix and task leader Gonçalo Diniz Vieira, the group has finalized the updated "ITA Contractual Framework Checklist for Subsurface Construction Contracts, (2nd Edition)," which at present is with the secretariat for publishing. When it is published, it too will be posted in the same location.

Current topics being discussed at the annual World Tunnel Congress meeting of WG 3 include:

- Training on the "Conditions of Contract for Underground Works" (Emerald Book; in cooperation with its publisher, FIDIC).
- Next steps on development of a document setting forth "Best Procurement Practices."
- Kick-off of a committee to work on development of a document on "Design Contracts."
- Further discussion on cooperation with standard contract form, such as NEC and FIDIC.

The UCA U.S. subcommittee for WG 3 is led by William Edgerton and includes Anthony Bauer (HNTB), Everett Litton (WSP) and Sarah Wilson (McMillen Jacobs Associates). More participants are welcome. The objective of this group is two-fold:

- To provide feedback to the UCA on the current state of international contractual practices.
- To share effective contract practices at use in the United States with the international members of ITA. Group meetings are planned for alternate months.

If you are interested in participating in a UCA working group, please email penoyar-perez@smenet.org. ■

Working Group	Subject matter for research	U.S. contact
WG 2	Research	William Hansmire
WG 3	Contractual practices in underground construction	William Edgerton
WG 5	Health and safety in works	Robert Labbe
WG 6	Maintenance and repair of underground structures	Henry Russell
WG 9	Seismic effects	Conrad Felice
WG 11	Immersed and floating tunnels	Christian Ingerslev
WG 12	Sprayed concrete use	Grover Vargas
WG 14	Mechanization of excavation	Brian Fulcher
WG 15	Underground and environment	Kamran Bakhsh
WG 17	Long tunnels at great depth	Lok Home/Brad Grothen
WG 19	Conventional tunneling	Nasri Munfah
WG 20	Urban problems – underground solutions	Sanja Zlatanic
WG 21	Life cycle asset management	Jim Brady
WG 22	Information Modeling in Tunneling	Vojtech Gall Jr.
WG 23	Design and construction of shafts	Verya Nasri
Young Member	ITA Young Member Group	Vojtech Gall Jr.

T&UC Tunnel Demand Forecast

COMPILED BY JONATHAN KLUG, DAVID R. KLUG & ASSOCIATES

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Gateway Tunnel	Amtrak	Newark	NJ	Subway	14,600	24.5	2022	Awaiting funding
2nd Ave. Phase 2	NYC-MTA	New York	NY	Subway	16,000	20	2021	Under design
2nd Ave. Phase 3-4	NYC-MTA	New York	NY	Subway	89,600	20	2022-27	Under study
Kensico-Eastview Connection Tunnel	NYC-DEP	New York	NY	Water	10,500	27	2024	Under study
Flushing Bay CSO	NYC_DEP	New York	NY	CSO	13,200	20	2026	Under study
Bay Park Conveyance Project	NY DEC	New York	NY	CSO	18,500	8	2020	RFQ submitted
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Rail	25,000	30	2022	Under study
Metro Tunnel Program - Northern	Boston MRWA	Boston	MA	Water	23,760	10	2027	Under study
Metro Tunnel Program - Southern	Boston MRWA	Boston	MA	CSO	50,160	10	2028	Under study
Silver Line Extension	Boston Transit Authority	Boston	MA	Subway	8,400	22	2024	Under design
Narragansett Bay CSO Phase III - Pawtucket Tunnel Conveyance Tunnel	Narragansett Bay Commission	Providence	RI	CSO	13,000 8,800	28 10	2020 2024	CBNA-Barletta JV Awarded Under design
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	Rail	40,000	32	2021	Awaiting funding
Alex Renew Long-Term Control Plan	City of Alexendria	Alexandria	VA	CSO	10,500	20	2019	Traylor-Shea JV awarded
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	24,000	18	2022	Under design
Superconducting Maglev Project - Northeast Corridor	TNEM/BWRR	Washington	DC	Rail	146,520	43	2021	Under design
Lower Olentangy Tunnel	City of Columbus	Columbus	OH	Sewer	17,000	12	2020	Granite Const. low bidder
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	Sewer	30,000 21,000	18 14	2019 2020	Under design Under design
Shoreline Storage Tunnel	NEORSD	Cleveland	OH	CSO	16,100	21	2021	Bid date 3/30/2021
Shoreline Consolidation Tunnel	NEORSD	Cleveland	OH	CSO	11,700	9.5	2021	Under design
Southerly Storage Tunnel	NEORSD	Cleveland	OH	CSO	18,350	23	2024	Under design
Big Creek Storage	NEORSD	Cleveland	OH	CSO	22.450	18	2029	Under design
Enbridge Line 5 Tunnel	Enbridge	Traverse City	MI	Oil	23,760	12	2020	Contractor selected - delayed

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

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
ALCOSAN CSO Ohio River Allegheny River Monongahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	 10,000 41,700 53,900	 14 14 14	 2022 2027 2030	 Under design Under design Under design
I-70 Floyd Hill Highway Tunnel	Colorado Dept. of Transportation	Denver	CO	Highway	15,840	60 x 25	2022	Under design
Minneapolis Central City Parallel Tunnel	City of Minneapolis	Minneapolis	MN	CSO	4,200	10-19	2021	Bid date 2nd quarter 2021
Stormwater Control Program	Harris Co. Flood Control District	Houston	TX	CSO	52,800	25-40	2021	Under design
Mill Creek Trunk Improvements	City of Nashville	Nashville	TN	CSO	13,800	10	2023	Under design
D2 Subway - 2nd Light Rail Alignment	Dallas Area Rapid Transit	Dallas	TX	Highway	3,000	22	2020	Under design
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	Transit	10,500	18	2024	Under design
LA Metro Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2020	LOI received
Folsom Area Storm Water Improvement	SFPUC	San Francisco	CA	CSO	4,000	12	2022	Under design
BART Silicon Valley Phase 2 Tunnel	Santa Clara Valley Transit Authority	San Jose	CA	Subway	26,400	56	2021	Under design
California Waterfix 1 California Waterfix 2	Delta Conveyance Design and Const.	Sacramento	CA	Water	39,905 403,400	28 40	2020 2020	Delayed Delayed
Yonge St. Extension	Toronto Transit	Toronto	ON	Subway	15,000	18	2022	Under design
Massey Tunnel	City of Toronto	Toronto	ON	CSO	20,000	18	2022	Under design
Inner Harbour West	City of Toronto	Toronto	ON	CSO	18,400	19	2022	Under design
Scarborough Rapid Transit Extension	Toronto Transit Commission	Toronto	ON	Subway	25,000	18	2018	RFQ due 1Q, 2021
Elington Crosstown West Extension	Toronto Transit Commission	Toronto	ON	Subway	40,000	18	2020	RFQ due 1Q, 2021
Blue Line Extension	Societe de transport de Montreal	Montreal	QC	Subway	19,000	20	2021	Under design
Green Line LRT	City of Calgary	Calgary	AB	Transit	26,250	20	2021	RFQ submitted
Nose Hill Project	City of Calgary	Calgary	AB	CSO	10,800	10	2020	Under design
Annacis Water Supply	City of Vancouver	Vancouver	BC	Water	7,500	15	2021	RFQ requested
Millennium Line Broadway Extenstion	Metro Vancouver	Vancouver	BC	Subway	18,700	18	2020	Acciona/Ghella JV awarded
Eagle Mt. Pipeline	Fortic BC Woodfibre	Vancouver	BC	Oil	29,500	13	2020	Short list announced
Stanley Park Water Supply Tunnel	City of Vancouver	Vancouver	BC	Water	5,000	15	2021	Under design

