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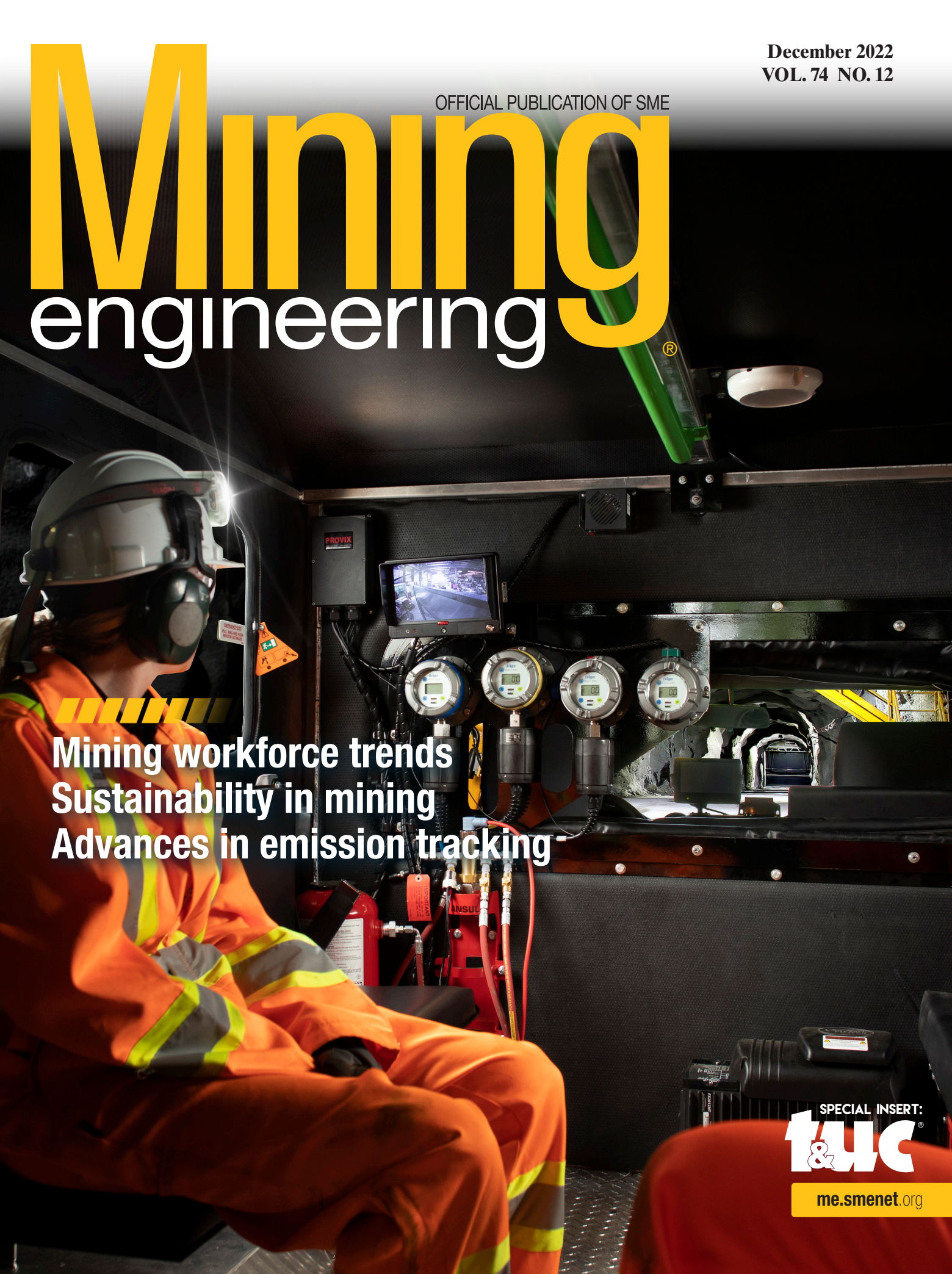

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Feature Articles

Technical-paper Abstracts from *Mining, Metallurgy & Exploration*

(peer-reviewed and approved)

SME News

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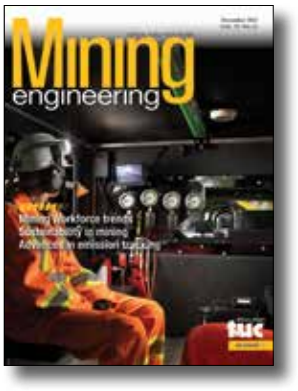
Cover

Sustainable development in the mining industry includes all aspects of materials discovery, sourcing, extraction and supply for the needs of present and future generations. Read about recent developments in the industry on page 18. On page 25, workforce challenges and opportunities in the mining and mineral processing industries are discussed. Cover: ©Karly Winfield 2022. Cover design by Ted Robertson.



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President's report from the Midyear meeting;

SME Board of Directors keeps the Society moving forward

Ronald Parratt
2022 SME President

This year SME held its midyear Board of Directors meeting at the Peppermill Hotel and Casino in Reno, NV from Sept. 19-21 followed by the one-day Thrive Conference.

The SME Structure and Governance Committee, with the support and encouragement of the university department heads, brought forth a proposal to establish a Mineral School Department Heads Committee to foster better exchange between the various schools and greater interaction directly with SME. In addition, the Structure and Governance Committee also recommended the approval of a revised charter for the Resources and Reserves Committee. Lastly, the Structure and Governance Committee brought forth a recommendation to dissolve the inactive SME Information Publishing Committee. SME will evaluate and review book topics with a small group of topic matter experts in the future rather than with a committee, which often may not be familiar with the proposed topic.

The Health and Safety Division announced that it has created the Health and Safety Division Scholarship Program with division funds as an encouragement to increase health and safety professionals in mining.

The UCA of SME Division brought forth a proposal to reduce the SME student membership fee from $35/year to $5/year. The belief was that this reduction would increase the number of student members in SME. This issue generated significant and lengthy discussion among the board, and from several meeting attendees. In the end, the board agreed to reduce the student membership fee to $20/year starting in 2023 and provide students with an electronic copy of *Mining Engineering* each month.

Financially, the Society continues to be strong. Revenues were strong from meetings during the past fiscal year due primarily to a better than expected annual conference and meeting in Salt Lake City and improved book sales and membership. Following the pandemic fiscal years of 2020 and 2021, where our operations were impacted and significantly disrupted, the Society projected an operating profit of more than $100,000 for the 2022 fiscal year. The budget for the next fiscal year, which began Oct. 1, 2022 was presented, indicating the expectation of a stronger fiscal year ahead as the effects of the pandemic continue to diminish.

Safety Share: Johns Hopkins prepared a list of mental health talking points for leaders and managers during COVID-19. While the pandemic has subsided and many people have returned to pre-pandemic life, the stress in the workforce has continued.

To address workplace stress, Johns Hopkins suggest:

- Be aware of the risks and what to look out for.
- Learn about the signs and symptoms of stress and distress and what to look out for in ourselves and others.
- Be willing to connect with each other in a meaningful way.
- Engage in meaningful conversation around what we are experiencing. Make time for each other and to listen to and understand each other.
- Be present and pay attention.
- Make information visible and easily accessible and give explicit permission to seek help without judgement, professional repercussions and with confidence.

Lately, the investment portfolio, however, has declined, with more volatility expected. These declines are not expected to affect the operating plan.

SME has a considerable number of strong, active student chapters; however, for a variety of reasons, several have been inactive for some time. Staff recommended that a few chapters that have been inactive for a lengthy period be closed. This will reduce the number of student chapters SME supports to about 72.

It was announced that SME is the recipient of a NIOSH/CDC grant entitled "Eliminating Barriers for the Implementation of Automation in the Mining Industry." Three universities will be working with SME, and SME will hold several workshops leading to the preparation of a detailed report that will be presented to NIOSH in two years. The goal of this work is to allow faster adoption of mining-related automation projects.

I have written about the annual challenge of finding recipients for many of the SME awards, and the decline in attendance at the Annual Awards Dinner. The board has recommended the creation of an ad hoc committee to review these issues and make improvements to the

(continued on page 12)

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Canada orders Chinese firms to divest from projects

THREE CHINESE companies have been ordered to divest their investments in Canadian critical minerals. The Canadian government said the order was made in the interest of national security.

The three firms ordered to divest their investments are Sinomine (Hong Kong) Rare Metals Resources Co. Ltd, Chengze Lithium International Ltd, also based in Hong Kong, and Zangge Mining Investment (Chengdu) Co. Ltd.

Reuters reported that China responded to the order by saying Canada is using national security as a pretext, and that the divestment order broke international commerce and market rules.

The Canadian government mandated the divestiture after "rigorous scrutiny" of foreign firms by Canada's national security and intelligence community, Industry Minister Francois-Philippe Champagne said in a statement.

"While Canada continues to welcome foreign direct investment, we will act decisively when investments threaten our national security and our critical minerals supply chains, both at home and abroad," Champagne said.

Sinomine was asked to sell its investment in Power Metals Corp.; Chengze Lithium was asked to divest its investment in Lithium Chile Inc., and Zangge Mining is required to exit Ultra Lithium Inc.

Canada has said it must build a resilient critical minerals supply chain with like-minded partners, as it outlined rules meant to protect the country's critical minerals sectors from foreign state-owned companies.

"The federal government is determined to work with Canadian businesses to attract foreign direct investments from partners that share our interests and values," Champagne said.

Canada has large deposits of critical minerals like nickel and cobalt, which are essential for cleaner energy and developing technologies. Demand for these minerals is projected to expand significantly in the coming decades.

Earlier this year, Canada, the United States, Britain and a few other countries established a new partnership aimed at securing the supply of critical minerals as global demand for them rises. ■

ISA nations call for pause to deep-sea mining

DURING THE United Nations-affiliated International Seabed Authority (ISA) meeting in Kingston, Jamaica, a number of the ISA Council's 36 member states called for a "precautionary pause" or a moratorium on deep-sea mining due to a lack of scientific data on the areas of the seabed targeted for exploitation.

Germany, France, Spain, Costa Rica, New Zealand, Chile, Panama, Fiji and the Federated States of Micronesia were among the ISA Council members calling for the pause to enact mining regulations by July 2023, a deadline established last year.

Beyond the ISA meeting, French President Emmanuel Macron called for an outright ban on deep-sea mining at the UN's Climate Summit, COP27 in Egypt. Meanwhile, Brazil, the Netherlands, Portugal, Singapore, Switzerland and other council members also indicated they would not approve any mining contracts until sufficient environmental protections for unique deep ocean ecosystems are in place, regardless of the July deadline, *Bloomberg* reported.

Some nations, however, including the United Kingdom and Norway, expressed confidence that the regulations could be finalized by the deadline. China cautioned against focusing "single-handedly on only the protection of the environment."

A comprehensive review of available research on areas of the deep ocean set for exploitation, published in March in the journal *Marine Policy*, concluded that a lack of scientific knowledge about those ecosystems precludes effective management of mining. The paper's authors included prominent scientists and four members of the ISA committee that writes mining regulations.

Mining companies have argued that deep-sea mining will have less of an environmental impact than terrestrial mining, and is necessary to provide the metals for electric car batteries and other green technologies needed to combat climate change.

The ISA, which includes 167 member nations and the European Union, was established in 1994 by the United Nations Convention on the Law of the Sea treaty to regulate mining in international waters while ensuring the protection of the marine environment. Over the past 21 years, the ISA has issued exploration contracts to state-backed enterprises, government agencies and private companies to prospect for minerals over more than 500,000 square miles of the seabed in the Atlantic, Indian and Pacific oceans. Each mining contractor must be sponsored by an ISA member nation, which is responsible for ensuring compliance with environmental regulations.

Until last year, the ISA Council had been slowly negotiating regulations that would allow mining to proceed. Then in June 2021, Nauru, a Pacific island nation with a population of 8,000, triggered a provision in the Law of the Sea treaty that requires the ISA to complete regulations within two years.

Nauru is a sponsor of a subsidiary of The Metals Co., a Canadian-registered company formerly known as DeepGreen that also holds mining contracts sponsored by two other small Pacific island nations. If the ISA does not approve regulations by July 2023, it may be required to provisionally approve The Metals Co.'s application for a mining license under whatever environmental protections are in place at the time. Nauru triggered the two-year rule after The Metals Co. told potential investors it expected to begin mining in 2024, according to U.S. securities filings. ■

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Mine permitting could get boost from US House; **Republicans could look to cut permitting times in the United States**

MINING PROJECTS held up by the lengthy and complex permitting process in the United States and those projects that have yet to begin the process could potentially see those permitting timelines shortened considerably after Republicans won control of the House of Representatives on Nov. 16.

Reuters reported that boosting American production of battery minerals and other critical minerals necessary for the energy transition is a top agenda item for a number of lawmakers who will take their seats in January. The majority control of the House gives them the power to influence how regulators approve or deny mining projects.

Republican leaders had promised voters during the election they would cut the mining permit review timeline in half and boost domestic electric vehicle (EV) mining, rather than seek more supply overseas. They also want federal agencies to coordinate better when reviewing mine permit applications, and to place time limits on when lawsuits against mines may be filed.

"We need to step up our mining activities if we're going to have an electrified economy," said Rep. Bruce Westerman, an Arkansas Republican who is poised to become chair of the House Natural Resources Committee.

Westerman and other Republicans will be partially stymied by Republicans' failure to wrest control of the U.S. Senate from Democrats.

"We're not talking about gutting environmental laws," Westerman told reporters. "We're talking about making environmental laws work so we can protect the environment and have a strong and vibrant economy at the same time."

Westerman said he has spoken with Sen. Joe Manchin, a West Virginia Democrat and chair of the Senate energy committee, about permitting reform and is "hopeful that it's an area where we can work together."

With their newfound control, Republicans could threaten to withhold funding from agencies perceived as taking too long to approve mines. President Joe Biden, though, will still oversee the permitting process.

Miners and their Republican supporters, who have long complained that the U.S. mine permitting process is capricious, say they are hopeful for some changes in the new Congress.

"We're optimistic that the oversight function will be robust and that the (Biden) administration will comply with legal statutes already laid out," said Rich Nolan, head of the National Mining Association.

In addition, Republicans plan to investigate Biden's decisions to halt development of Antofagasta Plc's Twin Metals copper project in Minnesota and Rio Tinto Plc's Resolution Copper project in Arizona.

"We want the politics to be out of the permit review process and let the facts, the science and the truth be the determinant as to whether a mine moves forward," said Rep. Pete Stauber, a Minnesota Republican set to become chair of the House's Subcommittee on Energy and Mineral Resources, which oversees mining on federal land.

Biden's regulators are also scrutinizing a Nevada lithium project from ioneer Ltd. Proposed mines from Lithium Americas Corp. and Polymet Mining Corp. face stiff court challenges. ■

Newswatch contents

Lundin to fill sinkhole in Chile while **repairing adjacent copper mine**

LUNDIN MINING announced plans to fill the giant sinkhole that formed near its copper mine in Copiapo, Chile in July while also sealing the mine that was affected by water seeping in.

The 36-m (120-ft) diameter sinkhole in the Tierra Amarilla commune, around 665 km (413 miles) north of capital Santiago, drew widespread global attention and saw charges by authorities against Lundin.

Reuters reported that studies to determine the causes of the sinkhole are already in "decisive stages" and a "technical body is already receiving all the information to be able to draw conclusions," Luis Sanchez, president of a local unit of Lundin, told *Reuters*.

The executive said that regardless of the outcome, the firm planned to fill the hole using material such as sand and rocks with the same characteristics as a river bed, as well as fully sealing the affected part of the mine.

Sanchez declined to predict the amount of material that would be needed or the total cost, though he said the firm had already spent some $10 million resolving the issue.

"We are observing a positive development in the recovery of the levels in the aquifer and this means that we can look positively at this solution and we can say that we are not facing irreparable damage, as some authorities have indicated," Sanchez said. ■

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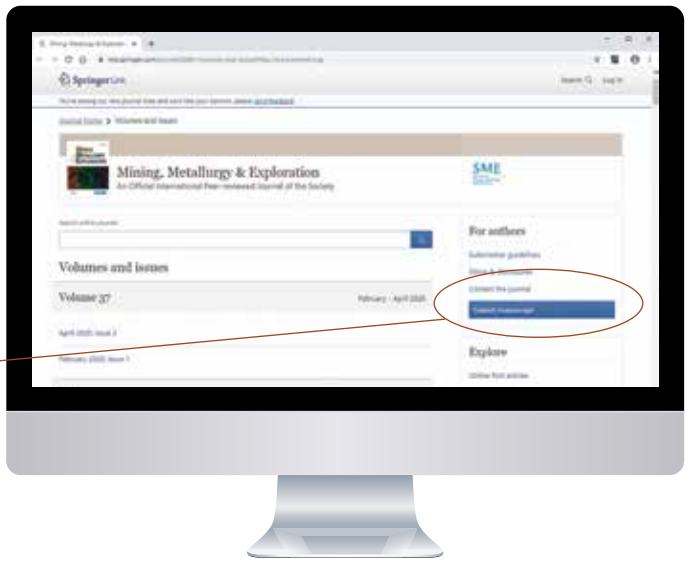

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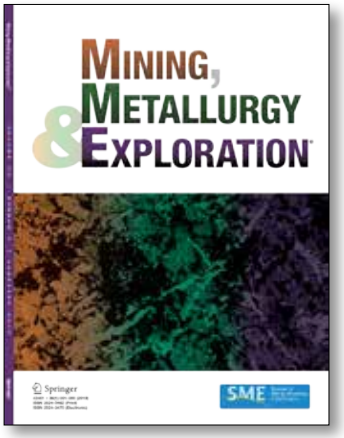

Collection in Honor of Dr. Patrick Taylor: All About Metallurgy

This special collection is to pay tribute to Dr. Patrick R. Taylor, who recently retired from Colorado School of Mines as Ansell Distinguished Professor of Chemical Engineering. Dr. Taylor is a registered professional engineer with over 45 years of experience in mineral processing and extractive metallurgy engineering, research, teaching and consulting. He is experienced and trained in pyrometallurgy, hydrometallurgy, and mineral processing. He has directed research for more than 100 graduate students and post-docs, and has taught extractive metallurgy and mineral processing university courses for the past 45 years.

This collection will honor the breadth of Dr. Taylor's career with papers in the areas of **extractive and process metallurgy, mineral processing, recycling, waste treatment and minimization, and thermal plasma processing** in a wide range of metals and materials, including base metals (copper, zinc, lead, etc.), critical metals (REEs, lithium, cobalt, nickel, indium, etc.), precious metals (gold, silver, platinum, etc.), and ceramic powders.