t&uc CLASSIFIEDS

Ad Index

Advertising Information

Hooper Jones
CENTRAL, NW U.S.
+1.847.486.1021
Cell: +1.847.903.1853
hooperhja@aol.com

Laura Lemos
EAST, SOUTH, WEST U.S.
Cell: +1.973.668.2449
Main: +1.973.822.9274
laura@boja.com

Darren Dunay
CANADA
+1.201.781.6133
Cell: +1.201.873.0891
sme@dunayassociates.com

Eberhard G. Heuser
EUROPE
+49 1520.9269629
Fax: +49 202 2838126
egh@heusermedia.com

Patrick Connolly
UNITED KINGDOM
+44 1702.477341
Fax: +44 1702.177559
patco44uk@aol.com

Gary Garvey
INTERNATIONAL SALES
+1.303.948.4243
Fax: +1.303.973.3845
garvey@smenet.org

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

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

Tunneling & Underground Construction

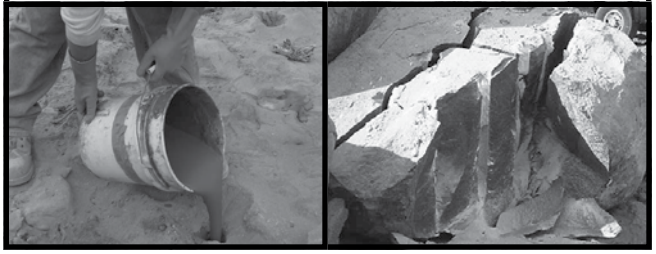
makers of **Underground** history

Dā-mite

Rock Splitting Mortar

Dā-mite Fractures Rock and Concrete in No Blast Conditions
Dā-mite aids and accelerates mechanical rock excavation
No fly rock, no vibration, no noise,
Applications: Boulders, mass rock, tunneling, concrete removal

DAIGH COMPANY, INC.
2393 Canton Hwy, Ste 400, Cumming, GA 30040
Office: 770-886-4711, Fax: 770-887-3783
www.daighcompany.com **sales@daighcompany.com**



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

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

Daigh Company, Inc.
111 Industrial Park Drive
Cumming, GA 30040
Telephone: +1-770-886-4711
Fax: +1-770-887-3783
Email: sales@daighcompany.com
www.daighcompany.com

Dā-mite®
Rock Splitting Mortar

Derrick Corporation

Founded by H. William Derrick Jr. in 1951, Derrick® Corporation was created to solve some of the most challenging mechanical separation needs of the Mining Industry. At the heart of our present-day offering resides the Integrated Vibratory motor. Our pioneering spirit pulses through the organization and inspires development of our leading-edge solutions.

Over the years, we have experienced exponential growth, expanding from our Mining roots to Oil & Gas Drilling, Civil Construction, Industrial and other challenging markets worldwide. We have an extensive network of thousands of cohesive individuals located across the globe.

SERVING THE CIVIL INDUSTRIES

Derrick has offered premium slurry separation and desanding equipment to the worldwide Microtunneling, Tunneling, Slurry Wall/Foundation Drilling, Horizontal Directional Drilling, Hydrovac Mud Processing, Water Well Drilling, Dredging and other Civil Construction Industries for over 30 years.

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

LEADING-EDGE EQUIPMENT MAKES THE DIFFERNECE

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

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

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

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

DERRICK HYPERPOOL TECHNOLOGY ENSURES HDD CROSSING RECORD*

Complete job from rig up to rig down took only 19 days!

"The Hyperpool shakers and innovative Derrick screen technology made a dramatic improvement in the drilling operation. The new Hyperpool (high-G recycler) with Pyramid screens proved to have a voracious appetite for waste cuttings, assuring a stable downhole within a spotless environment."

– Ricardo Place - President, Flowtex HDD S.A.

DERRICK | GLOBAL FAMILY. PIONEERING TECHNOLOGY.®

Derrick Corporation
15630 Export Plaza Drive
Houston, Texas 77032
Toll Free: (866) DERRICK
www.Derrick.com

** Record was for the longest HDD crossing in Argentina, 5800 feet (1768 meters).*

Master Builders Solutions

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

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

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

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

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

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

Dragados TBM Bertha
Photo credit-Catherine Bassetti Photography

Photo credit-Catherine Bassetti Photography

MASTER® BUILDERS SOLUTIONS

SOLVING YOUR UNDERGROUND CHALLENGES

Our customers shape the future. By listening to their needs and challenges, we have developed a complete and comprehensive offering for the tunneling industry.

We continue to focus our R&D efforts on safe, sustainable, innovative solutions for tomorrow's challenges.

www.master-builders-solutions.com/en-us/products/mining-and-tunneling

Photo credit: Catherine Bassetti Photography

A brand of MBCC GROUP

GMS Mine Repair

GMS Mine Repair & Maintenance is North America's premier underground contractor, whether for routine labor or the most specialized and demanding projects. Our deep experience and broad range of services and products allow us to serve the customer with unmatched efficiency and scale, supported by our own engineering personnel and fabrication facilities.

More than providing trained professionals and quality products, we are first a Solutions Provider. Our experienced technical specialists work with you to clearly define and strategically solve the most challenging projects. Then our skilled labor force reliably executes those solutions with precision and professionalism.

Chemical/Grout Injection

Widely used as an economical means to control water ingress in mines or tunnels, to solidify permeable soil, or to repair rock fractures, our specialized injection crews perform chemical and grout injections safely and efficiently.

The GMS Advantage

The GMS Advantage refers to innovative, proprietary products like ROSA and Badger, developed by GMS and used exclusively by GMS crews, giving GMS an advantage over competitors!

ROSA (Remote Oscillating Shotcrete Arm) is a quick mobilization, highly versatile attachment that mounts on most hydraulic equipment to allow GMS crews to remotely apply shotcrete from a safe location using any dry or wet shotcrete pump.