Editor: Fangyu Liu, Ph.D., Hatch Ltd.

DEADLINE: Submit by February 28, 2023
Email Chee Theng at theng@smenet.org if you have questions or need help.

Collection on Underground Ventilation

Technological advances in automation and control, underground equipment, computer modeling power, development of deeper and hotter mines, and strict mine health and safety regulations have brought significant improvements to mine ventilation engineering and mine atmospheric monitoring.

Editor: Purushotham Tukkaraja, Ph.D., QP, Associate Professor of Mining Engineering, South Dakota Mines
Submit by February 28, 2023

Collection on Ground Control in Mining

Mine ground control engineering has been constantly improving over the years to tackle the continual challenges of the mining industry. Stricter mine health and safety regulations, depletion of "easy-to-mine" resources resulting in more challenging mining conditions, and technological and computational advancements have been catalysts to mine ground control research over the years.

Editor: Deniz Tuncay, Ph.D., Assistant Professor of Mining Engineering, West Virginia University
Submit by February 28, 2023

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Lithium Americas splits into two companies; **Lithium Americas will own Thacker Pass Mine in Nevada**

LITHIUM AMERICAS will separate its North American and Argentine business units into two independent public companies.

The company announced that Lithium International will be an Argentina-focused company owning Lithium Americas' current interest in its Argentine lithium assets, including the near-production Caucharí-Olaroz lithium brine project in Jujuy, Argentina (Caucharí-Olaroz).

Lithium Americas (NewCo) will focus on North American projects and will own the Thacker Pass lithium project in Humboldt County, NV as well as the company's North American investments.

"Following a comprehensive review of the merits of separating Lithium Americas into two public entities, we have reinforced our beliefs that separating the North American and Argentine businesses will facilitate unlocking the full potential of their significant asset base to deliver maximum value to our shareholders and other stakeholders," said Jonathan Evans, president and chief executive officer. "Upon completion of the separation, Lithium Americas shareholders will retain ownership in two leading lithium businesses — one of the largest known lithium developments in North America, which is central to the U.S. domestic supply chain, and a near-term producing portfolio with significant growth from two high-quality projects in Argentina."

Upon completion of the separation, Lithium International will continue to hold the company's 44.8 percent interest in Caucharí-Olaroz and 100 percent interest in the Pastos Grandes lithium brine project in Salta, Argentina. It will also hold the company's approximately 17 percent investment in Arena Minerals Inc.

Meanwhile, Lithium Americas (NewCo) will hold the company's 100 percent interest in Thacker Pass, one of the most advanced lithium projects currently known to be under development in the United States, as well as the company's investments in Green Technology Metals Limited and Ascend Elements Inc.

The company is moving Thacker Pass toward production and has received all federal and state permits needed to commence construction, with a ruling on the Record of Decision appeal expected in early 2023. On July 20, 2022, the company celebrated the inauguration of its Lithium Technical Development Center (LiTDC) in Reno, NV, which was developed to demonstrate the processing of Thacker Pass ore. The LiTDC achieved battery-quality specifications with product samples being produced for potential customers and partners. Thacker Pass is aligned with the U.S. national agenda to enhance domestic supply of critical minerals and has the potential to be a leading near-term source of lithium for the North American battery supply chain.

Lithium International will be focused on ramping up Caucharí-Olaroz to bring stage 1 operations of 40 kt/a (44,000 stpy) lithium carbonate to production in the first half of 2023. Once at full capacity, Caucharí-Olaroz will be the largest known new battery-quality lithium carbonate brine operation to come into production in over 20 years. Lithium International will also be focused on further maximizing shareholder value within its Argentinian portfolio from a stage 2 expansion at Caucharí-Olaroz and advancing regional growth opportunities through Pastos Grandes and the company's collaboration with Arena Minerals.

It is anticipated that the separation will be completed by way of a plan of arrangement under the laws of British Columbia, with each shareholder of the company retaining their proportionate interest in shares of the company, which would become Lithium International, and receiving newly issued shares of Lithium Americas (NewCo) in proportion to their then-current ownership of the company. ■

Rio Tinto's $3.3 billion bid for Turquoise Hill put on hold; **Transaction put on hold by Quebec securities regulator**

RIO TINTO'S proposed $3.3 billion takeover of Canada's Turquoise Hill Resources and by extension the Oyu Tolgoi copper and gold project in Mongolia has been postponed indefinitely as Quebec's top securities regulator has decided to review the transaction.

Turquoise Hill announced that the Autorité des marchés financiers (AMF) is investigating whether a side deal between Rio Tinto and dissident shareholders is legal.

"The AMF considers the transaction as currently structured to raise public interest concerns," the company said.

"The special committee has been engaged with Rio Tinto in order to address the differential treatment of minority shareholders resulting from the agreements. In the event that terms are reached that satisfy the special committee's concerns, the company will provide shareholders with supplemental disclosure regarding such revised terms. In order to provide shareholders with sufficient time to consider such supplemental disclosure, the company has determined to adjourn the special meeting of Turquoise Hill shareholders, currently scheduled for November 15, 2022 at 10:30 a.m. (Eastern time), to a date to be determined," the company said in a statement.

Minority shareholder CaravelCapital Investments said last week the agreement inked by Rio Tinto, Pentwater Capital Management and SailingStone Capital Partners gives dissidents preferential treatment over smaller holders. ■

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President's Page: **Board considers many actions**

(continued from page 4)

process for identifying recipients of the SME annual awards, and to make recommendations to improve the awards dinner to increase attendance.

The progress on the previously approved Memorandum of Understanding with the American Institute of Professional Geologists (AIPG) was reviewed. The MOU was established to create collaboration between the parties to increase the exploration/economic geology programming at both the SME and AIPG annual meetings. The first joint programming will start with the MINEXCHANGE 2023 SME Annual Conference & Expo.

Staff further reported that MINEXCHANGE 2023, to be held in Denver, shows signs of being a strong meeting with an excellent keynote session entitled: "Embracing ESG to Build Trust in Mining Investments." Make plans now to attend.

Steve Holmes, SME Foundation President, gave an update and report on the SME Foundation.

The board also reviewed the "Jobs of Tomorrow" program produced by Workerbee.tv (see page 48).

Finally, Bill Edgerton discussed the status the project, "5 Myths of Mining." Outside evaluation of the current wording generated by SME of the 5 Myths was found to be too much "talking to ourselves," and likely would not resonate well with those outside of our industry. The SME Board will engage a PR firm to assist with the re-direction of this initiative.

These are some of the highlights of the meeting and are really pretty typical of a board meeting. Many more topics were discussed informing the board of the status of ongoing committee work. These commonly lead the board to request that the committee continue work on a given project, perhaps with modifications, with the goal of bringing it to the board to consider for action.

This is just a small window into the workings of SME. I would encourage you to get involved and contribute to the directions taken by the society. It's fun, rewarding and remember, the world is run by those who show up! ■

SME Silent Auction

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Germany turns back to coal power;
RWE dismantles wind farm to make way for coal mine expansion

IN LIGHT OF THE ongoing energy crisis taking place in Europe as a result of Russia's invasion of Ukraine, many European nations are looking for stable energy supplies.

Among those searching for more reliable energy sources is German energy company RWE, which announced that it will dismantle a wind farm to allow for an adjacent coal mine to expand.

Fox Business reported that the RWE will expand the Garzweiler coal mine, saying the decision is necessary to strengthen supplies amid the ongoing energy crisis.

"We realize this comes across as paradoxical," RWE spokesperson Guido Steffen said in a statement. "But that is as matters stand."

According to reports, one of the wind farm's eight wind turbines was dismantled in October, and two others are expected to be taken down next year. The remaining five turbines will be dismantled by the end of 2023, said a spokesperson for the company that builds and runs the wind farm.

RWE's decision to expand into the Keyenberg wind farm, which is located in North Rhine-Westphalia, has drawn the ire of climate activists.

North Rhine-Westphalia's Ministry for Economic and Energy Affairs repeatedly advocated against the destruction of the wind turbines.

"In the current situation, all potential for the use of renewable energy should be exhausted as much as possible and existing turbines should be in operation for as long as possible," a ministry spokesperson said in a statement, according to the *Guardian*.

The expansion comes in tandem with a plan to temporarily return three of RWE's lignite-fired coal units to the market, a decision that was approved by Germany's cabinet. The units were previously on standby.

"The three lignite units each have a capacity of 300 MW. With their deployment, they contribute to strengthening the security of supply in Germany during the energy crisis and to saving natural gas in electricity generation," RWE said in September.

"Originally, it was planned that the three reserve power plant units affected would be permanently shut down on Sept. 30, 2022, and Sept. 30, 2023, respectively," RWE added.

Germany's cabinet approved the decision to bring back the idled coal units to boost energy supplies, as energy imports remain hindered by the Russia-Ukraine War.

The expansion also comes after a legal fight for the disputed land in March of this year, when a court ruled in favor of RWE.

The turbines at the wind farm were constructed more than 20 years ago and are considerably less powerful than their newer versions. ■

Saudi Arabia looks to Australia
for support for its mining industry

SAUDI ARABIA Minister of Industry and Mineral Resources Bandar bin Ibrahim Al-Khorayef visited Australia looking for support from mining companies as his country seeks to diversify from its oil-dependent economy and develop more mining.

The kingdom says it is home to $1.3 trillion worth of untapped mineral deposits including copper, zinc, phosphates and gold, and has created a Vision 2030 project to tap into those resources.

Australian miners should "come, explore, do mining — the same as they are doing here," Al-Khorayef told *Bloomberg*.

The Vision 2030 project aims to reduce reliance on fossil fuels and embrace industries from mining to renewable energy and manufacturing. Of the $170 billion sought for mining, it envisages about 60 percent will come from private companies and the rest from state-owned entities.

Al-Khorayef said he had met with a number of smaller Austrlalian miners already, and hoped to meet bigger players such as BHP Group Ltd and Rio Tinto Plc at a major mining conference in Sydney.

Saudi investors are "interested in this sector," he said, but the country lacks domestic mining expertise and "you need to have partners who understand the sector quite well, and know how to utilize the resources."

Saudi Arabia's small mining industry is dominated by state miner Saudi Arabian Mining Co., commonly known as Maaden. The country should emulate Australia's model of junior, private-sector miners that develop riskier and early-stage mines, the minister said. ■

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Sustainable development across the minerals and metals value chain

by Karin Olson Hoal, Nicole M. Smith, Steven Fecht, Oscar Restropo Baena, Sebnem Duzgun and Corby Anderson

SME's Sustainable Development Committee brings together every division in the Society to help transform the minerals and metals industry for the future.

SME's Sustainable Development Committee (SDC) spans every division within SME and thus all aspects of the metals and minerals pipeline from exploration to extraction to impacts on society. The SDC is the only SME committee composed of members from each SME Division. We encourage all SME members to engage in activities that can transform our industry as a future-focused and impactful force for the sustainable development of humanity.

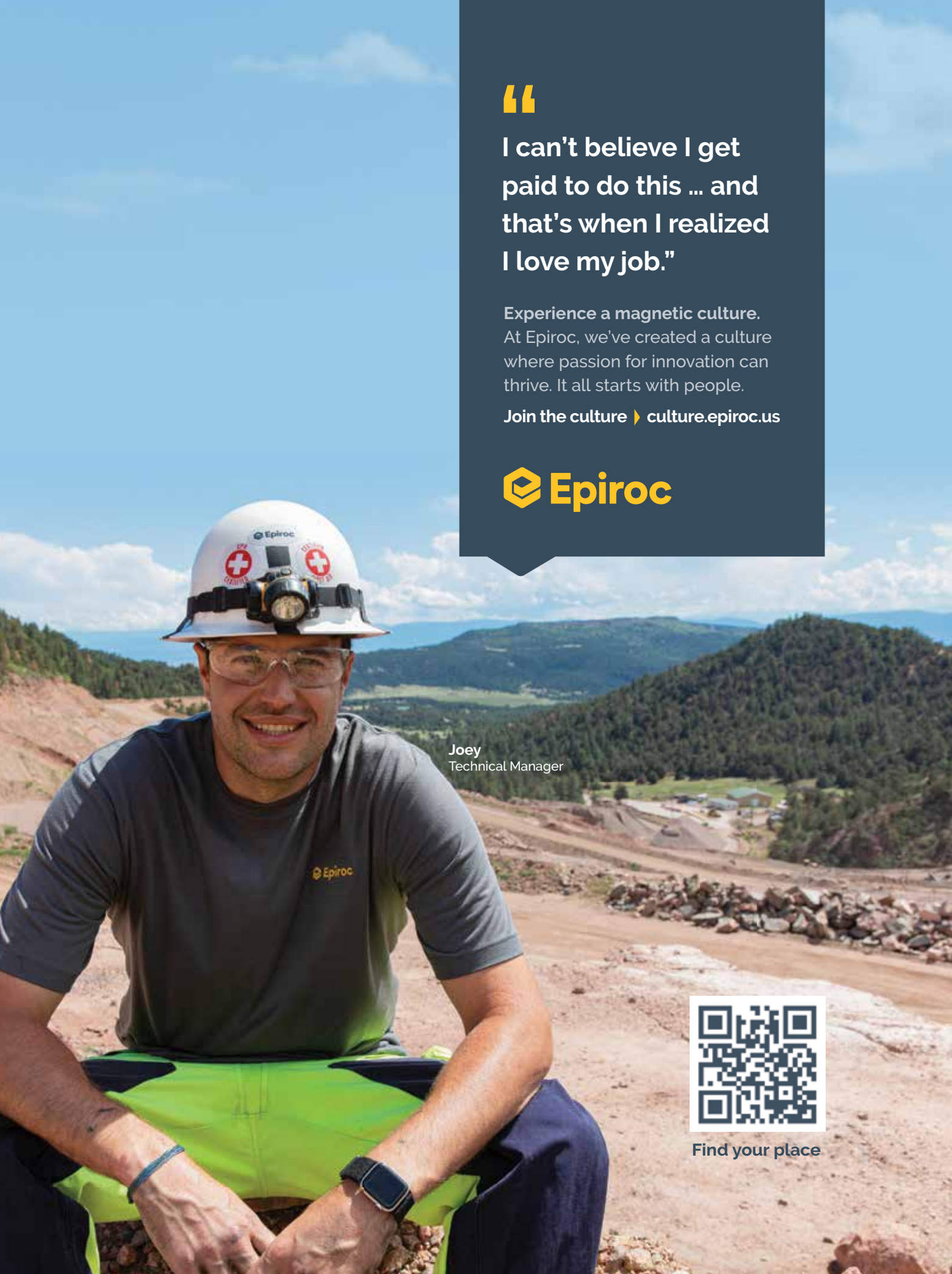
The SDC is a resource for SME members for identifying and sharing information on current tools, best practices and new developments on the contributions the minerals industry makes to sustainable development. The goal is to inform discussions and to support applications of these tools throughout the mine lifecycle. This committee, through the SME strategic plan, encourages increased awareness of how the minerals industry can contribute to sustainable development worldwide.

As the world shifts to recognizing the increase in raw materials necessary to supply the future needs of renewable energy, global infrastructure requirements and efforts toward poverty alleviation, the delicate balance of increased extractive activities with stakeholders, net-zero strategies and environmental equity is increasingly critical. Sustainable development in the mining industry today thus includes all aspects of materials discovery, sourcing, extraction and supply for the needs of present and future generations.

Sustainability occurs through incremental improvements at each step of the mining process and leads to more effective decision making, positive business outcomes, improved investor sentiment, greater societal visibility and a longer-term vision for predicting, improving and mitigating community and environmental impacts, all while building the wealth and supplying the necessary materials for society.

Incremental change at each step of the mining value chain creates better practices and greater contributions to sustainable development

Karin Olson Hoal is Wold Family professor in Environmental Balance for Human Sustainability, Earth & Atmospheric Sciences, Cornell University, **Nicole M. Smith** is assistant professor, mining engineering, Colorado School of Mines (CSM), **Steven Fecht** is mining sector lead and sustainable development consultant, Ramboll US Consulting, Inc., **Oscar Restropo Baena** is professor, materials and minerals, School of Mines, Universidad Nacional de Colombia, **Sebnem Duzgun** is associate department head, professor and Fred Banfield Distinguished Endowed Chair, mining engineering, CSM and **Corby Anderson** is Harrison Western Professor, director of the Kroll Institute for Extractive Metallurgy, mining engineering, CSM. Email: keo52@cornell.edu.



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in and around operations. Future-focused change also offers better engagement opportunities with young professionals who are interested in innovative design to transform the industry, and with the broader public that is largely unaware of industry initiatives. With this integrated approach, we can help SME reach new segments of society who hold creative and diverse perspectives, and who are key to identifying new and innovative solutions for minerals and metals supply, use and distribution.

Many topics of sustainability have common threads in the minerals industry — energy consumption and greenhouse-gas (GHG) emissions, water and land use, health and safety, environmental impacts and community engagement — such that improvements along each step of the process are linked in a network of positive developments from ore discovery to mine closure.

Stepwise improvements in exploration, blasting, extraction, autonomy, digital transformation, workforce transition, fleet movements, process development and operation, tailings management and elimination, and more, all impact the overall value of a project and its operational, business and stakeholder outcomes. They also provide an opportunity to increase positive visibility and public perception of an innovative mineral resources industry. Readers will be aware of many positive examples in their own fields and across the operational value chain. Our hope is to encourage dialogue among the divisions in SME in connecting such activities through communication, data sharing and aligned purpose as we transform the mining industry into one that is sustainable and dedicated to a better future for humankind.

Exploration and discovery

Sustainable activities in exploration and discovery are key to the success of a project, since geologists may be the first onsite and will raise expectations and concerns from the first appearance and earliest sampling and drilling, irrespective of the prospect for development. Integrated exploration plans incorporate advanced consideration of future factors that may never come into play but will be on the table from the start: risk potential, sensitive land use, early and transparent community communication and engagement, skill-development plans for locals and environmental impact plans with shared use of water and energy.

Predictive tools to inform and assist in the most effective and least impactful development options alleviate fears and lessen the risk of unexpected downstream events. During the front-end loading sequence of studies, characterization of the deposit is essential to mitigate risks: for example, in deleterious element content and waste management from the earliest stage. Reducing potential mitigating factors early on can breed confidence in stakeholders and increase the attractiveness of the project to investors. Effective use of advanced analytical techniques, remote sensing and terrain data analysis, geometallurgical modeling and machine learning methods based on target information can go a long way to lessen surface impacts until activities are appropriately understood, planned for, laid out, permitted and valued (for example, Olson Hoal and Frenzel, 2022). These efforts increase the effectiveness and value of projects for operators and increase transparency, stakeholders' value and positive visibility of the mineral resources business. A developing example incorporating social capital is the Mt. Milligan project in northern British Columbia, Canada in which community indicators are used to forecast specific social and economic outcomes for new mining projects (Nelson et al., 2010).

Mineral processing

Mineral processing of metallic and nonmetallic minerals can be understood as a group of physical operations destined to obtain certain minerals and elements contained in rocks in which materials are sometimes mobilized, transformed and consumed. These operations include the comminution for physical liberation of minerals in crushers and grinding mills that may have impacts on the environment, particularly in energy consumption and water use.

At face value, these effects are determined by the development of mining operations in terms of scale and geography (operations on increasingly larger scales affecting an ever-wider portion of the mining regions). Such impacts have been adjusted to the increasingly lower-grade, more-complex mineralogical composition and increasing inaccessibility of ore deposits over time. These technical challenges, which are increasingly complex and demanding, require new technical developments in response to increasingly challenging ores and minerals. Characterizing the ore prior to crushing and grinding, adapting comminution and beneficiation methods to the variability in ore types, using renewable-energy sources and recycled water on site and improving early ore-to-waste separation mechanisms are well-established methods for reducing energy, water, environmental and social impacts in the comminution stage, and toward implementing a

circular economy. Examples of incorporating sustainable operational methods into mineral processing include monitoring and reducing GHG emissions associated with primary mineral and metal production (Azadi et al., 2020).

Extractive metallurgy

The metallurgy sector is one of the most active sectors working to decrease energy-intensive activities, energy transition, water consumption and GHG emissions, as it is a direct target for carbon reduction initiatives worldwide. There are opportunities for companies to make subtle innovations to meet sustainability requirements and to develop more-efficient operations. For example, the pyrometallurgical transformation of iron ore releases a large amount of carbon dioxide (CO_2), making iron and steel production one of the largest industrial emitters of GHGs. Novel technological methods, perhaps through the use of hydrogen, may become more acceptable in the future.

Some of the best efforts to promote sustainability in extractive metallurgy relate to reducing the consumption of energy and water, for example, in cement production and in copper production. An example of these is the introduction of coarse particle flotation technologies to reduce comminution energy and the use of reclaimed water in flotation. Another example is the increased recovery of energy and gases from production processes, such as flash smelting and converting, along with efficient waste heat recovery and sulfur dioxide capture as practiced at Rio Tinto Kennecott.

In addition, the improvement of production technologies has generated opportunities related to furnace feeding and the control and automation of input and product flows, with the objective of providing greater continuity and integration of processes and avoiding energy losses between production stages.

Examples of technologies and processes now globally employed to promote energy efficiency in extractive metallurgy include enhanced systems for real-time control of process variables, optimized usage of process gases already used for heat recovery and gas cleaning, new technologies that promote a significant reduction of energy consumption in electric furnaces and electrolytic processes, including the respective automation and control systems, and hydrometallurgical selective leaching and metal separation and recovery systems with zero water discharge and no gaseous emissions. The Sibanye-Stillwater operations in Montana are a key example.

The Stillwater and East Boulder mines are shallow- to intermediate-level underground platinum group metals mines situated 136 km (85 miles) southwest of Billings in Sweet Grass County and approximately 57 km (32 miles) south of Big Timber, MT. Sibanye-Stillwater has a good-neighbor agreement signed with the community 20 years ago that has proven successful for both parties.

Tailings management

One of the more publicly visible areas of the minerals industry that sustainable technologies are addressing is in the area of waste rock and tailings management, in part incentivized by the circular economy. Dry-stack tailings, reprocessing of tailings through microbial leach technologies, recharacterization methods and re-evaluation of materials reuse potential all aim to better predict, manage and reduce waste rock and tailings.

The Golden Sunlight Mine in Montana, for example, aims to reclaim tailings and send resulting concentrated sulfide materials to Nevada to supplement roaster heat balances. Potential new critical-metals value residing in tailings and the need to reduce environmental risk from waste flows are both driven by characterization and understanding of what resides where in waste materials.

The U.S. Geological Survey's critical-mineral initiative is addressing the location of materials from byproducts (abandoned sites, tailings and waste rocks) in addition to new potential resources through the Earth Mapping Resources Initiative (Earth MRI), Critical Minerals Mapping Initiative and Abandoned Mine Lands programs, as included in the Infrastructure Investment and Jobs Act of 2022.

Renewable-energy integration

The minerals industry is entering an exciting time with respect to integrating renewable energy into operations, and there are many successful initiatives already in place globally. Mining activities can be energy-intensive, and reliance on power generated from fossil fuels may lead to increased regulatory, financial, community and societal risks. With the world target for a carbon-neutral/net-zero carbon future, and investors seeking environmental, social and governance (ESG) and GHG reporting, opportunities to become sustainable operators exist through cost-competitive renewable sources of power generation such as that implemented at Teck's Carmen de

Andacollo copper operation (Canadian Mining Journal, 2020).

Depending on technology and geographic constraints, significant opportunities exist to reduce costs and the carbon and water footprint, and to provide long-term benefit to local communities such as potential revenue streams. Agreements, partnerships and synergistic developments with local energy providers and communities will help in the shift toward mixed energy sources and diversified operations and revenue streams. A sustainable society and the renewable-energy sector that will support it requires responsible mining practices that investors, stakeholders, shareholders and the public are likely to support.

Environmental, social and governance factors

An important piece of integrating sustainability is to follow reporting requirements and standards and effectively communicate about ESG and materiality to investors, shareholders and stakeholders. Governments and lenders require companies to report on some aspects of ESG and materiality, and industry organizations are encouraging more transparent disclosures.

However, this is a complicated task as beyond regulatory reporting requirements there are numerous voluntary standards and guidelines for reporting, and defining what is material to a company and its operations is regionally complex and depends on the type, size and location of operations. For sustainable artisanal and small-scale miners, the task is even more difficult in the absence of large companies (Baena and Mendoza, 2021). Nevertheless, steps are being taken to move toward more standardization in ESG reporting.

Through a data-driven approach, Perdeli et al (2021) provided an overview of the scope and consistency of sustainability indicators used in the sustainability reports of mining companies. They demonstrated that internal issues are better represented than external issues, in particular transportation and supply-chain issues.

In 2020, the CFA Institute established an ESG working group to develop a voluntary global standard that would allow investors to understand and make comparisons of ESG reporting. In an effort to establish consistency and comparability in companies' ESG reporting, the World Economic Forum's International Business Council and its partners published a white paper in which they drew from and expanded existing ESG standards to establish a core group of metrics and disclosures mapped to the UN Sustainable Development Goals (World Economic Forum, 2020).

The International Financial Reporting Standards Foundation launched a consultation to assess demand for global ESG standards. The consultation recognized that a set of comparable and reliable standards will provide more transparency and greater assurances. The National Mining Association's (NMA) newly formed ESG taskforce is exploring the landscape of industry initiatives on ESG.

For SME members, the Society has developed an innovative and helpful ESG Toolkit to address these important issues (see https://community.smenet.org/esgtoolkit/.

Community engagement and development

Community engagement and development are closely linked to ESG performance and are perhaps two of the most important mechanisms through which companies can contribute to sustainable development. The need to engage early and engage often refers to the need for companies to disclose information, participate in dialogue, and listen to and address feedback at the beginning stages of a project and frequently throughout the project's lifecycle.

Efforts to empower communities and build their capacity may be rewarded with more positive outcomes for both parties and improve the company's capacity to manage potentially impactful events, such as expansion and mine closure. An established example of success in sustainable development is the past 30 years of development and operation of the Stillwater Complex in Montana by Sibanye-Stillwater and its good-neighbor agreement (Sibanye-Stillwater GNA Fact Sheet, 2021). Community engagement and development are often not straightforward, however, and may pose some of the biggest challenges for mining companies globally.

Several organizations have created guidelines or toolkits for community engagement and development. They include the Network for Business Sustainability, the ICMM and the Commonwealth of Australia. Each of these resources is useful for establishing guidelines and in some cases, step-by-step instructions for community engagement.

Companies also have internal guidelines for operating characteristics and corporate culture, and communities have diverse social, economic, political and historical circumstances. A standardized approach to community engagement and development can thus fall short of addressing the particulars of a project and its context, and may end up as misdirected

and ineffective.

SME's SDC welcomes case studies, novel approaches and lessons learned from the larger SME community through which we can learn different methods for community engagement and development, and compile a set of best practices for industry professionals to learn from and use to improve their efforts.

What more can SME do?

SME's SDC encourages all members to engage with transformation and to see challenges and inefficiencies as opportunities for creativity and innovation along every step of the value chain. Each change can add up to overall increases in project value, stakeholder gain and a shift in public perception. We invite SME members across the organization to consider broad sustainability initiatives in your areas of specialization, and to join us in transforming our industry to future-focused, sustainably driven and stakeholder-based practices.

SME Annual Conference. We invite all SME members to add sustainability issues into papers and presentations for the MINEXCHANGE 2023 SME Annual Conference & Expo in Denver in February 2023, highlighting how sustainable initiatives span the industry and are the drivers for incremental industry improvements. We hope to initiate future sessions, awards and challenges in sustainable development across the value chain at events and encourage input and ideas from the broader SME membership. ■

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Case study: Responsible mining and minerals processing

by Eric Wasmund, Asa Weber and Jose Concha of Eriez

The Eriez Hydro-Float has been used in mines at Rio Tinto, Newcrest and Anglo American. Early applications focused on recovering "lost" coarse metal units.

There is now a global focus to reduce the emission of greenhouse gases and this has led societies, scientists, industries and governments to consider the specific ways to achieve this transition. A significant portion of this global rethink will be technological, and it will involve engineering, capital and materials. These technology platforms will include processes to reduce the carbon intensity of dominant industries such as cement and steelmaking, carbon capture and sequestration, green hydrogen and electrification. It is probable that all of these technologies, combined with energy conservation, will be part of the vaunted net-zero economy.

Each of these nascent technologies will require significant increases in the production of mined metals and materials. For example, a number of credible forecasts suggest that copper demand will increase from about 25 Mt/a (27.5 million stpy) today to 40 Mt/a (44 million stpy) by about 2030. Vale has recently forecast a 44 percent increase in nickel demand over the same period. There will be an even more dramatic increase for strategic minerals, including battery materials such as cobalt, graphite and lithium, and for rare earth metals used in electronics and motors. The availability of these materials are a prerequisite for the green economy, and the gap between demand and current supply cannot be made up by recycling alone while the green economy is in expansion mode.

Many people in the mining world wonder where all of the new mines are going to come from in this future scenario, since these are all mined materials. There has been a steady decline in the head grade of new mines — copper head grades on average have declined from 0.7 to 0.5 percent over a couple of decades. As metal demand increases, one effect is to encourage the development of projects that were previously uneconomic because of low

head grades. Lower head grades necessitate processing larger tonnages of mined ore to get the same amount of finished metal.

Bulk mining is already a high tonnage enterprise, with some copper mines processing in excess of 300 kt/d (330,000 stpd) of ore; even higher earth moving is required when the strip ratio is considered. This will increase again because of these two related phenomena; higher output of metal and lower head grade. A 2021 study estimated that 3 percent of the electrical energy for global metals processing is used for comminution, and this will go up as metal production increases and cut-off grades decline. At the same time, mineral processing is wet, and lower head grades mean using more water to concentrate the same amount of metal.

Many mining resources are located in regions with low water availability, such as the Atacama Desert, or they are in close proximity to other significant water consumers, such as those needed for agriculture and cities, so there is a greater importance on recycling water. To summarize, the green economy is going to create significant challenges for miners around energy and water use.

Coarse particle flotation. Until recently, the basic flotation concentrator flowsheet has not changed much. Ore at or above the cut-off grade is identified by the mining operation, then it is crushed and ground to a suitable size to enable bulk froth flotation followed by an upgrading cleaner step to produce final concentrate for smelting and/or refining. For a typical porphyry copper ore, conventional flotation is not practical for particles above 200 microns, sometimes significantly less, so the endpoint of the grinding operation must be in this range, resulting in excessive grinding and serious challenges for water recovery, since dewatering becomes more difficult as the solids become finer. In a conventional plant, the usual way to address this is to thicken the tails and then pump to a water impoundment for settlement. In this scenario, a significant amount of water is lost to evaporation. Water losses means that the water in a concentrator cannot be operated in a closed loop and fresh water is always required. Other dewatering strategies exist, but they are energy and capital intensive.

Coarse particle flotation is a key disruptive technology that has a major impact on water and energy, and it will be a key strategy to conserve both. By increasing the size where ore particles can be floated, typically 2 to 3 times, less grinding energy is required. And because the flotation tail is much coarser, it is easier to dewater, and has less retained water.

Eriez introduced its HydroFloat Coarse Particle Flotation (CPF) equipment about 10 years ago with major base metal producers such as Rio Tinto, Newcrest and Anglo American. Early applications focused on recovering "lost" coarse metal units from conventional concentrator tailing streams. This typically represented at least 60 percent of coarse tails and a 2 to 6 percent global recovery improvement.

Now the focus is on including the HydroFloat inside the mill circuit as an ore sorter. The first application of this type was successfully demonstrated at Anglo American's El Soldado during 2021 and is now in full operation. This configuration of CPF allows a significant reduction in grinding energy and conventional flotation capacity, and it produces a coarse tail that can be easily dewatered or combined with conventional tails. As part of their FutureSmartMining family of technologies, Anglo American is piloting a technology to comingle coarse and conventional tails in unique ways to produce a waterless dry stacked tail.

Two-stage flotation. Another Eriez technology that has been introduced to increase the efficiency of concentrators is the StackCell, a high-rate mechanical cell that uses the two-stage principle. In the first stage, high shear mixing of bubbles and feed slurry occurs to optimize bubble-particle collecting. In the second stage, which is isolated from the first, the bubble-particle aggregates can float by buoyant forces in a fluidic environment with low turbulence and a low energy convective flow that minimizes bubble particle detachment and drop back. The two-stage flotation technology contrasts with conventional mechanical tank cells where bubble-particle contacting and buoyant separation occur in the same fluidic environment, which cannot be simultaneously optimized for both processes. The StackCell is now operating in commercial rougher flotation applications in a number of countries. It has been verified that in many scenarios, StackCells can operate with one quarter or less of the residence time required for conventional technology, and with 40 percent less impeller energy. This all means smaller concentrators with less energy use. ■

Emerging workforce presents challenges and opportunities

by Wiliam Gleason, Editor

As the Baby Boomer generation continues to leave the mining and mineral processing industries and enter into retirement, the industries are faced with multiple challenges moving forward. The obvious are how to replace not just the person, but also their institutional knowledge. The more subtle question is how to adapt the industries to become an attractive career choice for the emerging workforce, and one they will join and stay with for years to come.

Four generations, Baby Boomers (born 1946-1964), Generation X (1965-1980), Millennials (1981-1996) and Gen Z (1997-2010) are currently in the workforce working side-by-side. While their academic credentials might be similar, the motivations of each generation can be quite different.

"The "why" is much different for those generations," Skylie Estep told *Mining Engineering*. She is the human resources manager for South32's Hermosa project, where she is involved with recruiting and retaining a workforce for the developing zinc-lead-manganese project south of Tucson, AZ. She has held similar positions with Barrick and Newmont and noted that the "why" does not change for things such as health and safety in the industry, but that other motivations have changed over the past few years.

Things such as professional challenges and variety, flexibility and work-life balance are very important to the emerging workforce. Likewise are company values such as sustainability and diversity.

"The use of technology, being forward-focused and having a focus on sustainability makes a big difference for the emerging generation of the workforce," Estep said. "For a lot of people now, it's not just about making money — but it's how are you leaving a legacy as a company, what is the company doing to support the community, what is it doing to ensure that there is diversity in the workforce, and how is the company making its operations safer through the use of technology."

In its most recent annual survey of the top issues for mining and metals executives, EY found that environmental, social and governance (ESG) issues remain at the top of the list of concern. Investors and other stakeholders are demanding that mining

companies conduct their operations in a transparent and environmentally sustainable manner. Employees are among those stakeholders.

"It's a very different animal if you are an employer wanting to retain and attract top talent from the Millennial generation than if you are trying to attract and retain top talent at the Baby Boomer or Gen X level," said Rhonda Zuraff, co-founder of Pray and Co., a global talent recruiting agency that focuses on the mining industry. "It's great to have a robust and diverse approach to attract talent, but what are you doing to talk to those various demographics, and what are you doing to retain them?

"The emerging workforce wants very different things," said Zuraff. "Compensation is not what will typically prompt a person to make a move to your company or stay with your company. It's things like culture, job variety, and flexibility. The pandemic taught us that work can be done a lot of different ways and from different locations."

Opportunities abound

For those looking for employment, or even for students who are considering the fields for academic study the mining industry is full of opportunities.

Cayley Hoffman graduated with a mining engineering degree from the University of Arizona in 2020. She did not start college with the aim of obtaining a degree in mining, but was drawn to it by scholarship and career opportunities. She is now a mining engineer working for South32 at its Hermosa Project.

Hoffman said that an internship with South 32 helped her learn about the company and ultimately led to her employment with the company.

"I was able to experience the culture of the company, and learn how it works, which made for a very easy transition for me," Hoffman said.

Working for a company that is focused on health and safety as well as creating sustainable operations was attractive to Hoffman, as was the ability to stay in the area

and not work at a remote mine location.

As for factors that keep her at South32, she said flexibility to work remotely is an important factor. "Having the flexibility to work remotely or even a hybrid schedule is a make or break factor for a lot of people."

ESG policy

Many people entering the workforce place a high value on the opportunity to make a meaningful contribution in a company that they feel good about.

Taylor Dillion, a project manager from ERM, a consulting firm that helps mining companies meet sustainability goals, has a position that fits the bill for a lot of these. She has the flexibility to work from home and be engaged with her young children while also working with various clients, which offers her new challenges and exposure to various operations.

These are important in a place like Elko, NV where shifts at the gold mines often mean leaving for work in the wee hours of the morning, and returning home long after the sun has set.

"There are jobs that you have to be at the site, but not all of them," said Zuraff. "There are hybrid schedules, where a person might be able to work two days from home, or fully remote with acknowledgement that they might have to travel to sites more often. It can be a tough pill to swallow for those of us who are not accustomed to approaching work that way, but thinking outside the box to attract and retain talent is a must if you are going to compete for the top talent."

Technology plays an important role in remote or hybrid schedules. Estep said South32 is planning to have remote operating centers in its plans that could open jobs to even more potential employees, such as a person with physical disabilities who might not be able to work on a mine site.

"When you get away from the physical work to utilize technology it can make jobs safer and opens up more opportunity to build a more diverse workforce," Estep said.