Badger is a robust, remote-operated, excavation and utility machine (electric- or diesel-powered), that is nimble and compact enough to access areas too precarious or difficult to reach with a traditional skid steer or dozer. Underground examples include excavation in narrow or low areas, and under conveyors. Above ground, typical uses include highwall bench cleaning and remediation, or culvert and confined space cleaning. With optional attachments that allow you to drill, hammer, spray, cut or carry, the Badger is also extremely versatile! A single operator remains at a safe distance with enhanced sight lines, and an exhaust catalyst reduces emissions (diesel), making the Badger as safe as it is efficient!

GMS. We're prepared to tackle the most demanding jobs and you can be confident that it's done right.

GMS Geotechnical *is a complete turnkey provider of geotechnical services with regional offices throughout the United States and Canada.*

Solutions provided include:

- Micropilings
- Robotic Shotcrete
- Soil Stabilization and Nailing
- Sensitive Blasting Services (NxBurst / Gas Cartridges)
- Rock Bolting
- Retaining Wall Design and Installation
- PU and Grout Injection
- Void Detection, Fill and Backfill
- Dam Restoration
- Bore Hole Scope/Camera
- Engineering Services
- Bench Cleaning, Servicing and Confined Space Excavation with proprietary *Badger*

GMS GEOTECHNICAL

GMS Geotechnical • 32 Enterprise Drive, Oakland, MD 21550

202.446.8884

www.gmsgeotech.com

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 brands at www.jennmar.com , www.xcaltools.com, or www.xcalindustries.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 Specialty are excited to be a part of such an impressive job. Twelve miles of tunnel ribs and shaft rings. Great job everyone! #civilengineering #infrastructure #tunneling

JENNMAR Civil & Specialty Products are in GA with Garney/Bradshaw Construction for re-alignment of a gravity sewer line. This elliptical design is supported with JENNMAR shaft rings and ConTech liner plate. Great work! #civilengineering #infrastructure #manufacturing

JENNMAR

SAFETY, SERVICE, AND INNOVATION

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

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

ANTRAQUIP CORPORATION – your reliable, innovative partner

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

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

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

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

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

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

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

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


AQ6 Hydraulic Cutting Attachment


AQC180 on CAT336

ANTRAQUIP® CORP

Experienced, Innovative & Reliable

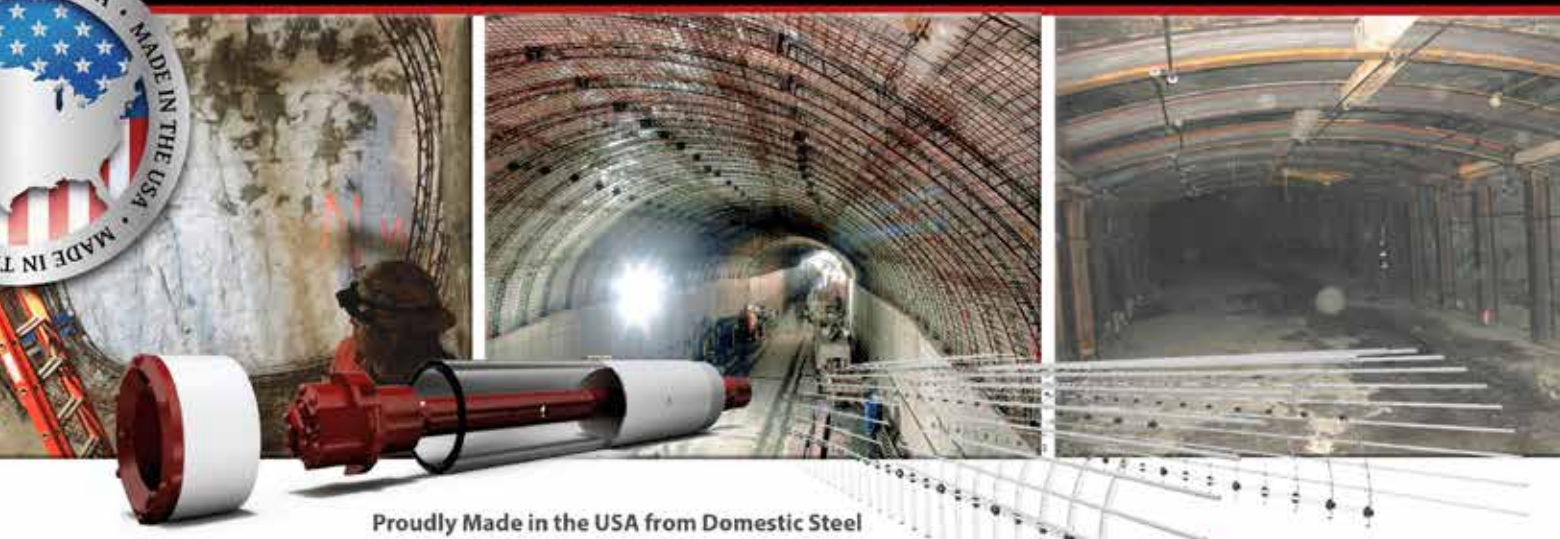
YOUR PARTNER FOR PERFORMANCE

DRUM CUTTER ATTACHMENTS

ROADHEADERS 13 - 85 TONS

THE ULTIMATE CHOICE FOR TUNNELING SOLUTIONS!

ROADHEADERS • ROCK AND CONCRETE CUTTERS • SCALING ATTACHMENTS • TUNNEL / GROUND SUPPORT SYSTEMS



Proudly Made in the USA from Domestic Steel

GROUND SUPPORT PRODUCTS

LATTICE GIRDERS • ARCH CANOPY SYSTEM • PIPE ROOF SYSTEM
SPILES & ROCK BOLTS • STEEL RIBS & MORE

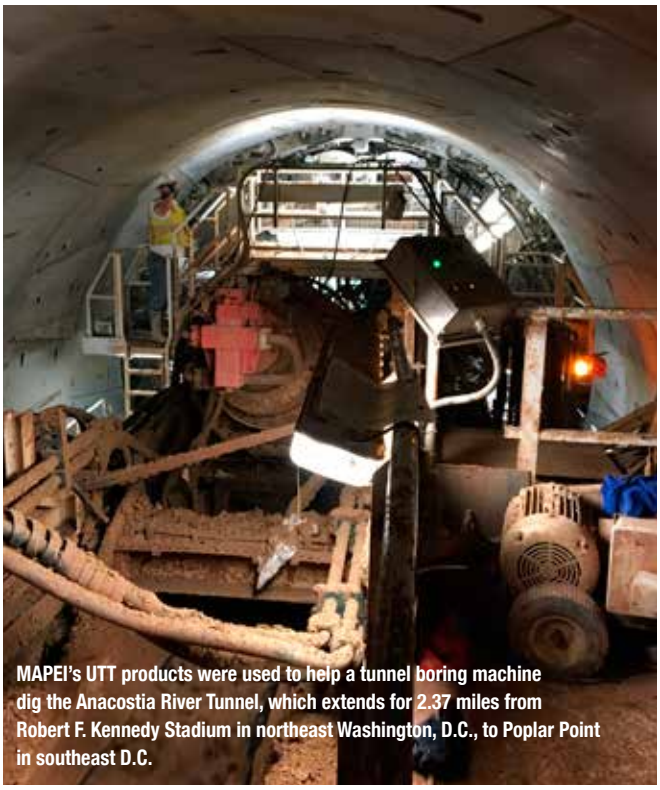
antraquip.net | info@antraquip.net | 301.665.1165