Having a strong ESG policy and making commitments to the community is not only a demand of investors, but also of potential employees.

Dillion is a first-generation mining engineer. She began her education at Missouri University of Science and Technology in Rolla, MO, as an engineering student, and an internship with Barrick Gold got her hooked on the mining industry. "ESG matters to employees, people want to feel like the work they do matters, and that it is more than just a paycheck," said Dillion.

ERM works closely with a number of mining clients, one of which is working to develop a lithium mine in Nevada. Dillion said that she has seen many young people interested in that project, in large part because they want to be involved with a mine that will produce a mineral that is part of the green-energy transition. Lithium and battery metals represent a huge growth segment for the mining industry.

At the University of Arizona, where some of the next wave of mining engineers will be taught, Jodi Banta, program manager at the School of Mining and Mineral Resources, and her team created a mining expo on campus as a way to introduce the profession to engineering students who might be unaware of what the industry has to offer. The event, held on Nov. 15, was called Mines for Limitless Minds and caught the attention of 15 companies eager to attract talent, including mining giants like Freeport-McMoRan, BHP, ASARCO, Copper World, Florence Copper, Hexagon, Hudbay and the Lundin Group, as well as General Motors and the Arizona Department of Environmental Quality.

"Our objective was to showcase the industry. We wanted to show the exciting opportunities in the industry to the students," Banta said. "It was really about how do students view mining. Do they see it as something that they might be interested in? Is it relevant to what they are studying. And this event also gave the sponsors the opportunity to showcase their company and their culture."

The career fair focused heavily on mining's role in the energy transition, as well as the technology that the industry uses.

Showing off electric vehicles, explaining what goes into them, and highlighting mining and sustainability was part of the expo. Banta said the expo helped illustrate that mining is not a profession with a shovel and pickaxe, but one in which employees use the most cutting edge, state-of-the-art technology in the world.

Banta said the career fair allowed companies to introduce the industry to students, and help students understand that mining is essential to their daily lives.

"The more the students learn about mining, the more they begin to understand that everything we have has to come from somewhere, and what mining's role is in our daily lives," said Banta. "When they are introduced to the opportunities in mining, some of them will see it's a great career option." ■

Internships: Eye-opening ways to learn and prepare for a career in mining

by Nancy Profera, Associate Editor

The Sasan Power Limited, Sasan village near Waidhan, Singrauli, Madhya Pradesh, India.

Pertinent work experience can be just as valuable for career preparation as studying and passing examinations, and internships are a way that job candidates can stand out.

According to the results of the U.S. National Association of Colleges and Employers 2019 student survey, more than half of all graduating seniors who applied for a full-time job received at least one job offer. Within this group, 57.5 percent of students who had an internship and 43.7 percent of graduating seniors who did not have an internship received a job offer.

The survey results also showed that in terms of job offers, graduating seniors who participated in an internship received 1.17 job offers, while those who did not received 0.98 offers.

The value of internships is no different in India. Jai Anand, who is the secretary of external relations and alumni affairs and a student advisor for the SME Indian Institute of Technology (Indian School of Mines) — or IIT (ISM) — student chapter, a former secretary of the chapter and who organized Khanan '22, a three-day mining festival held Nov. 4 to 6 in India, spoke to *Mining Engineering* (**ME**) about the festival and what his internships meant to him.

ME: How have internships helped you?

Anand: I've had two vocational training experiences and one internship.

The first was at Bharat Coking Coal Limited (BCCL), in Moonidih, Dhanbad. During this time, I was trained in the main installation under mine survey, mine planning, haulage and transport, winder, compressor, development section, vertical section and washery, and I got to see various aspects of longwall mining and the machinery involved in the process. I gained practical knowledge about underground coal mining operations, and these applications are of great interest to me. I also suggested an idea based on the results of a project I worked on called "Productivity analysis of LHD in Underground Mines," which is based on the application of machine learning.

My second assignment was at Sasan Power Limited, Singrauli, Madhya Pradesh. I observed all the work and practices closely of this coal mine and now understand each and every concept. I worked with all the departments of this company including planning, production, drill and blast and fleet management systems in my training.

Now in my fourth semester of training, I have completed a project on the study of different neural network models for slope stability. While gaining field exposure from my time at Sasan Power, I also found a problem with bench stability and factor of safety of the slope there, and I suggested a method for improvement and developed an artificial neural network for the study of blast parameters for dragline bench. Intrigued by this work, I would also like to contribute to modernizing the practices and innovating by implementing ideas of artificial intelligence and machine learning in the field.

I believe this would significantly increase the safety factor in the mines and boost production.

I also worked at Steffen, Robertson, and Kirsten (SRK) Consulting, India, as a summer intern. During my internship, I developed an application by using the React web application with material user interface for an underground mining method selection based on UBC methodology.

I have also worked on digital mining software and performed quality assurance/quality control measures, mine planning and market research for underground coal and metal mines. I also analyzed the capital and operating costs of various projects. Using data from a feasibility report, I created a prediction about the near future on the trends of production and performance by Excel and Tableau.

ME: What is different about studying mining in India as compared to other parts of the world?

Anand: Studying mining in India is quite different from most institutes worldwide. Most of the Indian institutes offer mining as a discipline focus, and the research is entirely on mining and its allied areas. This paves the way for developing a vibrant atmosphere in the Indian institutes that fosters enthusiasm for conducting research in mining and other earth sciences.

In India, especially in the mining field, there is a direct relationship between academia and the industry. Many collaborative research projects are undertaken between the two, which helps students to have a smoother transition from being in an academic institute to becoming an able industrial leader.

ME: How did you get 10 sponsorships for Khanan '21?

Anand: Khanan is India's largest annual mining festival, conducted by the SME IIT (ISM) student chapter. Last year, I was the secretary of the student chapter and overall coordinator of Khanan '21. A chain of events including panel discussions, guest lectures by eminent personalities of the industry, paper presentations, case studies and many more fun and enlightening events are organized as part of the three-day festival.

Guest speakers included Abani R. Samal, international advisor, SME India Section, and founder and principal, GeoGlobal, LLC; Satish Penmesta, chief executive officer of GroundHog; Subrato Ghosh, managing director, SRK Consulting, India; and Vaibhav Raj, associate service fellow.

Khanan is designed to provide a real-time learning environment for aspiring mining and earth-science students, exposing them to the real-world problems and challenges of the mining industry. The conclave also aims to improve the decision-making and problem-solving skills of students to bring out new ideas and innovative technologies.

Left to right: Internship students Abu Zarshaiban, Jai Anand, Suyash Ranjan, Saket Srivastav, Diwakar Raj, Saif and Rishabh Kaushal.

Right and below: Bharat Coking Coal Limited, Moonidih Project and map of the site, West Jharia area, Dhanbad, Jharkhand, India.

We had contacted many companies (more than 100) and got sponsorships from 10, including Sandvik Mining (title sponsors), Dassault System, Epiroc, Oil Natural Gas Corp., Western Coalfield Limited, Mahanadi Coalfield Limited, National Mineral Development Corp., JSW, Engineer Parcel (delivery partner) and Weblibox (book partner).

I was successful in getting sponsorships due to our strategy, networking skills and alumni in the industry. We prepared points on why the company or organization should sponsor us. We were able to convince them in clear, concise, straightforward messages of how they could benefit by sponsoring Khanan, India's largest mining festival. For the 2022 festival, I was able to obtain 11 sponsorships. As we organize this festival every year, many mining companies are attracted to our Khanan brand. ■

Advances in software-as-a-service platforms to perform emission inventories for quantifying fugitive emissions and tracking efforts to reduce the dust footprint of extractive industries

by Hasan Zolata and Sekhar Bhattacharyya

In recent years airborne particulate matter and respirable coal mine dust have been at the center of research focused on worker health in the resource and infrastructure industries because of a resurgence of severe forms of lung disease among mine workers. Federal research agencies have heavily invested in finding the root cause. Attempts are also being made to coordinate various research findings.

The Environmental Protection Agency (EPA) requires maintaining of Emissions Inventory (EI) where a detailed estimate of "criteria" pollutants and "hazardous" air pollutants is performed. Respirable dust falls under the "hazardous" category. However, it is unclear whether there are modern tools to perform emission inventories in the mines where such respirable diseases are prevalent.

Performing EI has the potential to increase the awareness about dust footprint in extractive industries. This article is the first of a two-part series in which the authors present available platforms for EIs and their pros and cons. The second part will focus on recent achievements in respirable-dust-related research at various universities and organizations.

Introduction

Much of the world is currently focused on climate change, the carbon footprint and green energy, and has substantial familiarity with the concept of quantifying the greenhouse-gas (GHG) emissions associated with a certain process or product. Companies worldwide face public scrutiny on how sustainable their operations are, how much water they use, and whether their recycling programs are efficient as investors are increasingly concerned about the performance of portfolios in terms of environmental, social and governance (ESG) factors (Eccles and Klimenko, 2019).

The World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) have created a set of valuable tools to assist companies in calculating their carbon footprint using GHG protocol accounting standards (WRI and WBCSD, 2022) alongside the ISO 14064-1:2018 (ISO, 2018) international standards for environmental management. The tools are primarily Microsoft Excel-based spreadsheets that are regularly updated from the WRI/WBCSD and can be easily downloaded. The objective is to standardize the way GHG emissions calculations are performed to ensure the results of different processes or goods are comparable.

Equally important is the determination of a company's dust footprint or fugitive emissions, which refers to the quantification of particulate matter (PM) emissions, also known as PM10 or PM2.5, that cannot be readily measured at the source and therefore require the application of estimation techniques. Even though a series of well-established regulations are in place addressing both the maximum permissible limits for human health as well as occupational exposure, and the methodology for calculating these emissions at the source, there is a lack of modern tools to assist in the quantification process. The most-used guidelines are the AP-42 (USEPA, 2022) from the U.S. Environmental Protection Agency (EPA), which contains emission factors for various industrial processes.

To model emissions from mobile onroad and nonroad sources, the MOVES3 software (USEPA, 2021) can be used. Still, its application is focused on fleets of onroad vehicles, and there is little test data available on nonroad engines.

In many instances, onroad emission factors are used to model nonroad vehicle emissions. For fugitive emissions from fixed and floating-roof storage tanks, there is an outdated program called TANKS 4.09D (USEPA, 2012) that the EPA developed to estimate volatile organic compounds and hazardous air pollutants. The need for a standardized tool is crucial because the results of a fugitive emissions inventory are used as an input for air dispersion modeling, and companies are required to go through the lengthy emissions quantification process every year to prove compliance with local regulations.

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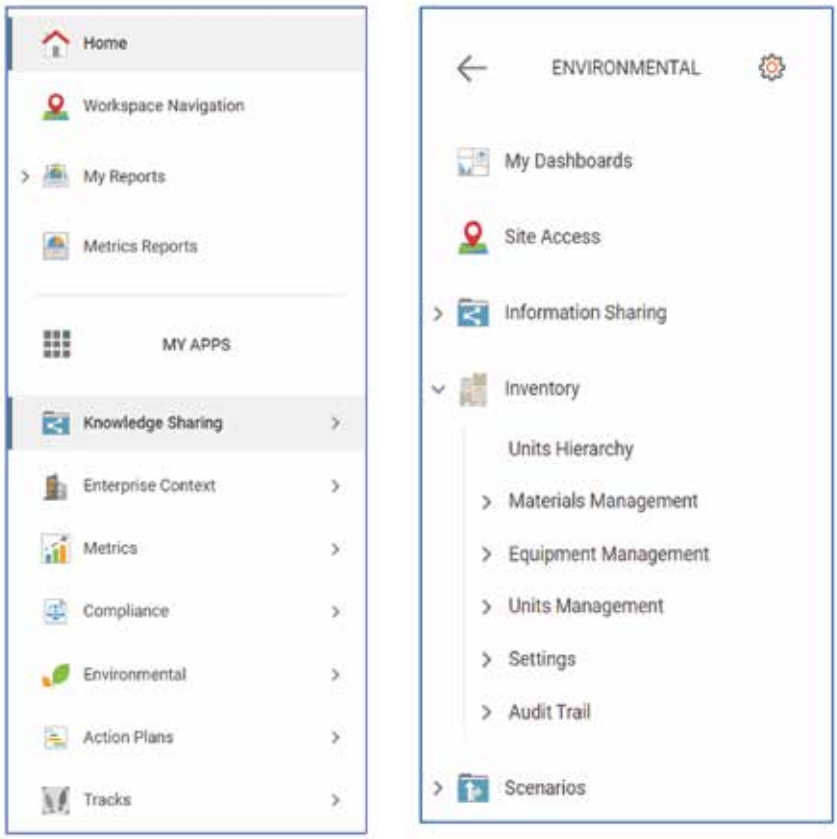
Figures 1 and 2

Modular structure of the Enablon EHS software (left), and an environmental module inventory drop-down menu (right).



Emission inventory reporting framework – why it is crucial

The importance of an emission inventory (EI) lies in the valuable information that it provides. Using EI, key polluting activities can be identified, and control efforts can be strategically directed to address the sources of major concern. To progressively reduce PM emissions it is essential to quantify them and track their progression over time to determine the effectiveness of the chosen strategy.

Reducing the dust footprint is the main objective of every company's management plan, oriented toward continuous improvement and achieving excellence in its environmental and health and safety best practices. Counting on a well-structured and organized EI allows the company to limit its liabilities, as it can be used as an input to run air dispersion models and determine the impact of the operations on the air quality in the influence area and nearby critical receptors, if any.

Challenges to EI reporting

Spreadsheets have been used for EI reporting for a long time, and little has changed since their early adoption. They are powerful and flexible tools that can be easily deployed in multifaceted scenarios. However, there is a limit to the amount of data that spreadsheets can process. This is why the use of an online platform developed on a proper database is a game changer. EI data files can become large over the course of a few years, and spreadsheets will eventually fail to display the data either in a tabular or graphical way. With the use of a database, these limitations can be overcome.

Online platforms offer the ability to interact with the data displayed, analyze the flow of information and calculations performed, and make changes to the time consolidation interval — this is something that cannot be accomplished in Excel.

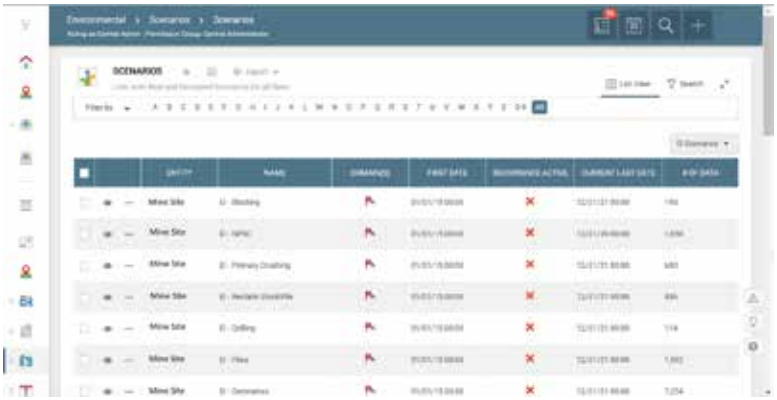
Currently available platforms

It is a challenging task to choose between expensive but comprehensive programs like AQMIS CLOUD [Lakes Software, 2022] and generic environment, health and safety (EHS) risk-management software like Enablon (Wolters Kluwer, 2022), Intelex (Intelex Technologies, 2022) and VelocityEHS (VelocityEHS, 2022), to name a few. AQMIS CLOUD performs the AP-42 calculations based on the inputs users provide. This also has geographic information system mapping capabilities to interface with integrated air dispersion modeling programs. It has been widely used by regulatory agencies and governments to track statewide emissions reported by different companies operating within their jurisdiction.

EHS risk-management software like Enablon, Intelex and VelocityEHS are not designed to account for emission inventories. Some of these programs' modules can be customized to perform emission calculations, but the implementation process is not straightforward and requires effort from the developer and users. These programs are mostly used by large organizations to track the metrics of different mining sites spread around the globe, and it is unusual to deploy them on a small scale: for example, just one site. Small-to medium-size companies will most likely use a simple Excel spreadsheet to track their emission inventories. Although North America is expected to hold the largest market share of EHS software in the next five years, the fastest-growing market could be in the Asia-Pacific region with a forecasted compound annual growth rate of 12.37 percent (Mordor Intelligence LLP, 2022).

Figure 3

Enablon scenarios depicting typical mining processes.



EHS risk-management software modules

Software-as-a-service (SaaS) platforms are made up of several modules that can be individually purchased to tailor the end user's needs. The most common modules are generally used to track health-and-safety-related metrics and air-quality monitoring program results to show compliance with applicable regulations and corporate guidelines.

Figure 1 shows some of the modules available on the Enablon platform. The author, Zolata, had the experience of working alongside the developers' team at Enablon to customize the environmental module. These modules are normally used to log events that can have potentially adverse environmental effects like hazardous substance spills or refrigerant gas leaks, but they lack the capabilities to handle EI calculations.

During this effort, Zolata provided the team with an Excel spreadsheet with more than 20 tabs that was tailored to the needs of a specific mining company. The spreadsheet is structured in separate tabs to account for the inputs required for each process, the EI calculations performed, and the key outputs to be displayed. Zolata assisted the team in the customization of the module and later populated the module with the information required to build the EI in the online platform. These platforms allow the user to create custom-made reports for an interactive and dynamic visualization of the information so that historical data can be quickly retrieved and visualized in a variety of tabular and graphical formats. Information can also be filtered to narrow down the scope of the search, and results can be drilled down to visualize the inputs used in the calculations in real time.

Typical platform data flow

For this study, the authors considered some of the features of the Enablon platform that have proven capable of handling the challenging task of performing all the calculations required in a mining-site EI. These features are common to other platforms as well and are useful in these kinds of complex scenarios, where the number of calculations is time consuming and prone to human error.

The platform has access privileges, allowing designated users to access only the authorized modules to contribute or validate the information. In the case of an EI, there is a specific data flow to set up the calculation of every macroprocess. For example, in the case of a rock-crushing process, the Enablon calculation would require the following steps:

- Selection of the input to be used: the amount of ore (material) processed in tons per year.
- Determination of the airborne pollutants, such as PM10 or PM2.5 (compounds) generated in the crushing process.
- Association of a specific machinery (equipment) to the process, in case equipment-specific emission factors are required.
- Review of the parameters to be calculated, defined in the function of the template (unit) used for the emitting process: for example, daily, hourly and yearly emissions.
- Grouping all the similar processes in the same macroprocess (scenarios), such as material handling.
- Generation of the calculation pools (subscenarios) for every year assessed.
- Execution of the calculation in the platform.

Figure 2 shows the Enablon environmental module drop-down menu to manage the input data in the three separate categories of materials, equipment and units. The calculations of the different pollutants are executed automatically in the platform, and they require no intervention from the user. It is fundamental upon initial deployment of the solution to perform an extensive quality assessment/quality control analysis to validate all the calculations and emission factors used. The latter can be easily changed in case of an amendment or update of the current factors. That is not the case if a change in the calculation is required, as it involves modification of the formulas used in the templates by the solution administrator.

Data processing

Every year, the person in charge of preparing the EI will upload all the required

information for the given year, including but not limited to the quantity of combustible used, the specifications of the machinery, the flow of material processed in the different processes, the control efficiency of a given control system, and volumetric flow of the air pollution control devices. Upon completing this first step, the user will launch the subscenarios corresponding to the year assessed and obtain the results in a tabular form.

Figure 3 shows a list of macroprocesses responsible for dust fugitive emissions in the mining industry alongside the deployment date and amount of data calculated in the platform. Finally, the user will generate the desired reports to visualize the EI data calculated and validate the entire process. If there are few to no changes over the years, the EI elaboration on the platform will be a straightforward process. If there are substantial changes, the user will have to update the materials, compounds, equipment units, and so on. In the case of changes in the process or the methodology used to estimate the emissions, a change in the calculation template will be required. This means editing the parameters that the units calculate to reflect the above changes, which can be a lengthy and complex process.

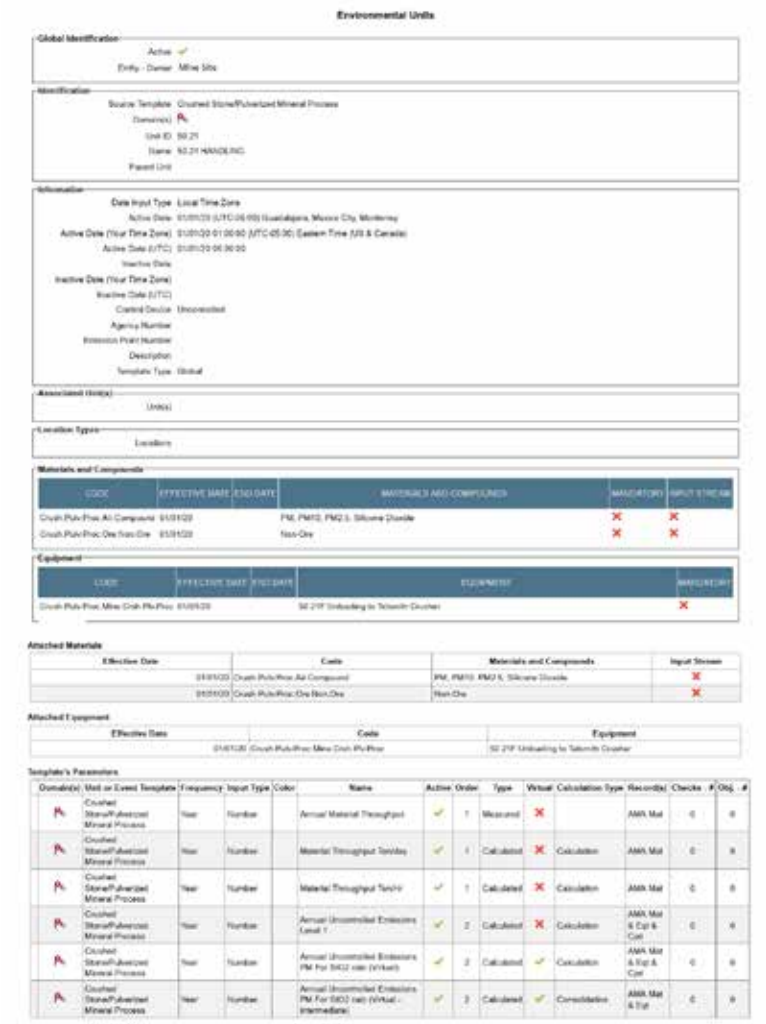
Input and output data flow

The template chosen when creating the environmental unit will determine which inputs will be required from the user and which outputs will be calculated by the platform.

Figure 4 shows a typical Enablon template used for selecting inputs and defining outputs in the case of a rock-crushing process. The inputs in this case correspond to all the operational data of the given process, while the outputs correspond to the airborne pollutants the platform will calculate upon running the subscenarios. Inputs can be prefilled with the previous year's data if the option is selected in the template, and formatting can be added to accept only input values in a specified value range. This lowers the probability of human error while inputting the required data. Input can also be imported in bulk into the platform, filling in a predefined Excel spreadsheet and then uploading it into the platform. Data will be validated and imported if inputs are listed in the correct format. If the process does not change, the inputs will remain the same, and so will the outputs. However, a change in the process may affect the accuracy of the EI calculations, and therefore a change in the template will be required.

For example, the installation of a more efficient dust collection system in the primary crusher will lower the amount of controlled emissions calculated in the EI. To account for this, a new emission factor or an equipment-specific control efficiency shall be specified. Note that the change will be effective only after the chosen start date so that the previous year's calculation will not be affected retroactively. The change can be tracked as the platform allows for formula history for quality-control and verification purposes. Both the inputs and the outputs can be exported to a variety of formats including Excel, PowerPoint, PDF and JPEG, to verify the information provided as well as the calculation results.

Figure 4
Enablon environmental unit template summarizing inputs and outputs.



Advantages

There are many advantages to using an online platform, such as ease of access to information, 24/7 availability, redundancy, scalability and a virtually maintenance-free environment with zero downtime. The role of each user can be easily defined so that only the administrator will be able to modify the key elements of the platform, such as the templates,

Figure 5

Enablon environmental report and data drill-down menu.

and contributors will be able to enter the inputs required for the calculations without the worry of potentially altering the formula contained in a given spreadsheet cell. Once the validator approves the EI, the process is complete, and output data cannot be changed or recalculated without the approval of the validator. Information stored in the platform database about previous years will not be modified by future changes to the parameters unless the user again runs the corresponding subscenarios. In any case, the platform will keep track of all the changes in the parameter's history section. Results over the course of months, quarters or years can be easily displayed with the preferred integration time, and the software can instantly calculate trends and average values for a given parameter. Specific results can be drilled down to determine exactly the inputs associated as well as the formulas used in the calculation process, as can be seen in Fig. 5 for the different processes the ore undergoes in the primary crushing circuit.

Disadvantages

Every time there is a major update in the platform, migration of all the templates created to perform the EI calculations is required. This is not a straightforward process, and it implies that every time a quality assurance/quality control check will be required to ensure the accuracy and consistency of the migrated solution. On top of that, there is no way to automatically perform the migration, and the assistance of a third party is required. This increases costs and reduces the already limited flexibility of the built solution. Graph-editing options are quite limited in the online platform, and often the easiest way to make changes is to export the graph and edit it in PowerPoint. Even the addition of a threshold line can be challenging in most reports.

The same concept applies to tabular data, where there is a limited amount of formatting rules that can be added to a given table. Exporting the tables into Excel turns out to be the easiest solution in the majority of cases. The creation of a new template can be quite lengthy, and ensuring that the new parameters are properly calculated may require multiple iterations. This is mainly due to the way the platforms are built, and often help from the software developers' team is required to set up the template correctly. Literature is limited and does not encompass in detail all the stages of implementation. The learning curve can be relatively steep at the beginning and gets smoother only after constant practice.

Conclusion and recommendations

There is ample opportunity for the SaaS industry to fill the gap between the current status of software advances and the concrete needs of companies required to file annual EIs. This evolution can only be achieved by acknowledging the current limitations and working in synergy toward a solution that can be globally recognized and used. Existing platforms have the potential to evolve into valuable assets in mining companies' portfolios, but substantial efforts should be focused on developing software that end users can easily and quickly deploy. In the majority of cases, users have limited resources to dedicate to training and need a ready-to-deploy solution that can easily be implemented and used to effectively track the results of air-pollution control programs. SaaS platforms can become a key element in the decision-making process when assessing environmental metrics and sustainability performance. Excel spreadsheets have proven to be a valuable asset in the past, but there is a need for a state-of-the-art solution to be able to overcome the limitations of the current solutions available. ■

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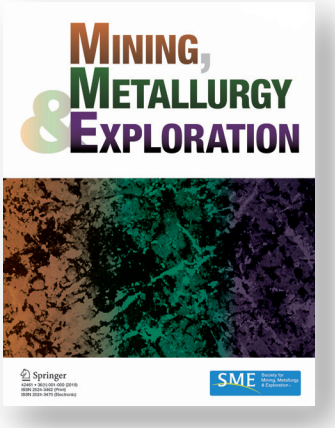

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Collection on Mine Ventilation

Investigation of explosion hazard in longwall coal mines by combining CFD with a 1/40th-scale physical model

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Keywords: Longwall, Coal mining, Mine ventilation, Computational fluid dynamics, Scaled modeling

To evaluate methane explosion hazards in underground longwall coal mines, researchers at the Colorado School of Mines developed a computational fluid dynamics (CFD) model along with a 1/40th-scale, optically accessible, physical model of a longwall mining section. In this project, CFD models assisted in the design of the physical model to ensure specifications were met to accurately represent the scaling physics as well as to assist in narrowing the experimental matrix and identifying key locations for sensor placement to measure velocity, pressure and gas concentrations. This research will help develop strategies for methane monitoring to prevent methane ignitions and explosions in longwall coal operations.

Introduction

Adequate ventilation and a mine-wide atmospheric monitoring system are keys to preventing explosions in underground coal operations. The use of point-type methane sensors to detect explosion risks relies heavily on sensor placement. In addition, methane monitoring within the gob area is difficult as the caved area is inaccessible. To evaluate the flow patterns and gas mixtures in these critical areas, a 1/40th-scale physical model of a longwall coal mine panel was built [1,2]. To complement and guide the development and testing with this model, CFD modeling is used to help identify critical ventilation parameters, such as flow dynamic and kinematic scaling, gas mixture distribution, and sensor placement. The goal of this project is to develop early detection methods to improve methane explosion prevention and mitigation strategies in longwall coal operations.

Method

Physical model overview. The dimensions of the 1/40th-

scale physical model are length of 7 m, width of 6 m and height of 0.61 m, equivalent to a section of a longwall mine that is 280 m long, 240 m wide and 24 m high. The modeled active longwall panel includes the longwall face, gob area and surrounding mine entries as well as the ventilation control required to simulate different ventilation scenarios. The scaled version has optical access on the sides and tops to visually observe the airflow patterns by injecting a visible tracer gas. Flow-velocity and gas-concentration sensors are installed in critical areas to validate the flow distribution and gas mixtures inside the gob area and surrounding mine entries. The dimensions of the mine entry are width of 145 mm and height of 72.4 mm, equivalent to full-scale width of 5.8 m and height of 2.9 m, which is typical for many longwall mines.

The length of the longwall face is 5.5 m, equivalent to 220 m in full scale, and it is separated into 11 face segments or carts, consisting of 10 shields per cart. These face carts (FCs) can be advanced individually to simulate different face advance positions and shearer cutting scenarios.

Each gob cart is 0.6 m long, 0.5 m wide and 0.61 m high. The model can accommodate up to six rows of gob carts, equivalent to face advances of 24, 48, and so on, up to 144 m. The gob carts can be filled with objects of different geometries and sizes to simulate the varying gob porosities and permeability distributions observed in real longwall gobs.

Surrogate methane gas inflow into the model occurs through two main injection systems, allowing independent control of flow rates to the face and gob regions. Due to safety concerns, methane is substituted with a mix of 70 percent helium (He)/30 percent carbon dioxide (CO_2), which has similar molecular weight and transport properties, providing comparable mixing characteristics to methane. In addition, CO_2 is easily detectable in low concentrations, allowing accurate gas concentration measurements throughout the gob, face and mine entries.

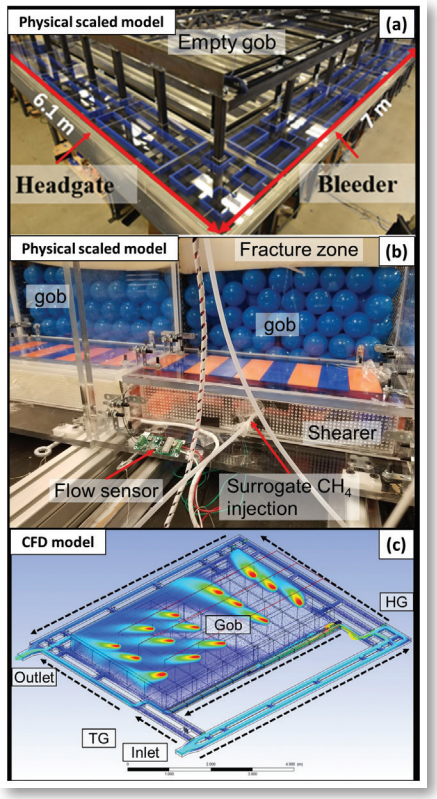

Fig. 1 (a) Overview of assembled physical scaled longwall model, (b) close-up view of physical model longwall face, (c) overview of the corresponding CFD model.

CFD model. ANSYS Fluent v.18.2 software is used for the CFD simulation. The CFD model represents the physical model dimensions, features and ventilation controls. The model is separated into multiple segments, such as the mine entries, face carts, gob carts and methane injection system. These segments are meshed separately before combining them in the ANSYS Fluent software for the simulation. For the gob resistance, the gob fringe resistance is assigned a viscous resistance value of 6.5×10^6 /m^2, while a viscous resistance value of 1.05×10^7 /m^2 is assigned to the five rows of center gob. These viscous resistance values are based on flow resistance tests with 58 mm- and 38 mm-diameter plastic spheres packed randomly in the gob. The rider coal bed at the top of the gob is represented by foam material having a viscous resistance of 1×10^8 /m^2.

Figure 1 shows images of the physical scaled model and the corresponding CFD model.

Results and discussion

The results of the scaled physical experiments are compared with results from the CFD model. The modeled ventilation scenario is a bleeder system, with the main fan set to supply 100 L/s of fresh air to the mains and 3.0 L/s of methane surrogate (the helium and CO_2 mix) injected into the model (1.5 L/s to the longwall face and 1.5 L/s to the gob area). Figure 2 shows a comparison of airflow velocity and surrogate-methane profile across the longwall face between experimental results and CFD prediction. The measured CO_2 concentration is converted into an equivalent methane concentration. The shearer is located at face cart number 11, near the tailgate.

The results in Fig. 2 show that the CFD and scaled physical models show overall good agreement in the velocity and methane concentration profile across the face. Velocities near the headgate side show greater discrepancies due to flow separation and reattachment as the airflow makes a right-angle turn from the headgate into the face, creating turbulence. The predicted methane concentration at the face sensors located at 1 m and 3 m away from headgate are within 0.5 percent methane equivalent, while the predictions at the sensor located 5 m away from headgate agree within 1 percent methane equivalent. Both models also confirm that the methane-equivalent concentration in the face increases toward the tailgate side.

Conclusions and future work

A CFD model is used to aid in the design and development of a 1/40th-scaled physical model of a longwall coal mine.

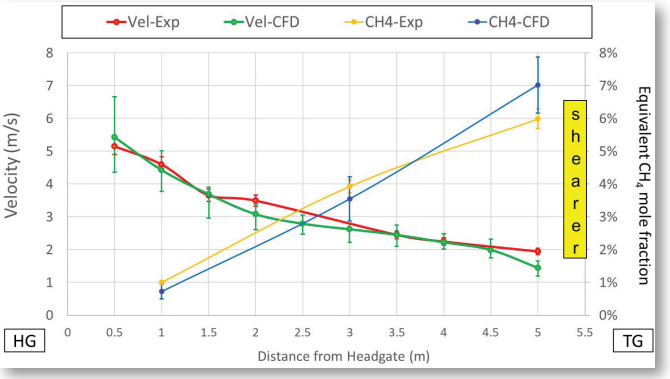

Fig. 2 Comparison of airflow velocity and methane equivalent across the longwall face between experimental results and CFD prediction.

Data from the scaled physical model, such as airflow patterns, leakage rate and methane-equivalent distribution are used to validate the CFD model. Comparison of experimental and CFD simulation results shows overall good agreement in terms of flow patterns and gas distribution in the longwall face and gob regions. This confirms the viability and advantages of this coupled modeling approach, which can be used to develop more-robust, full-scale longwall coal mine CFD models to aid in the design and improvement of ventilation and air-quality monitoring practices to reduce the risk of longwall mine explosions. For future work, the CFD model will be used to simulate different ignition scenarios, such as longwall face ignitions during shearer cutting operation and in-gob ignitions. ■

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TGA kinetic analyses of zinc ferrite reduction with H_2

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Keywords: Thermogravimetric analysis, Reduction roasting, Isoconversional method, Zinc ferrite

Zinc ferrite is considered an integral phase of zinc residues as their presence can render the processing of zinc and critical metals difficult. It is a refractory phase, formed at high temperature in the presence of zinc (Zn) and iron (Fe) during oxidative roasting in zinc processing plants. Because it is refractory to efficient leaching, unreacted zinc ferrite gets concentrated in the final zinc residue, making it a viable source of zinc and indium extraction. The refractory nature of zinc ferrite makes the extraction of associated critical metals difficult. In order to explore a potential economic and carbon-neutral zinc ferrite processing technique, our previous study proposed the partial reduction of zinc ferrite followed by sulfuric acid leaching of the roasting product [1-3]. As demonstrated in our previous studies, partial reduction of zinc ferrite results in a mixture of ZnO, Fe_3O_4 and FeO, which can be further subjected to leaching for efficient extraction of zinc and critical metals such as gallium and indium.

Background

This study explores the kinetic parameters and reaction controlling mechanism in a specific set of conditions — 10 to 30 percent hydrogen (H_2) gas concentration and temperature in the range of 300 to 700 °C — using the isoconversional method of kinetic analysis to analyze the thermogravimetric analysis (TGA) data. TGA kinetic data were fitted into selected isoconversional kinetic models to determine the reaction controlling mechanism and calculate kinetic parameters.

Materials and methods

The 99 percent-pure zinc ferrite used for TGA experiments was bought from alfa-aesar. Isothermal reductions of zinc ferrite in the presence of H_2 and nitrogen (N_2) were performed on a NETZSCH STA 449F3 thermal analyzer. Isothermal reduction experiments were conducted at 300, 400, 500, 600 and 700 °C with 10 percent H_2 and at 400, 500 and 700 °C with 30 percent H_2. The total flowrate of reducing gas was maintained at 100 mL/min. The solids were characterized with scanning electron microscopy (SEM).