ANTRAQUIP® CORP

PROVIDING INNOVATIVE SOLUTIONS FOR TUNNELING, SCALING, TRENCHING, & SOIL REMEDIATION PROJECTS

MAPEI Corporation

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



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

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

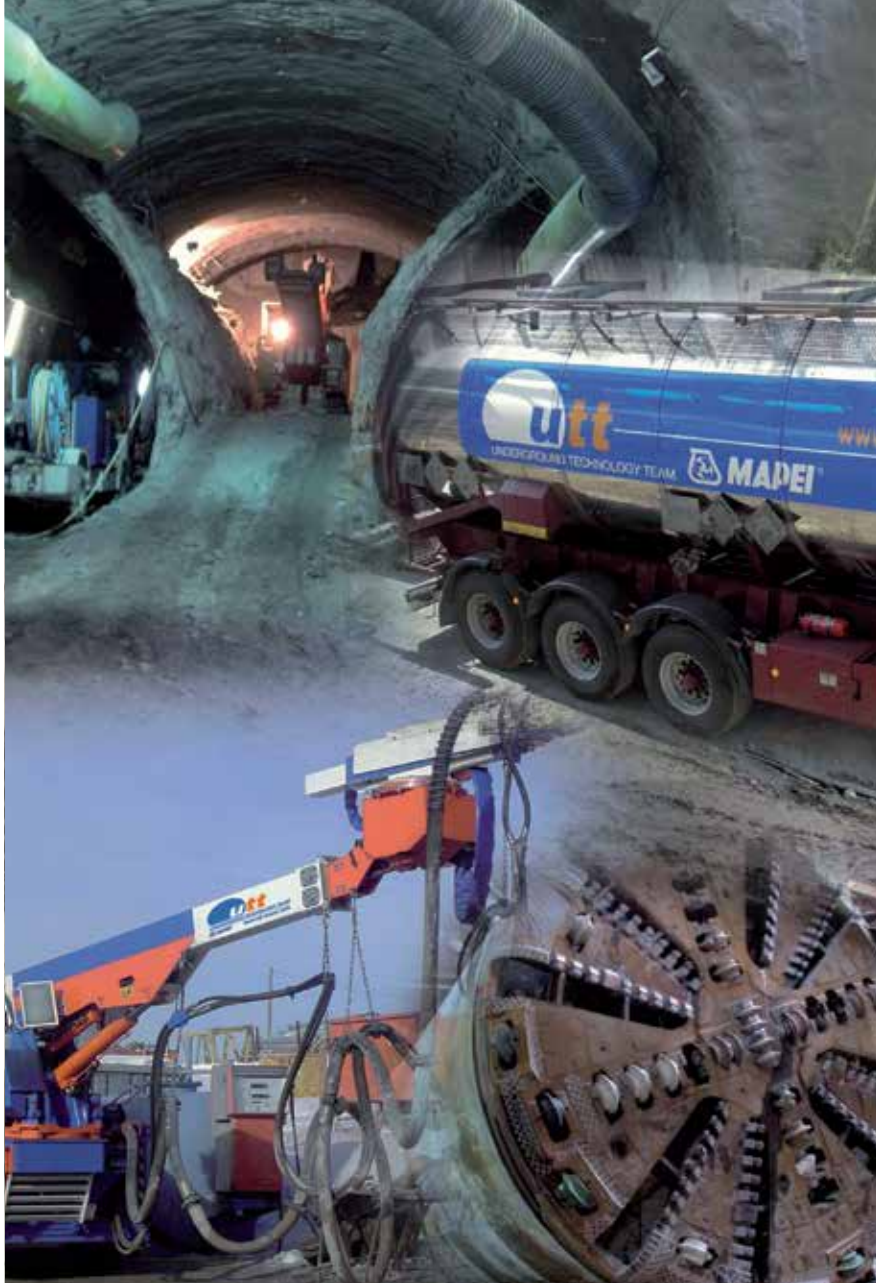
"The UTT group started in earnest in the U.S. in 2015," stated James Pinkley, Country Manager UTT – North America. "But the business has grown substantially since then." In the underground industry, speed is essential – not only of the products themselves, but also of the evolution of technology. MAPEI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

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

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

Proven Technology for

Underground Construction



Our commitment is the detail that makes the difference.

Reliable technology and expertise for underground construction

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

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

MAPEI USA

utt MAPEI

DSI Underground

Reinforcing Progress - DSI Tunneling LLC.

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

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

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

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

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

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

DSI UNDERGROUND

www.dsiunderground.com
502.473.1010

DSI UNDERGROUND

Reinforcing Progress

The world relies on tunnels to drive economic growth and progress. And tunneling companies rely on us to drive their progress underground. By reinforcing their tunnels, protecting their people and optimising their investment, we keep their tunnels moving forward, opening up new opportunities to advance communities and countries. **We reinforce progress - for our customers, and for the world.**

DSI Tunneling LLC
502-473-1010

dsitunneling.com

Kiewit

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

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

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

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

Kiewit

NO JOB TOO SMALL.

Kiewit provides smart engineering, detailed planning as well as right-sized equipment and resources to all of its projects. As a local contractor with an expansive reach, Kiewit possesses the agility to react and mobilize for any size tunnel project; big or small.

Our typical small job services include:

- Shotcrete
- Ground support – rockbolts and steel sets
- Drill and blast excavation
- Rehabilitation of tunnel and shafts
- SEM excavation
- Cast-in-place concrete lining
- Civil infrastructure and mining projects

Kiewit Infrastructure Co.
1926 S 67th St., Suite 300, Omaha, NE 68106 | (402) 346-8535

KIEWIT.COM

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

Herrenknecht: Pioneering Underground Together

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

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

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

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

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

Innovative solutions for underground supply and disposal systems.