Results and discussion

The extent of conversion was found to increase with temperature and H_2 concentration (Fig. 1). With increasing temperature, some of the reactions, such as volatilization of zinc as vapor and further reduction of magnetite to wustite, are thermodynamically possible, and consequentially, relatively higher mass loss can be observed. Increase in H_2 concentration enhances the mass transfer and thus increases the reaction kinetics.

With 10 percent H_2 concentration, the maximum extent of conversion (0.723) was obtained at 700 °C, whereas at

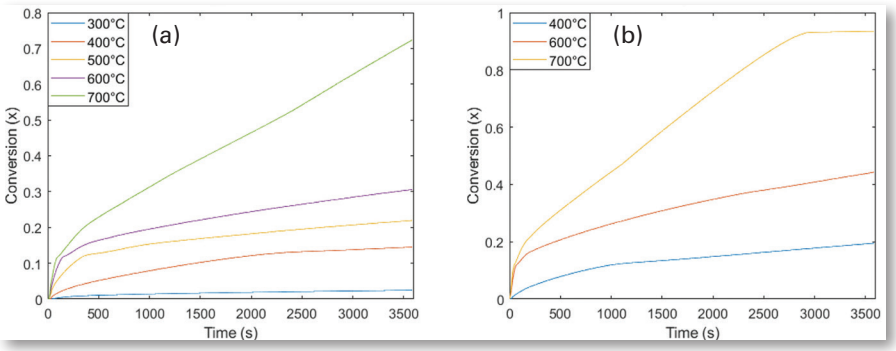

Fig. 1 Extent of conversion of zinc ferrite reduction with (a) 10 and (b) 30 percent H_2 concentration.

Table 1 — Linear model fitting results for $x = 0.024$ to 0.123.

	D1	D2	D3	R3	R2	F1	A2	A3	A4	D4
R^2	0.968	0.967	0.965	0.913	0.912	0.915	0.774	0.709	0.673	0.966
E_a (kJ/mol)	76.63	76.97	77.32	59.30	59.22	59.47	50.45	47.47	46.01	77.09

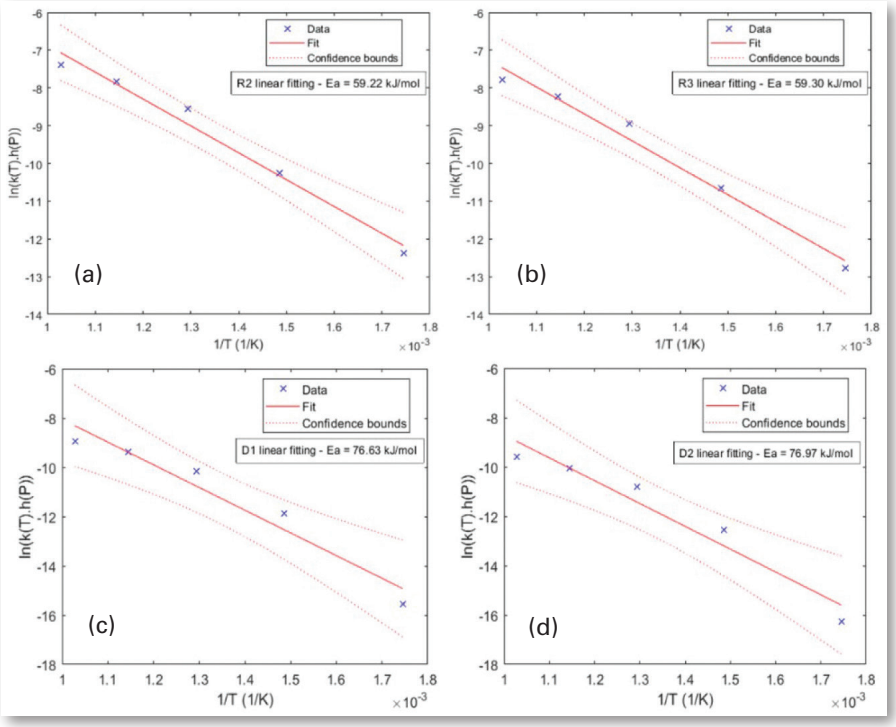

Fig. 2 Arrhenius plots for stage 1 reduction: (a) R2, (b) R3, (c) D1 and (d) D2.

600 °C, the extent of conversion was limited to 0.305. The increase in temperature from 600 to 700 °C increased more than twice the extent of reaction. The effect of increase in H_2 concentration from 10 to 30 percent is vividly evident at 600 °C, resulting in an increase in the extent of conversion from 0.305 to 0.442 in about 60 min of reduction time. The increase in extent of conversion in the same time period is facilitated by an increase in reaction rate. At 600 °C, the initial reaction rate ($t < 405$ s) with 10 percent H_2 is comparable to that with 30 percent H_2. The apparent reaction rates in both cases were calculated as 1.032×10^{-4} and 1.39×10^{-4} s^{-1}, respectively.

The model fitting was carried out for three stages of reaction: $0.024 < x < 0.123$, $0.123 < x < 0.175$ and $0.175 < x < 0.219$. Average R^2 values of model fitting for the first stage of reaction are shown in Table 1. Note that these are average R^2 values obtained for every model in the temperature range of 300 to 700 °C. Although the diffusion models (D1-D4) showed the best goodness of fit, activation energy values were relatively higher than expected for diffusion control mechanism (Fig. 2).

The surface morphology of zinc ferrite reduced at 400 °C revealed that the zinc and iron exist together, and evolution of separate zinc oxide and iron oxide crystals was not observed. Local energy dispersive spectroscopy (EDS) spot analysis of roasting product obtained at 700 °C revealed patches with high Fe concentration (Fig. 3). The formation of Fe at low temperature has been observed by Gaballah [5] as well. In addition to high Fe-bearing patches, FeO crystals were found to be present at 700 °C. The presence of separate wustite crystals indicates that zinc oxide might have volatilized as Zn(g) to some extent. Note that the volatilization of Zn at 700 °C was also observed in our previous study [1].

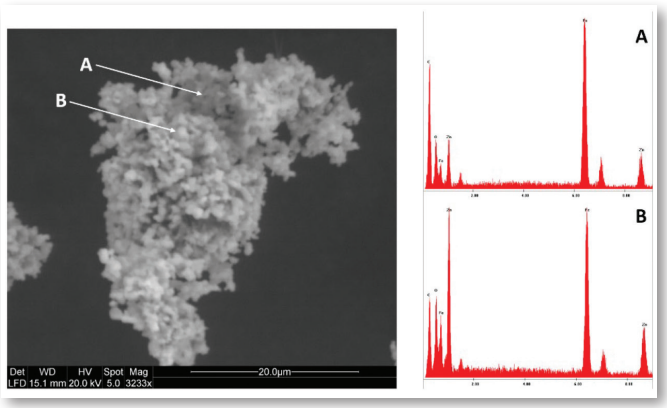

Fig. 3 SEM image showing high Fe concentration in the 700 °C roasting product.

Conclusions

This study explored the chemical kinetics of zinc ferrite reduction using H_2 as reductant. The partial reduction of zinc ferrite is feasible at low temperature; however, the extent of conversion is limited to only about 2.48 and 14.52 percent at 300 and 400 °C, respectively. Further increase in temperature to 500, 600 and 700 °C resulted in 21.95, 30.58 and 72.37 percent extent of conversion, respectively. The increase in H_2 concentration was also evaluated for three temperature levels. Increase of H_2 concentration from 10 to 30 percent at 400, 600 and 700 °C further pushed the reaction extent to 19.48, 44.26 and 93.44 percent, respectively.

Isoconversional method was employed for kinetic analyses, and solid-state kinetic models were fitted into experimental data. The linear model fitting results suggest that the reaction was controlled by contraction of reaction interface in the initial stage ($0.024 < x < 0.123$) with an activation energy of 59.26 kJ/mol.

As the extent of reaction increases ($x > 0.123$), diffusion was found to be the controlling mechanism with an activa-

tion energy of 52.7 for $0.123 < x < 0.175$, and 62.74 kJ/mol for $0.175 < x < 0.219$. The reaction order with respect to partial pressure of H_2 was calculated as 0.971 ± 0.013. The SEM analyses of roasting product further verified the presence of sintered structure, which could be the primary reason for diffusion being a controlling mechanism. ■

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Analysis of steel prop supports subjected to vertical and lateral loading

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Keywords: Steel props, Coal ribs, Buckling, Lateral loading

Standing supports have been used in coal mines for decades to enhance roof support capability. Occasionally, standing supports are used to resist the lateral movement of spalled ribs. Researchers from the National Institute for Occupational Safety and Health (NIOSH) are conducting a testing program for standing supports to investigate the effect of lateral loading on their vertical loading capacities and the factors affecting their lateral loading capacities. The Mine Roof Simulator (MRS) was used to determine the response of steel props to vertical and horizontal loadings. Finite element models (FEMs) were developed and verified using the tested steel props. Prop models were used to study the effect of a range of roof and floor materials — gray shale, shale and claystone — on the critical buckling loads of the steel props.

Background

Over the past decade, rib falls resulted in 16 fatalities, representing over 50 percent of the ground-fall fatalities in U.S. underground coal mines. Statistical analyses on the fatality cases resulting from underground coal pillar rib falls from 2010 to 2019 show that more than 70 percent of the accidents occurred during the development loading [1]. More recently, falls of rib or face led to all three of the ground-fall-related fatalities in 2018 and 2019.

The design of rib supports in U.S. underground coal mines is based primarily on local practices and experience rather than on the engineering design process. Current rib supports fall into two main categories: (1) rib control based on intrinsic supports and (2) rib control based on external supports. Prop-type standing supports sometimes could be the only choice to stabilize fractured ribs. When prop supports are used for rib control, it is important that they be secured in such a manner that a hazard is not created because of dislodged supports. Ignoring the importance of lateral loading capacity of standing support as a factor that could determine the stability of standing supports could lead to serious outcomes.

Problem description and methodology

The performance characteristics of steel props were studied under vertical and lateral loading conditions. FEMs were then developed using the tested steel props. The models were used to answer the questions of how the boundary conditions and the spatial location of the lateral load along the support affect its lateral loading capacity.

Fig. 1 Vertical load capacity test setup for steel props.

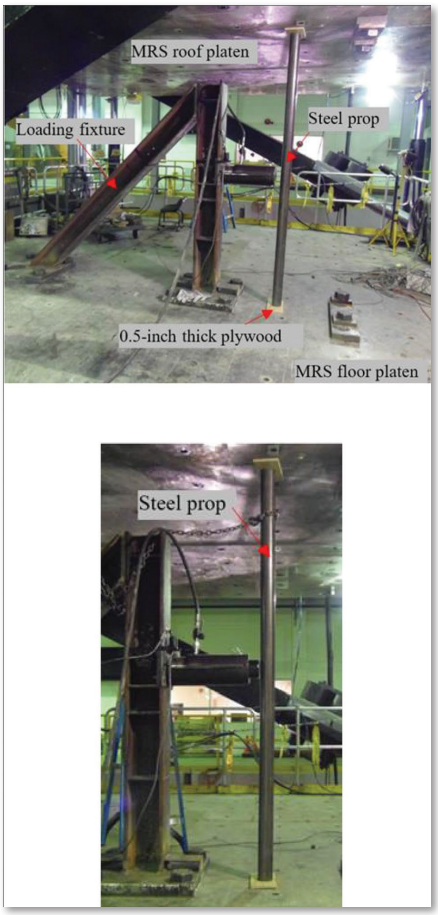

Fig. 2 Setup for lateral load capacity tests.

Full-scale testing for steel props. *Vertical load capacity tests.* This study conducted full-scale buckling and lateral loading testing for steel props under vertical loading. The steel prop was placed in the MRS with full roof and floor contact to establish uniform loading on the support. To simulate the convergence of the mine roof and floor, the convergence of roof and floor platens continued until the prop became unstable. Figure 1 shows the buckling failure of a square 8-ft prop. Buckling failures generally occurred near the mid-height of the prop as shown in Fig. 1.

Lateral load capacity tests. The testing of steel props for lateral load capacity was also conducted in the MRS. Like the vertical test, the steel prop was placed with full roof and floor contact. A lateral loading fixture attached into the floor platen of the MRS (Fig. 2) was used to apply lateral loading on tested props.

Finite element models for the tested steel props. FEMs were created and compared with the MRS results. The ANSYS [2] FEMs were developed to simulate the loading and deformation behaviors of the steel props. The prop model successfully calculated the critical buckling load for the tested prop with an error of 6 percent at maximum.

Figure 3 shows the deformed shape of the modeled prop compared with the prop after testing. It shows that the deformed shape of the prop model is very similar to the deformed shape of the tested steel prop.

Discussion

Factors affecting lateral load capacity of steel props. Finite element modeling successfully calculated the lateral loading capacity for tested steel props. The prop models were then used to study the effects of a range of roof and floor materials — gray shale, shale, and claystone — on the critical buckling loads of the steel props. For example, the maximum prop support load with claystone rocks boundary conditions was about 60 percent compared to the steel boundary. However, the prop response became insignificant at large roof-to-floor convergence (about 0.6 in.).

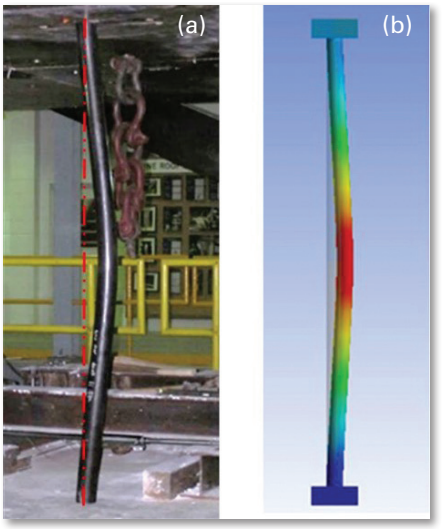

Fig. 3 Deformed shape of prop: (a) loaded vertically, compared with (b) FEM model.

Several models were also developed where the lateral loading was applied at various heights along the prop. The smallest resistance to the lateral loading capacity of the support was observed when the load was applied at the mid-height of the steel prop, while the highest was observed around 10 percent of the prop height.

Conclusions

- The tested steel props failed due to buckling in the process of plastic deformation.
- The modeled elastic stiffness of the steel props setting up against the claystone rocks has a reduced stiffness about half of that tested in the MRS.
- The modeled maximum support load with claystone roof and floor rocks was about 60 percent of that obtained by the MRS test.
- For slight lateral displacement, less than 0.5 in., the greatest lateral loading capacity was observed when the lateral load was applied near prop ends, at about 0.1 prop height. For great lateral displacement, more than 4 in., little effect was seen of the position of lateral loading on the lateral loading capacity. ■

Disclaimer

The findings and conclusions in this study are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH) or the Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH.

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A derivative method to calculate resistance sensitivity for mine ventilation networks

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Keywords: Mine ventilation, Ventilation network, Ventilation stability, Resistance sensitivity

A reliable and stable ventilation system is essential to the safe operation of underground mines. The stability of a mine ventilation system becomes extremely critical when responding to a fire incident, as an unstable ventilation system will pose a risk of airflow reversal. The reversed airflow could bring fire contaminants, such as toxic gases and smoke, unexpectedly to working areas. In the past few years, there has been a growing interest in the study of ventilation network stability using the concept of resistance sensitivity, which is described as an indicator of how the airflow in an airway is reacting to a resistance change of other airways. Several methods of calculating the resistance sensitivity in a mine ventilation network have been developed by researchers and scholars around the world. However, those proposed methods rely heavily on a vast number of mine ventilation simulations, which is time-consuming and computer-resource intensive, especially for a large-scale mine ventilation network. In this study, a derivative method calculating the resistance sensitivities with a single mine ventilation simulation is developed and implemented into the MFIRE mine fire simulation software. The results from the derivative method were verified against the results from a traditional method. The derivative method is proved to be reliable and accurate.

Background

Derivative method. The resistance sensitivity of an airway is an indicator of how much the airflow in the airway is affected by the change of resistance in a certain airway. It is mathematically defined as [1,2]:

$$s_{ij} = \lim_{|\Delta R_j \to 0|} \frac{\Delta Q_i}{\Delta R_j} = \frac{\partial Q_i}{\partial R_j} \qquad (1)$$

where s_{ij} is the sensitivity of airway i to the change of resistance in airway j, R_j is the resistance in airway j, and Q_i is the volumetric airflow rate in airway i.

Given a ventilation network with N airways, each airway can have N sensitivities to the rest of the airways and itself. Therefore, an $N \times N$ sensitivity matrix, S, can be formed for the ventilation network:

$$S = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1N} \\ s_{21} & s_{22} & \cdots & s_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ s_{N1} & s_{N2} & \cdots & s_{NN} \end{bmatrix} \qquad (2)$$

For a given airway k with resistance R_k, the sensitivity of any airway i to the resistance change in airway k, denoted as $\partial Q_i / \partial R_k$, can be obtained using:

$$\begin{aligned} &\textstyle\sum_{j=1}^{N} 2b_{ij} R_j Q_j \left(\sum_{i=1}^{M} c_{ij} \frac{\partial Q_i}{\partial R_k}\right) - \frac{\partial H_{Fi}}{\partial R_k} - \frac{\partial H_{Ni}}{\partial R_k} = 0 \\ &\qquad (i = 1,2,\ldots,M)\ \ (k \neq j) \\ &\textstyle\sum_{j=1}^{N} 2b_{ij} R_j Q_j \left(\sum_{i=1}^{M} c_{ij} \frac{\partial Q_i}{\partial R_k}\right) + \sum_{j=1}^{N} b_{ij} {Q_j}^2 - \frac{\partial H_{Fi}}{\partial R_k} - \frac{\partial H_{Ni}}{\partial R_k} = 0 \\ &\qquad (i = 1,2,\ldots,M)\ \ (k = j) \end{aligned} \qquad (3)$$

The derivation of Eq. (3) is the result of the application of Kirchhoff's first and second laws with differentiation operation. Details can be found in the full-text paper.

Method and results

Verification of the derivative method. The above mathematical model of resistance sensitivity is implemented into the National Institute for Occupational Safety and Health's (NIOSH) MFIRE, an open-source mine fire simulation software, to calculate the resistance sensitivities of a mine ventilation network. Furthermore, the resistance sensitivities obtained from the derivative method are compared with those calculated by changing the resistance of each branch one at a time by "Delta R" and running the ventilation simulation for each. Taking an example of a target branch from a 49-branch ventilation network, we calculated the airflow changes in each branch while the absolute resistance changes of the target branch are 0.1, 0.2 and 0.8 (10^{-10} * in.w.g./cfm^2), respectively. To better understand the correlation of the results, the normalized scatterplot by Delta R is used to display the relationship between the sensitivity from the derivative method and the results from the fixed resistance changes. It can be seen from Fig. 1 that the resistance sensitivity of the target branch calculated from the derivative method is linearly related to the results obtained from the various resistance changes with a Pearson coefficient of 0.999.

Conclusions

Resistance sensitivity of a ventilation network is a valuable tool to understand the degree of the interdependency of each branch and the overall stability of the network. This paper presents a derivative method to calculate the sensitivity in a ventilation network without the need for numer-

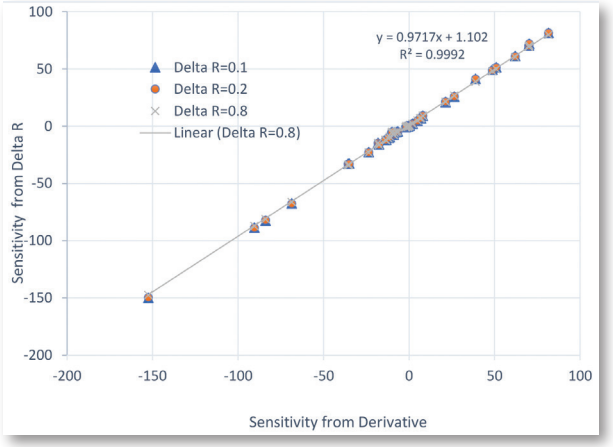

Fig. 1 Correlation between the sensitivity from the derivative method and normalized resistance changes.

ous simulations of the ventilation network as used in other methods. As compared to other methods, the advantage of the derivative method is savings in time and computer resources, as the derivative method only requires running the ventilation network simulation one time. The proposed method has been implemented into NIOSH's MFIRE mine fire simulation program and has proven to provide a useful addition to the software features. The verification study of the derivative method has shown that the calculated sensitivity results from the derivative method are in excellent agreement with the airflow rate changes from the example cases using a manual resistance change, Delta R. The sensitivity matrix of a ventilation network provides a good picture of how the airways correlate with each other. It can help mine operators to perform ventilation control and diagnose ventilation problems such as abnormal airflow. ■

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute an endorsement by NIOSH.

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Determining the benefit of air receivers in South African deep-level mines using a genetic algorithm

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Keywords: Air receiver, Deep-level mining, Compressed air, Optimization, Modeling, Genetic algorithms, Economic dispatch, Artificial intelligence

Rising electricity costs in South Africa have resulted in a need for optimized compressed-air networks in the mining environment. As a result, the financial benefit of air receivers needs to be reconsidered along with the economic dispatch strategy. This study investigates the use of an evolutionary algorithm in the mining industry to determine the potential financial benefit for various-sized air receivers, as well as their dispatch strategy. A genetic algorithm was selected due to the improved solution reliability and accuracy compared to other optimization techniques. This study indicates that a genetic algorithm can be used to determine the optimal dispatch of compressed air in the deep-level mining industry. Further, this study indicates that air receivers are financially viable in the mining industry and can be used to reduce operating costs, improving profitability.

Background

In the deep-level gold mining industry, compressed air is required for underground rock drilling. It forms part of the blasting process, which is required for the production process in mining operations. Various alternatives to compressed air have been developed and tested, including water and electric drilling. The alternatives proved to be both financially viable and more efficient in terms of operation. However, capital expenditure and life of mine have limited the viability of implementing these alternatives. The most cost-effective solution is therefore to optimize the existing compressed-air infrastructure and operating strategies by addressing the wastage of compressed air and improving its supply and management by introducing alternative technological solutions.

The deep-level mining industry presently uses dams to implement economic dispatch for optimization in systems such as dewatering and cooling systems. However, compressed-air systems in the mining industry do not use storage facilities. Compressed-air storage facilities, known as air receivers, were previously used in deep-level mining but are no longer present as air receivers became unfeasible due to the

low cost of electricity. However, with rising electricity costs, they can now provide substantial financial benefits.

Genetic algorithms can be used to determine the financial benefit of an air receiver. Genetic algorithms form a class within evolutionary algorithms used for optimizing nonlinear systems with specific parameter constraints. Genetic algorithms can promptly find solutions, making it a popular choice for optimization. A basic understanding of the problem is required to define the problem area. The genetic algorithm can then sample the constrained area for a solution. The economic dispatch of a system can therefore be determined with the use of a genetic algorithm.

Method

The optimization of a compressed air system requires a thorough understanding of the required demand and supply capabilities of the specific operations. An air receiver can then be sized according to the demand requirements, as well as the supply specifications. The economic dispatch and financial benefit are determined by considering the demand requirements, supply specifications, and air-receiver capacity. Figure 1 shows the process to determine the financial benefit of an air receiver.

A 1.17-km section of unused haulage was identified as the potential air receiver at a case-study mine in South Africa. The resulting air receiver has a potential volume of 1.87×10^4 m^3. The change in mass is thus 5.38×10^4 kg. The two limiting factors in determining the ideal-size air receiver are the maximum compressed-air generation possible by the compressors and the air-receiver capacity. The ideal-sized air receiver, based on the demand, is 1.06×10^5 m^3 with an air mass capacity of 3.03×10^5 kg. The genetic algorithm developed in this study determines the daily optimal dispatch strategy, which is compared to the current operation to determine the financial benefit of the air receiver.

Results

The tariff structure varies between winter and summer. As a result, each season has its own optimal dispatch strategy. The dispatch strategy for a summer tariff structure, in the form of compressed-air flow and air-receiver level and pressure, is provided in Fig. 2.

The compressed air supplied by the air receiver during the morning peak period (area highlighted in red in Fig. 2) is supplied by the compressors during off-peak electricity tariff times. Similarly, the compressed air supplied during the evening peak period by the air receiver is supplied by the compressors in standard electricity tariff times. The amount of compressed air generated for the day remains constant, irrespective of the air-receiver capacity. As a test, the compressed air generated for the day must be a constant value between the economic dispatch strategies and the baseline.

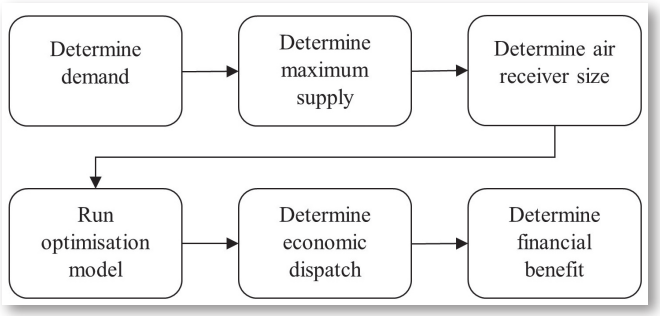


Fig. 1 Compressed-air optimization model process.

The air receiver provides a benefit equivalent to 2.5 million rand ($163,200) per year. The benefit of the air receiver is directly proportional to the capacity of the air receiver, and the ideal-size air receiver would result in a benefit equivalent to 7.67 million rand ($500,700) per year. The cost of the implementation is 1.5 million rand ($97,900). With a financial benefit of 2.5 million rand ($163,200) per year, the payback period is approximately seven months.

Conclusion

Compressed-air systems in deep-level mines require great amounts of electricity, whose cost is rising faster than inflation. Compressed-air storage, in the form of air receivers, allows for compressed air to be generated asynchronously to the demand. The result is that compressed air can be generated outside of peak electricity tariff periods and consumed as and when required. A genetic algorithm was used to determine the economic dispatch strategy of the compressors, using the operating cost as the fitness function and various general constraints.

The case study of the specific mine indicated that an air receiver with a volume of 1.87×10^4 m^3 will result in an annual financial benefit of 2.5 million rand ($163,200). The cost of converting the 1.17-km inactive haulage into an air receiver is 1.5 million rand ($97,900). Thus, the payback period is approximately seven months. ■

References

A list of all references is available in the full paper.

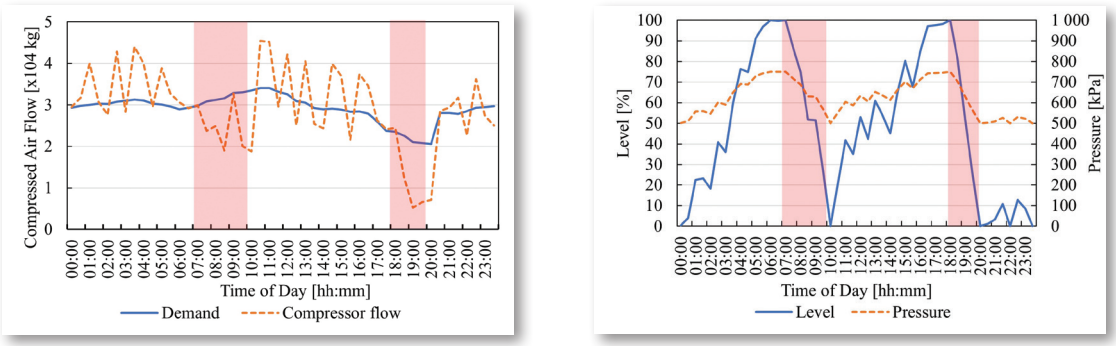


Fig. 2 Summer economic dispatch of compressors with maximum-capacity air receiver for compressed-air flow and air-receiver level.

Becoming the best operator through Rio Tinto's

Safe Production System

by Scott Severinsen, senior operations coordinator concentrator, Rio Tinto Kennecott

In 2021 Rio Tinto kicked off the Safe Production System. It was designed by Rio Tinto employees, for Rio Tinto employees, and included front-line operators, craftspeople, support functions, supervisors and managers. The Safe Production System (SPS) started its journey at the Copperton Concentrator at Rio Tinto Kennecott in Salt Lake City, UT, and has since been rolled out across several of Rio Tinto's global sites. Input was taken from employees over the course of a few months around their concerns as well as what is going well across the site. The SPS is based off different best practices that are owned by the Safe Production Centric Team (SPCT). These practices are designed to keep safety at a forefront in all we do, as well as empower front-line employees to make decisions and improvements in their work areas. Some of the different practices that are helping improve safety and performance throughout the company include:

- **Safe Production Centric Team (SPCT).** Comprised of an operations coordinator, maintenance coordinator, process lead and electrical specialist, the SPCT works together in the same room to solve problems and improve teamwork and collaboration between all groups. Working this way has allowed us to operate in a more proactive manner as opposed to continually responding to breakdowns. We work together as a team to problemsolve, discuss improvements, address plant concerns, and take actions to improve safety and daily performance. The SPCT is also responsible for maintaining and maturing current SPS practices, as well as introducing new practices as required.
- **Front line improvement routines.** This allows operators and craftspeople to raise concerns around safety and wellbeing at work and provides them the support and resources needed to make the improvements themselves.
- **Clean and inspect.** As part of keeping our plants in the best condition, operators follow standardized clean and inspect routes. When there are areas of concern with plant condition, they are raised and addressed in a daily shift start meeting. Notifications are then entered to correct the cause of the problem.
- **Work management.** There are several practices built around work management. They are designed to ensure our front-line employees feel empowered to create notifications and for our craftspeople to have a clear understanding of what needs to be corrected and the priorities. This provides a structure that improves communication and alignment between all groups and ensures issues are addressed in an efficient and effective manner.
- **Centerlines.** This practice was developed to ensure that equipment is run safely and efficiently as per design. This empowers our front-line employees to adjust operating parameters if we are operating outside the defined centerline.
- **Performance rituals and cadences.** This practice defines our routine meetings and activities. Our meetings keep safety at the forefront in all we do.

Health checks and field verifications are performed on all practices to mature the practices and drive consistency between plants as well as Rio Tinto operations throughout the world.

These practices will improve over time, and new practices will be added throughout the years. Each operating site will contribute improvement ideas to each practice, but the core of the SPS will remain the same. This will add consistency and value to Rio Tinto globally. We like to imagine a future where, regardless of what site you visit throughout the world, everyone is aligned to the same safety and performance standards that are understood and agreed by every employee.

On a personal note, I am thankful to work for a company that is on the journey to become the best operator in the world. I am proud of the work I am doing as the senior operations coordinator here at Rio Tinto. I am confident that the practices we are putting in place are keeping my coworkers safe and allowing them to return to their families at the end of each day. My son has recently returned from the Army National Guard and has a desire to be a second-generation miner here at Rio Tinto. I hope that the SPS is the standard for years to come, so that I know he will have a safe, successful, and happy career at Rio Tinto. ■

SME News Contents

SME Foundation plans for Gala Dinner and Silent Auction;

Black & White Gala at MINEXCHANGE

Please join the SME Foundation on Feb. 26, 2023 for our Gala Dinner and Silent Auction. Sponsored by First Majestic Silver, this annual event kicks off the MINEXCHANGE 2023 SME Annual Conference & Expo with an evening of entertainment, delicious food and reconnecting with associates and friends.

The evening will include a cocktail reception, dinner (with wine service sponsored by Black & Veatch), special door prizes sponsored by J.H. Fletcher & Co., and an awards program recognizing major contributors and scholarship recipients.

Afterward, join us for an after-dinner reception complete with cocktails, black and white desserts, and entertainment provided by the Atomic Fusion Initiative, a local band who has been entertaining audiences in Colorado and around the United States for more than a decade. Be sure to dress in your favorite black and white business or cocktail attire.

Individual dinner tickets are $135 each and tables of 10 are $3,500. Our annual SME Foundation events would not be possible without the support of our generous corporate sponsors. Tickets and table sponsorships can be purchased online at smeannualconference.com today.

Silent-auction donations are needed

A silent auction will be held during the gala dinner on Sunday evening. In addition, the SME Foundation will hold a virtual auction in conjunction with SME divisions that will allow nongala attendees to bid on items throughout the week. We are seeking silent-auction item donations valued more than $100 for this event. We also invite you or your organization to make a matching contribution toward the proceeds of the silent auction. All auction donors receive recognition in the April issue of *Mining Engineering* magazine. All donations are tax deductible.

Your gala attendance, table sponsorship, silent-auction donations and purchases are excellent ways to raise funds to benefit the education and outreach programs the SME Foundation supports. ■

SME Foundation Corporate Roundtable Partnership Program

We invite you to join the Corporate Roundtable Partnership along with the following dedicated contributors. Please contact the smefoundation@smenet.org for information on partnership opportunities.

We are grateful for the ongoing support of our generous 2022 Corporate Roundtable Partners. For more information please visit https://community.smenet.org/smefoundation/crp/home. ■

SME Patrick Taylor honorary symposium; MPD celebrates a lasting career

by Fangyu Liu, Ph.D., MPD Chemical Processing Unit Committee chair and Patrick Taylor Honorary Symposium chair, Hatch Ltd.

On the occasion of Patrick Taylor's recent retirement from the Colorado School of Mines as Emeritus Ansell Distinguished Professor of Chemical Engineering, the SME Mineral & Metallurgical Processing Division (MPD) will host an honorary symposium at the MINEXCHANGE 2023 SME Annual Conference & Expo in Denver, CO in 2023.

Taylor is a registered professional engineer with more than 45 years of experience in mineral-processing and extractive-metallurgy engineering, research, teaching and consulting. He is experienced and trained in pyrometallurgy, hydrometallurgy and mineral processing. From assistant professor to associate professor, professor, department head (at two universities), and director of the Kroll Institute for Extractive Metallurgy at the Colorado School of Mines, he has directed research for more than 100 graduate and post-doctoral students. Over the past 45 years, he has taught extractive-metallurgy and mineral-processing university courses. In addition to his academic achievements, he has developed and taught 10 short courses to industry. He wrote professional-engineer exam questions for 25 years, and he is active in many professional organizations, including participation in SME (Distinguished Member), TMS, ASM (Fellow) and MMSA.

"Dr. Pat Taylor's retirement brings back memories of his significant contributions to the mining industry. He has contributed through his research work, his undergraduate, graduate and doctoral students who populate the industry in many areas of expertise. For me, his retirement reminds me of his selfless dedication to his industry, his colleagues and his country! Congratulations to a true hero and a person of distinction, who has served others his entire life!"

– Marc LeVier, SME President-Elect

The honorary symposium, chaired by Fangyu Liu and Mark Strauss, aims to address new research and technologies in advancing metallurgical processing for the most discussed critical and battery metals and precious metals. It will include the following technical sessions with 38 presentations:

- **Innovative Extractive Processing for Rare Earth Materials:** Featuring "Evaluation of various separation techniques for the removal of actinides from a rare-earth-containing solution generated from coarse coal refuse," by Deniz Talan (2022 Rong Yu Wan Ph.D. Dissertation Scholarship recipient), West Virginia University; and "Recovery of rare earth elements from acid mine drainage using organo-phosphorus extractants and ionic liquids," by Tommee Larochelle, Virginia Tech.
- **Battery Metals (I): Primary Resource Processing:** Featuring "Pressure oxidation leach versus smelting for cobalt production: Pros and cons," by Joseph Trouba, Colorado School of Mines.
- **Battery Metals (II): Recycling from Secondary Resources:** Featuring "Innovative metal recovery from spent lithium-ion batteries," by Corby Anderson, Colorado School of Mines.
- **Hydrometallurgical Innovation in Copper Extraction:** Featuring "Copper concentrate roasting and leaching (a re-imagined replacement for smelting)," by Terence McNulty, T.P. McNulty and Associates, Inc.; and "Low-temperature extraction process for metals from metal oxides using ionic liquids," by Ramana Reddy, University of Alabama.
- **Precious Metals Refinery and Processing:** Featuring: "Recent advances in the GlyCatTM process for extraction of gold and silver in the presence of copper," by Glen O'Malley, Curtin University.
- **Innovative Methods in Metal Processing:** Featuring "Oxidative precipitation and formations of cobalt and manganese in presence of ozone," by Younes Shekarian, Pennsylvania State University.

"Pat Taylor's legacy is that he produced an army of extremely talented and productive mineral-processing, extractive and materials engineers over his long career. Their scientific contributions, especially to applied engineering, made those who studied under his guidance, worked for him, and simply know him proud of that legacy. ... From a personal perspective, through Pat I found joy in the capstone of my career teaching and researching with the very best students and people."

– Erik Spiller, who has worked with Taylor for many years as a research professor at the Kroll Institute for Extractive Metallurgy

In addition to the symposium, SME's *Mining, Metallurgy & Exploration* (MME) journal will include a special Collection in Honor of Dr. Patrick Taylor with the theme of "All About Metallurgy," guest-edited by Liu. This collection will honor the breadth of Taylor's career with papers in the areas of extractive and process metallurgy, mineral processing, recycling, waste treatment and minimization, and thermal plasma processing in a wide range of metals and materials including base metals (such as copper, zinc, lead), critical metals (such as REEs, lithium, cobalt, nickel, indium), precious metals (such as gold, silver, platinum), and ceramic powders.