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

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

HERRENKNECHT
Tunnelling Systems

CLEAN RIVERS PROJECT, WASHINGTON, DC

METICULOUSLY UPGRADING THE UNDERGROUND

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

› herrenknecht.com/cleanrivers

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

PIONEERING UNDERGROUND TOGETHER

HERRENKNECHT
Tunnelling Systems

Miller Contracting

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

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

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

MILLER

shaft division

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

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

The Robbins Company

Robbins, Revitalized

U.S. TBM Supplier is Focused Forward

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

A Glimpse into the New Era: Remote Machine Acceptance

Adaptability has been key for ongoing projects across the U.S. and Canada into 2021. Last year Robbins assembled a 7.95 m diameter Single Shield TBM at a facility in Mexico and conducted the company's first ever fully remote machine acceptance testing. The Robbins machine was disassembled and transported to the Ashbridges Bay Treatment Outfall in Ontario, Canada, where it is in the process of being launched alongside a continuous conveyor system. This tunnel will be bored through shale interbedded with limestone, siltstone and sandstone to replace a 70-year-old existing outfall.

The Largest Hard Rock TBM in the U.S. Changes Diameter

In Dallas, Texas the largest hard rock TBM ever to operate in the U.S. is undergoing a size conversion. The Main Beam TBM, which is partway through its bore on the Mill Creek Drainage Relief Tunnel, is being changed underground from its original 11.6 m diameter to a more streamlined 9.9 m. Designated essential by the City of Dallas, the tunnel's purpose is to provide 100-year flood protection for east and southeast Dallas; both areas affected by severe storms in the past. Launched in April 2020, the Robbins TBM and continuous conveyor system have excavated around 2,500 m of the 8 km long tunnel for Southland/Mole JV thus far.

From Disused Gold Mine to World Class Research Facility

There are more than just TBM tunnels in progress in the U.S. this year. A Robbins conveyor system is currently being readied for a Spring 2021 startup at the Long Baseline Neutrino Facility (LBNF), a project for Fermilab in Lead, South Dakota. Contractor Kiewit will use the conveyor to revamp a disused gold mine into a world-class neutrino research facility. Crews will be excavating two caverns by drill & blast and roadheader, both 1.5 km below the surface. A cable hoist will transport rock up the 1.5 km deep Ross Shaft to a rock crusher at the surface using much of the original but refurbished mining equipment. The crushed rock will then be transported via conveyors. The Robbins conveyor system is designed for the unique application and includes the longest overland conveyor Robbins has ever provided (550 m), which travels over a main road, city park, and near a residential area. The system includes sound dampening, dust filters, sound-proofed transport points, and monitoring systems, among other features.

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

FEAR NO ROCK

REPAIRING THE WORLD'S LONGEST TUNNEL

Designed for water pressures up to 30 bar and featuring enhanced probe drilling, a 6.8 m diameter Single Shield TBM tackled tough ground and won. The machine repaired a leak in New York City's Delaware Aqueduct below the Hudson River, completing the job on budget and ahead of schedule.

Delaware Aqueduct Repair Project
New York, USA
6.8 m Single Shield TBM

therobbinscompany.com

Robbins
RELIABLE | RESPONSIVE

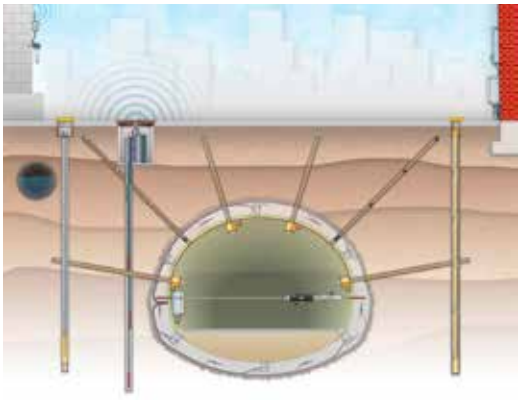
GEOKON

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

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

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

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



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

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

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

AECOM - Managing Urban Underground Projects

By: Nasri Munfah, Senior Vice President, Director of Tunneling and Underground Engineering, AECOM

Throughout the world, tunneling and underground construction in urban areas are becoming increasingly desired solutions to traffic congestion, dwindling right of way, aging infrastructure and rapidly expanding urban centers. Complex challenges arise for safe underground construction due to potential impacts on existing buildings, structures, utilities and the public. As a result, the need for program and construction management services is growing significantly and AECOM is providing such services to our clients in urban areas.

These complex underground projects require project oversight and program management skills to produce efficient designs, manage project budgets, reduce risks, meet the overall program schedule, address the public and stakeholders issues, support the client in obtaining approvals and permits, and support the project's implementation. There are many critical roles that a successful program manager plays for tunnels and underground construction projects including:

- Addressing community and stakeholders' issues
- Ensuring equity for all
- Buy-in by the construction community
- Ensuring fairness among all participants
- Change-order accountability and dispute resolution
- Addressing Risks
- Safety Planning

The decision of placing an underground project faces many challenges among various competing interests. Political views, community interest, commercial benefits, and tax incentives often affect the project configuration, transit station locations, and potential future developments. One of the major responsibilities of a program manager is ensuring environmental justice to treat all participants fairly and equitably.

Informing potential contractors about a program in advance will lead to ideas for reducing cost, addressing risks, lowering bid contingency and encouraging competition. An effective program manager divides the project into manageable, biddable segments while meeting the skillsets required for each segment.

In addition, an effective community outreach can help change project adversaries into supporters. Active collaboration with project stakeholders and the general public is essential to successful tunneling projects, especially in urban areas. Successful program managers listen to concerns and use them to improve the project's design while minimizing its negative effects.

By following a comprehensive and systematic approach that includes best practices, program managers support their clients in delivering underground projects safely and efficiently.

//aecom.com/tunneling

Sika Corporation

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

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

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

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

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

Sika's Total Construction Expertise

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

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

Some of Sika's Solutions included; Sika® ViscoCrete® Superplasticizers, Sigunit® Shotcrete accelerators, SikaTard® Set retarders, Sika®-PM Shotcrete spraying systems, Aliva® TBM Spray robots, and the Sikaplan® Tunnel waterproofing system. In total, Sika supplied more than 40,000 metric tons of products, including over 3 million m² of waterproofing systems.

Building Trust

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

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

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

OVER 100 YEARS UNDERGROUND
THAT'S BUILDING TRUST
NOW PROUDLY EXPANDING OUR EXPERTISE IN NORTH AMERICA

For more than a century, Sika has been pioneering underground construction and continues to be involved with the most challenging tunneling and mining projects ever built. We will continue forging ahead to bring modern day shotcrete, tunneling and mining technologies a step above the rest.

Focused on the entire North American continent, our Sika Shotcrete, Tunneling and Mining team incorporates the credibility of King Shotcrete with the global experience of Sika. Speak to one of our technical representatives today regarding our comprehensive portfolio of products: **Shotcrete; Concrete; Grout; Paste Backfill; Sika® Aliva® Equipment; Asset Maintenance; Infrastructure Repair.**

Visit us on usa.sika.com

SIKA CORPORATION - STM - NORTH AMERICA
Phone: 800 933 7452 · usa.sika.com

BUILDING TRUST

True Wireless Underground Communications for Voice & Data

Innovative Wireless Technologies (IWT) believes that being underground shouldn't mean being out-of-touch, and should always be reliable. IWT systems are designed specifically for underground environment, unlike surface technologies that often do not face up to the challenge.

Our networks are highly-reliable, scalable, and offer a wide variety of integrated products and solutions. From crystal-clear voice communication and real-time tracking, to multi-gas monitoring and data analytics, an IWT network is an expandable, *single* network that is easier to use and less costly to operate and maintain.

Self-configured nodes form a network of repeaters to relay voice and data from one device to the next from the deepest working area to the surface operation. Wireless transmission between nodes means no cable to run (or break) resulting in high reliability and low installation and maintenance costs.

Regardless of tunnel height, length or construction material, an IWT network has you covered with multiple infrastructure solutions including fixed-location line powered devices, or rapidly deployable battery units. Additionally, IWT solutions are completely recoverable after project completion and redeployable at your next jobsite.

Have a short-term inspection or project?
IWT offers flexible rental options for portable communications and networks.

Start the conversation today at iwttunneling.com

IWT®

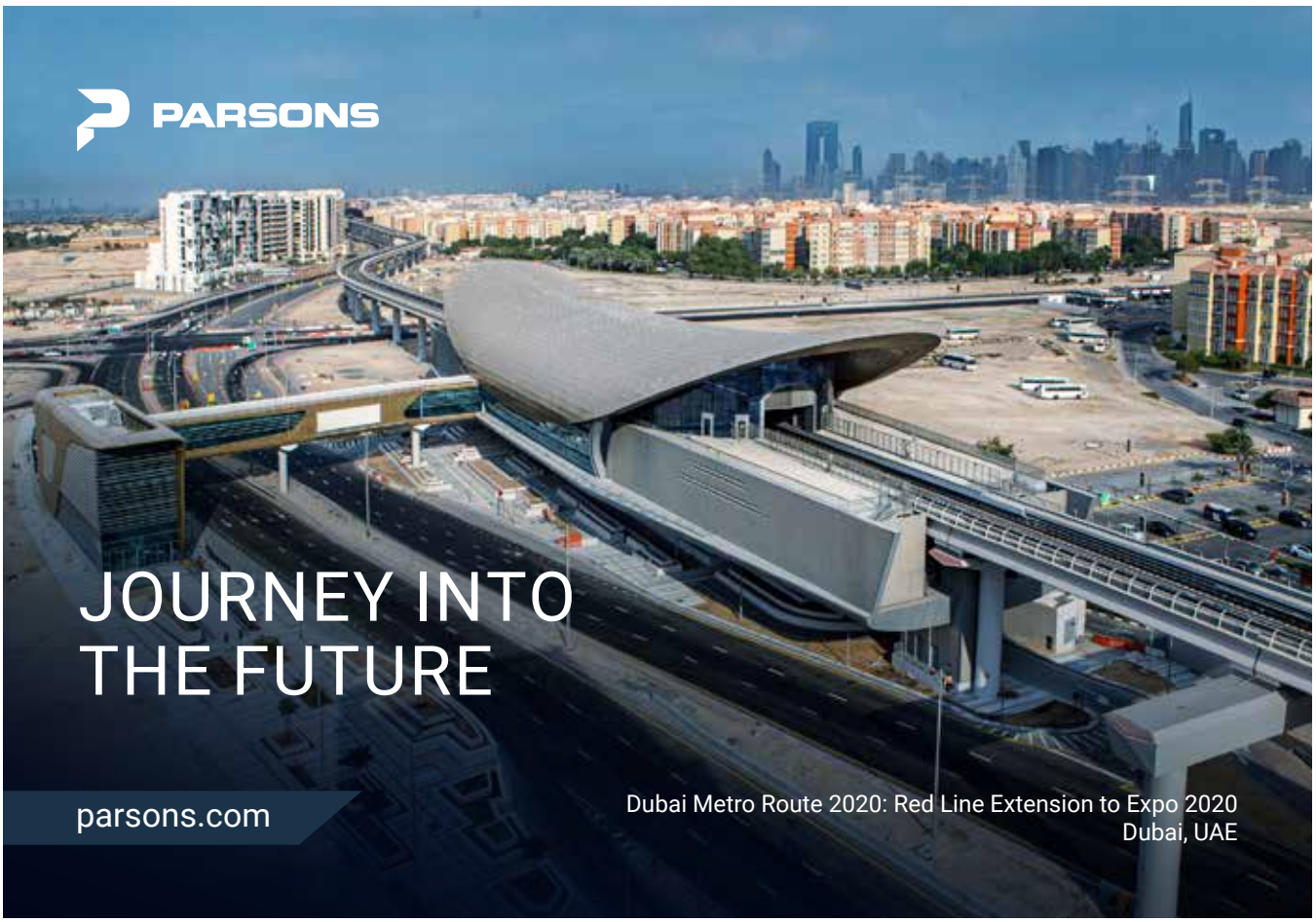
Industry leaders. Delivering innovative solutions.

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

From planning and design through construction management and operations, Parsons provides a complete range of services for underground utilities, water storage, wastewater, and transportation tunnels, as well as underground buildings. Whether your project involves soft ground, rock, or mixed-faced conditions, our dedicated staff of more than 110 tunnel professionals have the experience and skills to manage the risks and deliver safe, economical, and innovative solutions. We offer a host of cutting-edge tunneling techniques to minimize the risks associated with underground structures of all sizes and levels of complexity. Our award-winning projects, such as Lake Mead Intake No. 3, Anacostia River Tunnel and Ohio River Bridges-East End Crossing Tunnel, demonstrate Parsons' position as an industry leader and our dedication to delivering on challenging projects.

Learn more at parsons.com/tunnel/

Southern Nevada Water Authority, Low Lake level Pumping Station, Las Vegas, NV.



ABC Industries, Inc.

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

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

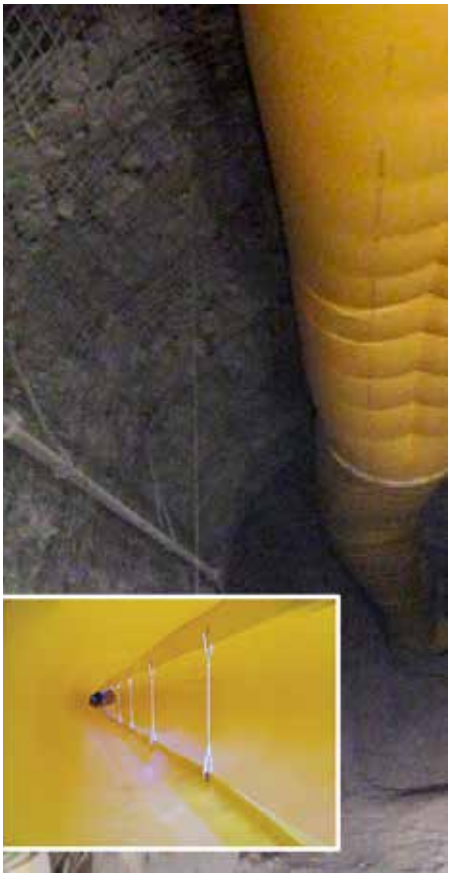
RIGIDUCT®

Filament-Wound Fiberglass Tubing

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

www.abc-industries.net • (574) 267-5166 • (800) 426-0921

RigiDuct®, MineVent®, and TruOval MineVent® are registered trademarks of ABC Industries, Inc.



Premier Pipe Systems Manufacturer for Over 95 Years

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

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

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

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

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

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

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

Quotations are immediately available on inquiry.

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

Mining Equipment Ltd.

Mining Equipment Rolling Stock for Columbus, Ohio

"Rolling for more than 35 years"

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

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

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

Mining Equipment 10 Ton Locomotives for Columbus, Ohio

Drill Tech Drilling & Shoring, Inc.

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

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

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

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

CDM Smith – A Leader in Tunnel Engineering

CDM Smith is a leader in underground space and tunnel engineering. Working collaboratively with our clients, we employ our extensive global tunnel design and construction experience to develop holistic and optimal solutions for a wide range of projects.

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

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

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

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

- Transportation
- Environment
- Water/wastewater
- Mining

Award-Winning Projects

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

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

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

Contacts:
Michael Schultz, PE | SchultzMS@cdmsmith.com | 617-452-6399
Mahmood Khwaja, PE | KhwajaM@cdmsmith.com | 617-452-6391

Howden

Howden is the de facto choice for your ventilation needs. Whether you are building a new tunnel or mine or maintaining an old one, Howden is equipped with 160 years of OEM expertise. Our unblemished safety record places us above the competition while supporting the brands, people, know-how, and products to make your project pain-free.

The Howden range of fans, blowers, compressors and steam turbines, together with premier legacy brands such as Joy Fans, Westinghouse, TLT-Babcock, and Buffalo Forge, are highly reliable and efficient solutions for the tunnel and mining markets.

The Howden portfolio of solutions is enhanced with a Data Driven Advantage. Howden Uptime offers a unique and innovative digital solution; increasing the availability and reliability of critical assets, enabling optimization, and delivering cost-effective solutions and energy savings. Our Ventsim DESIGN software empowers you to design optimal ventilation.

The Howden service team is skilled in your applications and experts in ventilation. Our Long Term Service Agreements provide routine maintenance and OEM spare parts for the lifetime of your equipment. Our Remote Assistance offers a direct link to Howden product experts, enabling real-time communication to deliver a faster resolution even when travel is not possible. Howden combines our technology and worldwide engineering expertise to design and deliver solutions and services that optimize and enable your vital processes, creating a more sustainable world.

Howden's safe, simple and straightforward project management is backed by the OEM knowledge, technical expertise, and field experience you trust.

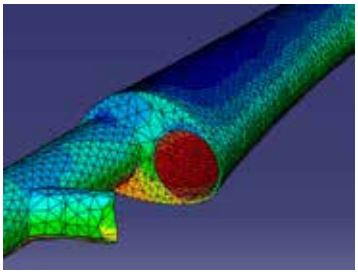
Contact us today at: www.howden.com

Dr. Sauer & Partners

Dr. Sauer & Partners is a specialist, independent consultancy providing the full range of design and construction management services for tunnels, shafts and caverns. Delivering innovative, cost-effective and environmentally aware designs, the company has nearly 40 years' experience providing solutions for some of the world's most challenging tunnelling projects for Metro, Highway, Water, Rail and Mining, for urban and rural tunnels in all geologies.

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

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



www.dr-sauer.com

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

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

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

For more information: For more information:

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

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

MICHELS

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

As one of North America's largest infrastructure contractors, Michels design-build capabilities ensure cost effective, engineered solutions for even the most complex deep foundations projects. Look to us for a variety of foundations work including drop shafts, secant piles, mini-caissons, micropiles, and more. Our in-house professional engineers can design temporary and permanent solutions that are stable, durable and cost effective.

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

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

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

Strata Worldwide

Strata Worldwide is a global leader in advanced safety systems and communication technologies for underground working environments. With over 28 years of underground experience, the company is now taking a deliberate and strategic step forward within the tunneling industry to bring Strata's proven solutions to the global world of underground construction.

Strata offers a collection of safety and support technologies including emergency refuge chambers, communication and monitoring networks and proximity detection systems. These solutions can each be used independently, or uniquely interfaced together to expand their functionality and deliver valuable report generation for productivity and safety analyses.

Through partnerships with global-leading chemical companies, Strata offers a full suite of specialty solutions for countless applications and problem-solving options.

- Control of groundwater either in groundmass or in the excavation workings
- Modification of the groundmass properties to enhance stand-up time or fill voids
- Durable and non-durable technologies for areal support of excavations with shotcrete

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

For more information, please contact Mike at +1.385.234-1474 or the main office at 770.321.2500. info@strataworldwide.com

Brookville

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

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

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

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

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

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

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

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

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

David R. Klug & Associates, Inc.

Since 1996, David R. Klug & Associates, Inc. has provided international and national manufacturer's representative services to the underground heavy civil and mine construction industries. The company specializes in the sale and coordination of specialty products, equipment and services for soft ground, conventional and NATM/SEM tunneling practices. Expertise is offered in the supply of various componentry used in the manufacture of one pass precast segmental tunnel linings inclusive of EPDM gaskets, plastic and steel connectors, grout lifting assemblies and precision steel segment casting moulds plus final lining forming systems for C-I-P final lining applications. Through their distribution company, Klug Construction Systems, LLC offers Nittetsu ultrafine cement, GFRP rock bolts and soft-eyes, steel and synthetic fiber reinforcement, prefabricated welded wire fabric and rebar reinforcing panels, and specialty grout systems for various tunnel backfill grout requirements for highway, rail, subway, water and CSO tunnel construction applications.

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

Bradshaw Offers Innovative Tunnel Engineering and Construction Technology

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

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

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

Gall Zeidler Consultants

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

The company specializes in mastering difficult ground conditions by using cutting-edge ground improvement methods such as dewatering, grouting, and ground freezing. GZ has a history of over 300 miles of successfully completed national and international tunneling projects. The company's expertise has consistently been sought after by major contractors and project owners in the industry developing tailored tunnel solutions and to assist with the mitigation of risks associated with tunneling.

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

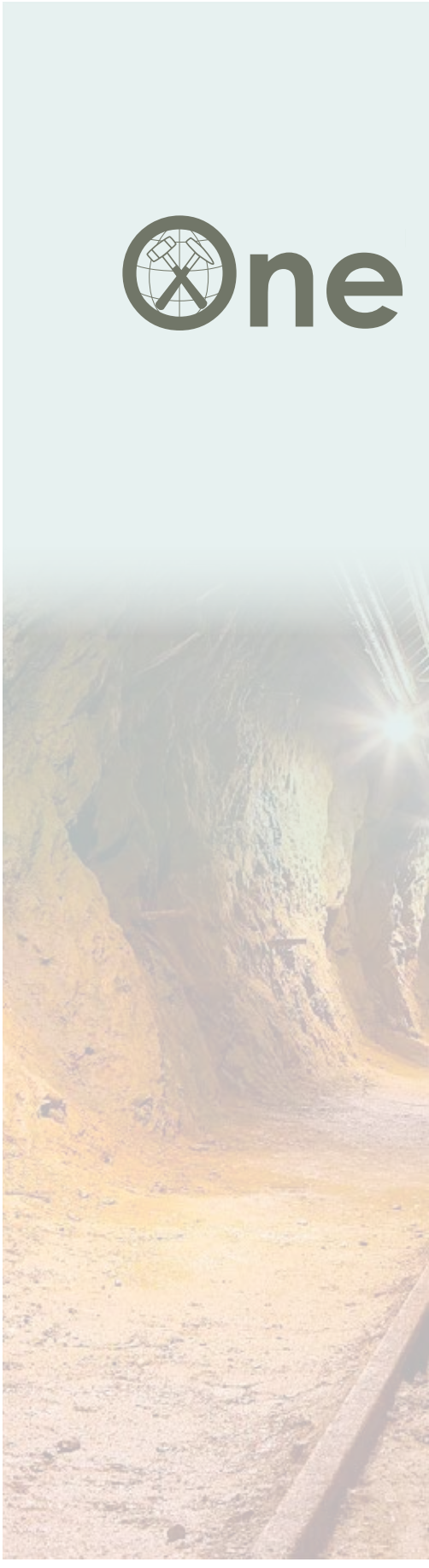
ELEVATED THINKING, UNDERGROUND.

With over 300 miles of tunneling projects completed worldwide, Gall Zeidler Consultants is a leader in tunnel design, engineering, geotechnics, tunnel rehabilitation, and program and construction management. From the drawing board through turn-key completion - we provide the expert services to see projects through to their use at the highest quality.

GZ Gall Zeidler Consultants
Geotechnics | Tunnel Design | Engineering

Washington DC · London · New York · San Francisco
Salzburg · Santiago de Chile · New Delhi · Singapore

www.gzconsultants.com



Terratec

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

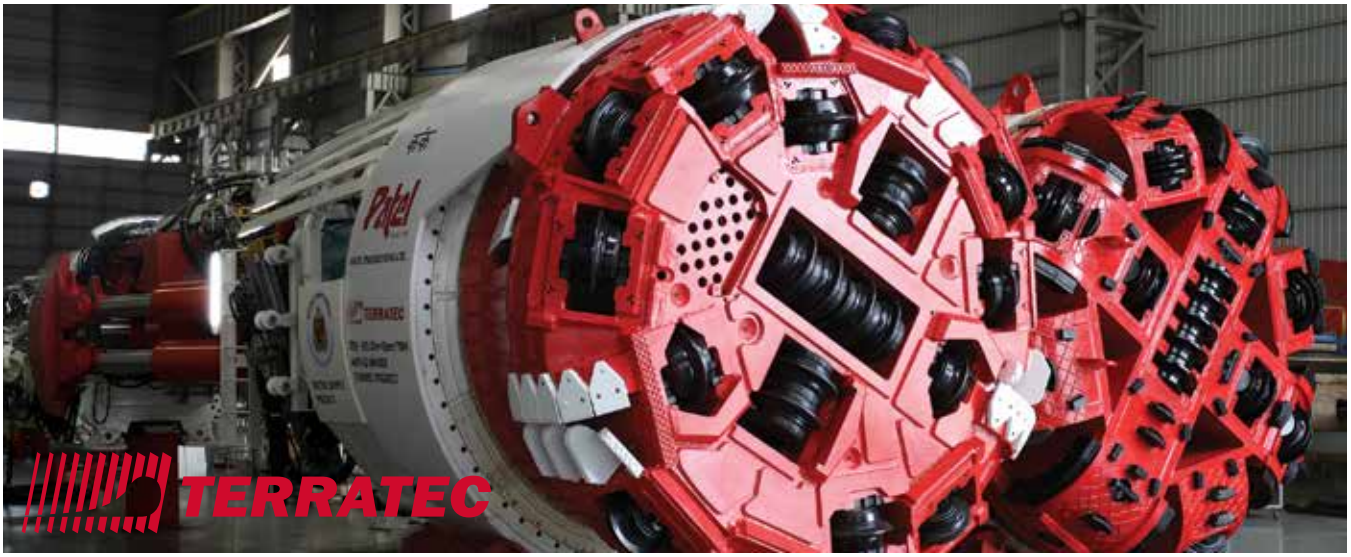
TERRATEC products are well-known in the industry as Robust, Durable and Safe, basic principles that must prevail in the design of any equipment made to work in the extreme conditions encountered underground. As a provider of Total Tunnelling Solutions, TERRATEC's scope of work extends to custom engineering,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

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

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

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

Company address:
171 Davey Street, Hobart, Tasmania 7000, AUSTRALIA
Company email address:
info@terratec.co
Company telephone number
+ 61 362233282



Move Your Career in the Right Direction

Find resources for all phases of your career path with your UCA membership.

Professional Development

Earn PDH credits and stay current with a range of professional development opportunities, both online and in person.

Get Involved

Inspire the next generation of underground engineers and support Down for That, an exciting workforce initiative at **undergroundcareers.org**

Career Center

Find a new job or career insights at the UCA Career Center and connect with your next great job. Create an account at **tunnelingjobs.smenet.org**

Make the most of your membership with UCA resources.
Learn more at **ucaofsme.org**

Make Plans to Attend

21 sessions | **100+** speakers | **200+** exhibitors

Keep up with the ever changing and growing tunneling industry at RETC. Learn about new trends and technologies, as well as innovative concepts, new equipment, materials, management, financing, and design challenges.

Attend THE NATION'S LEADING tunneling conference

RETC2021

June 13 – 16, 2021
LAS VEGAS, NEVADA

Visit www.retc.org for more information.

Registration opens spring 2021.

SME
Society for Mining, Metallurgy & Exploration

RAPID EXCAVATION AND TUNNELING CONFERENCE®

RETC2021

June 13 – 16, 2021
LAS VEGAS, NEVADA