Lastly, the Colorado School of Mines' Mining Engineering Department will dedicate its SME CSM Alumni Reception to Taylor and his honorary symposium at the upcoming MINEXCHANGE 2023 SME Annual Conference & Expo in Denver, CO.

If you have any questions about these events, please contact Fangyu Liu at fangyu.liu@hatch.com. ■

Fine Grind **serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Mineral & Metallurgical Processing Division. Accordingly, all material published herein is signed and reflects the individual views of the authors. It is not an official position of SME or the division. Comments by readers will be referred to the division for response. The division chair in 2022 is Ronel Kappes.**

Support the Mining & Exploration Division scholarship fund with your donations to the annual silent auction

by Robert Washnock, Vice Chair for Program Planning

Dear Fellow Mining & Exploration Division Members:

The SME Mining & Exploration Division's Richard E. Gertsch Memorial Silent Auction is pleased to announce that the event will be held in conjunction with the MINEXCHANGE 2023 SME Annual Conference & Expo Feb. 26 to March 1, 2023 in Denver, CO.

The in-person auction will take place at the M&E Division Luncheon on Wednesday, March 1, 2023, starting at noon at the Colorado Convention Center.

The Mining & Exploration Division has given three to five scholarships annually for many years, and these scholarships are needed to attract and retain the most promising students to the mining and geology fields. Due to the enormous debt these students are forced to incur, our scholarship amounts must increase to provide significant financial support.

All proceeds (Yes, 100 percent) from the items donated will be deposited into the division Scholarship Fund.

We request your help in making our auction event a huge success by generously donating. This is an excellent way for you to give back to our industry, help a student financially, advertise on behalf of your company, and donate to the Mining & Exploration Division.

Popular items to consider donating include:

- Scale models of mining equipment.
- Historical mining memorabilia.
- Mineral and fossil specimens.
- Jewelry and gems.
- Private VIP tours of mines.
- Adventure outings.
- Sports tickets/sports memorabilia.
- Electronics and technology items.
- Professional services.
- Gift baskets.
- Artwork.

Your item must be received by Feb. 3, 2023 to allow for shipping and handling by SME staff.

If you would like to make a tax-deductible donation please send to:

Attendees examine auction items at the the M&E Division silent auction during the MINEXCHANGE 2022 SME Annual Conference & Expo in Salt Lake City, UT.

SME – M&E Division
Attn: Robert Washnock
12999 E. Adam Aircraft Circle
Englewood, CO 80112-4167

Thank you for your time and consideration.
Sincerely,

Robert V. Washnock
M&E Fundraising Chair

Upcoming SME Events

SME Arizona Conference
Dec. 4-5, 2022
Tucson, AZ

MINEXCHANGE 2023 SME Annual Conference & Expo
Feb. 26-Mar. 1, 2023
Denver, CO

2023 SME Minnesota Conference
April 17-19, 2023
Virginia, MN

For additional information, contact: Meetings Dept., SME
Phone 800-763-3132 • 303-948-4200 • Fax 303-979-3461 • email sme@smenet.org • www.smenet.org

SME Environmental Division announces
two important upcoming events

by Julie Neilson

The Environmental Division Membership Committee welcomes all SME members to an Afternoon Pick-me-up event on Dec. 7 at 3 pm MT. The event will feature a special presentation by TerraMovers, the 2022 winners of the SME Move Mining Competition. Please join us for this event to hear more about the Environmental Division and the ideas from the Peruvian TerraMovers group on how to change the public perception of mining. For more information or to register for this event, please follow this link: https://smemi.personifycloud.com/PersonifyEbusiness/Events/SME-Events-Calendar/Meeting-Details/productId/44442212.

Environmental Division Student Poster Contest at MINEXCHANGE 2023

Undergraduate and graduate students have a chance to show off their work and a chance to put cash in their pockets to further their education. The Environmental Division (ED) Student Poster Contest will be held at the MINEXCHANGE 2023 SME Annual Conference & Expo in Denver, CO, Feb. 26-March 1. The poster contest will be held the morning of Feb. 28 prior to the ED luncheon, and winners will be announced during the ED luncheon.

The ED hosts the student poster contest as a way to encourage and foster the next generation of geologists, geological engineers, environmental engineers, and environmental scientists, and to support the students' academic achievements. Abstracts are submitted via email.

During the poster session, students will have five minutes to present their poster to a panel of judges. All students will be judged in a single level and judging will be based on the quality of the abstracts, posters and presentations. Prizes are:

First — $1,000.
Second — $500.
Third — $250.

More information and poster guidelines are available at the following link: https://www.smenet.org/Professional-Development/Awards-Competitions/Environmental-Division-Student-Poster-Contest.

We encourage all students to take this opportunity to highlight their research at MINEXCHANGE 2023. Abstracts are due by Jan. 31, 2023. ■

The *Environmental Division* page serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Environmental Division. Accordingly, all material published herein is signed and reflects the individual views of the authors. It is not an official position of SME or the division. Comments by readers will be referred to the division for response. The division chair in 2022 is Lisa Gonzales.

SME introduces Jobs of Tomorrow
Six episodes will focus on mining jobs

SME has been working with Workerbee.tv to create six episodes for the docuseries "Jobs of Tomorrow" to be aired in 2023.

Docuseries are television series that follow a particular person or group and their involvement in real events or situations over a period of time.

The objectives of this project for SME include driving new member recruitment, improving engagement with existing members, enhancing the awareness, education and advocacy of mining and tunneling and underground construction jobs, and to develop informative, educational and inspirational high-quality content.

These are 22-minute length videos that will be aired on different entertainment platforms directly targeted at young people exploring careers. There will also be "microseries" created out of the filming that will be designed to run on social-media channels. Microvideos are also being created and are three to five minute short videos made to air on association and sponsor websites. Audio versions of the series for podcasts are also in the works.

The six episodes are currently in development. The series is being targeted to air on Amazon Prime videos, Fox's Roku and Tubi, Viacom's xumo and Comcast's pluto tv.

The episode titles are: #1 "Sustainability: Make Mine ESG;" #2 "Community Relations: What's Mine is Yours;" #3 "Mining Data for Mining Innovation,"sponsored by Freeport-McMoran; #4 "Mining 2.0: Progress and Innovation in the Industry," sponsored by Komatsu; #5 "The Ore Next Door," sponsored by Luck Stone; and #6 "The Elements of Clean Energy."

Look for the videos to air starting in early 2023. You too can be an ambassador for SME by sharing the videos with your friends, family and networking connections. ■

MEC K-12 outreach pilot program kicks off at Denver Public Schools in Colorado

by Akudo Nwokeukwu, Minerals Education Coalition Outreach Coordinator

The Minerals Education Coalition (MEC) is working with diverse members with different mining and outreach backgrounds to bring mining and minerals education outreach to K-12 schools. This program is currently being piloted in Colorado at two Denver Public Schools — Place Bridge Academy (grades K–8) and Denver South High School (grades 9–12), bringing lessons, hands-on activities, tours to local mines and mining schools, and other educational programs into the classroom.

Heather Lammers conducts the "dig into doughnuts" activity with second-graders at Place Bridge Academy in Denver, CO.

MEC is happy to announce that its first classroom presentation of this pilot program kicked off at Place Bridge Academy (K-8) on Friday, Oct. 28, 2022. The lesson, "Snacks with Mineral Professionals," was an hour-long, in-person presentation with discussion about mineral resources and careers in mining. SME Colorado Section members Heather Lammers and Dick Beach engaged second-graders in the hands-on activity, "Dig into Doughnuts," using the doughnuts as make-believe rock strata and drilling into the doughnuts, some contained filling — representing valuable minerals — and some did not. This set the stage for discussions about exploration for valuable mineral deposits. Lammers and Beach proudly also modeled their personal protection equipment including hard hats, safety glasses, vests and steel-toed boots. In the end, the second-graders were each handed a hardhat to take home courtesy of Colorado School of Mines (CSM), and had fun decorating their hats with CSM stickers as they enjoyed their doughnuts.

Through its small-scale program, MEC K-12 Outreach team members have prepared 14 different K-12 in-person and virtual lessons from which teachers may choose. Lessons include titles like "Rocks and Minerals," "the Minerals Scientific Method," "Colorado Mining History," and "Mine Design," as well as "Snacks with a Mineral Professional," and field trips to a CSM laboratory or the CSM Edgar Mine.

Snacks with Mineral Professionals took place at Place Bridge Academy in Denver, CO on Oct. 28, 2022.

The short-term goal of the MEC K-12 Outreach Pilot Program is to assist local SME sections in establishing a speaker's bureau to conduct in-school and virtual presentations with hands-on rock and mineral samples. If successful in Colorado, this program will be replicated in two Utah K-12 schools for the 2023/2024 school year, after which an Outreach Action Toolkit will be developed and disseminated to SME Sections to help aid their outreach efforts. To learn more about the MEC K-12 Outreach Pilot Program or to donate rock and mineral samples, please visit https://mineralseducationcoalition.org/mec-outreach-program. ■

New MEC poster shows the natural
resources needed to build a house

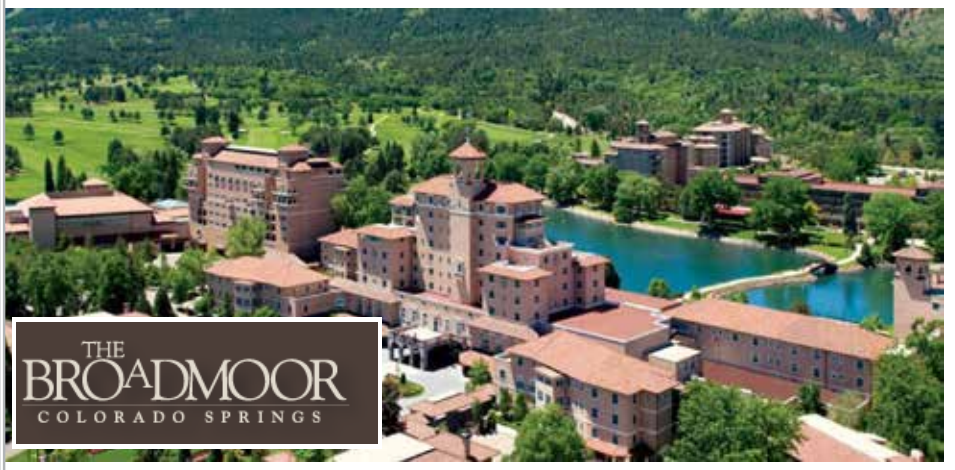
In the ongoing work to update MEC content and materials, the popular "Look Around . . . Everything is Made from Something" poster has a new, exciting look with updated content and graphics about the many natural resources required to build a new home. The new 32-inch by 23-inch poster is $6 in the MEC online store. Get yours now at MineralsEducationCoalition.org/everything-is-made-of-something-poster. ■

MoveMining Next Gen;
Deadline for submissions approaching

Please have your students, children and grandchildren submit their entries early to ensure that the video and accompanying information come through in plenty of time before the Jan. 18, 2023 noon MT deadline. Go to MoveMiningNextGen.org to help K-12 students get started on their three-minute videos showing how important mining and minerals are to all of our lives. A group of expert judges will score the entries. Highest score of all will win the Best Overall Prize of $1,000, remaining highest score in each category will win $250 prizes, and second highest score in each category will win $150 prizes. The categories are Grades K-5, 6-8, and 9-12. There will be no People's Choice/public voting portion of the contest this year.

Thank you so much to our sponsor, Newmont.

Questions may be directed to MoveMiningNextGen@smenet.org. ■



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COLORADO
MPD SUBSECTION

72nd Annual Colorado MPD Meeting

Mining Today, Powering Tomorrow

Technical Program:

Thursday, April 27	1:00 PM—4:00 PM
Friday, April 28	8:30 AM—4:00 PM
Saturday, April 29	8:30 AM—12:00 PM

Golf Tournament:

Saturday, April 29 — 1:30 PM

Spouse Activities:

Bubbles & Brunch — Time TBD
Friday, April 28

Conference registration opens in January.

Hotel reservations currently available. Book now to ensure your spot!

For conference registration and details, please visit our website:

www.ColoradoMPD.com

You may also contact

Jenny Pergola:	303-451-7677	jenny@pumpsplusinc.com
Richie Waller:	303-517-8664	rswaller@bechtel.com
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The Department of Mining Engineering at the University of Kentucky invites nominations and applications for a tenure-track faculty position at the rank of assistant or associate professor. Candidates for the position must hold a Ph.D. degree in mining engineering, or a closely related field, and must be committed to excellence in the areas of teaching, research, and service. In addition to these qualities, preference will be given to candidates who have experience in the mining industry and have obtained professional licensure.

The University of Kentucky, located in the heart of Kentucky's scenic Bluegrass region, is home to more than 30,000 students and 14,000 employees. As a land-grant university for the commonwealth, the mission of the University of Kentucky is to provide excellent education, conduct outstanding research, and perform service in an academic environment in a manner that ensures the professional success of our students, meets the needs of our constituents, and responds to the technological challenges of the commonwealth.

The Department of Mining Engineering is one of the larger mineral-related programs in North America. The department consists of seven faculty members who have diverse specialties that cover a wide range of the mining engineering discipline.

Responsibilities of the successful applicant will include teaching and student advising at both the undergraduate and graduate levels. The selected candidate will also be expected to develop a sustainable research program that attracts external research funding and addresses the needs of the mining industry. The position is open to all the specialty areas of mining and geological engineering, including contemporary issues in mining, such as reclamation, health and safety, and mine operations.

Applicants should submit the following: 1) cover letter, 2) curriculum vitae, 3) a teaching statement (upload as specific request 1), and 4) a research statement (upload as specific request 2) .

Applications submitted by January 31st, 2023 will receive full consideration. However, the position will remain open until filled.

To apply, go to **https://ukjobs.uky.edu/** and click on Search Jobs and enter requisition **#FE03259**, or use: **https://ukjobs.uky.edu/postings/429723**

Department Head

The Department of Mining and Minerals Engineering (MME) at Virginia Tech seeks applications and nominations from talented individuals for the position of Department Head. The Head is responsible for the management of fiscal and human resources, including 9 tenured and tenure-track faculty and numerous research, teaching and administrative faculty and staff. The Head also acts as MME's advocate and liaison to college and university administration, as well as external stakeholders.

MME is one of the largest and most prominent mining-related programs in North America and serves approximately 125 undergraduate (sophomore to senior) and graduate (PhD, MS, MEng) students. The department is recognized as a global leader in the field, with a stated mission to serve society through education and innovation that support safe, efficient, and environmentally responsible production of energy and mineral resources. MME has world-class facilities in Holden Hall, a recently updated and renovated 1940s structure which has added over 80,000 square feet of cutting-edge research, laboratory, instructional, and advising spaces. The Department is home to two renowned and highly productive research centers (the Virginia Center for Coal and Energy Research, and the Center for Advanced Separation Technologies), and its faculty include globally recognized experts in mineral processing, geoenergy, and mine health and safety.

Virginia Tech is a public land-grant university and is committed to teaching and learning, research, and outreach to the Commonwealth of Virginia, the nation, and the world. Building on its motto of Ut Prosim (that I may serve), Virginia Tech is dedicated to InclusiveVT—serving in the spirit of community, diversity, and excellence. The university's College of Engineering undergraduate program ranks 16th, and its graduate program ranks 31st among all U.S. engineering schools (USN&WR). The main campus is located in Blacksburg, Virginia, an area consistently ranked among the country's best places to live.

The department fully embraces Virginia Tech's commitment to increase faculty, staff, and student diversity; to ensure a welcoming, affirming, safe and accessible campus climate; to advance its research, teaching, and service mission through inclusive excellence; and to promote sustainable transformation through institutionalized structures.

Candidates must hold a Doctoral degree in engineering or applied science that is substantially related to the field of mining and minerals engineering. Candidates from other engineering or applied science disciplines (e.g., civil, environmental, materials, mechanical, geoscience, etc.) with related experience are strongly encouraged to apply. The successful candidate must have academic credentials commensurate with appointment at rank of Professor with tenure. An endowed professorship may be available for well-qualified individuals.

Candidates who wish to be considered for this position should apply online at **www.jobs.vt.edu** to job number **522450** and must submit a cover letter expressing interest in this critical leadership position and vision for MME; a curriculum vitae; a statement on contributions to advancing diversity, equity and inclusion; and contact information for at least three references who can discuss the applicant's leadership, communication, and decision-making style. Review of applications will begin on December 1, 2022 and will continue until the position is filled.

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jessica.stacy@mineraltechnologiesusa.com
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Index of Display Advertisers - December 2022

This is not your father's career

William Gleason
Editor

In an attempt to rebrand the Buick LaCrosse sedan to make it more appealing to younger drivers, Buick launched an advertising campaign with the tag line "this is not your father's Buick."

Human resource directors in the mining industry and recruitment officers at the mining and metallurgy departments in the nation's universities that offer such degrees may want to consider a similar message because as Bob Dylan sang, "The times they are a-changin.'"

The workforce in the mining and extractive metallurgical industries is facing rapid and dramatic changes driven by technology, the pandemic, environmental, social and governance (ESG) issues and a generational changing of the guard. The Baby Boomers (born between 1946 and 1964) are collecting their gold watches and heading for well-earned retirement plans at a rapid pace. Generation X (born 1965–1980) is moving into leadership roles, but the number of Gen X-ers in the mining industry is small by comparison to the Boomers, leaving a void that is being filled by the Millennial Generation, also known as Generation Y (born 1981–1996).

For those Millennials moving into leadership, Bob Dylan is a Nobel Prize-winning songwriter, but that's beside the point.

During the SME Midyear Meeting in Reno, NV, Sarah Sladek gave a presentation about how membership in professional organizations like SME has changed over the years. The trend reflects the changes in the overall workforce. Gone are the days of working for the same company for an entire career. There is workforce data now that suggest that for Millennials and Generation Z, also known as the iGen (born 1997–2010) 19 months in the same position is an adequate amount of time.

Sladek spoke about the characteristics that defined each generation — Baby Boomers were born on the heels of WWII, and most of them stayed in the same profession and often at the same company for their entire professional career. Membership in a professional society or labor union was common. It was the right thing to do. Gen X-ers' outlook was defined by the Civil Rights movement, the personal computer and space exploration. They were raised in dual-income households and grew to be independent and self-reliant. Millennials were shaped by the Great Recession, the Sept. 11, 2001 terrorist attacks, and the expansion of social media and the internet. And Generation Z have little to no memory of life without smartphones and social media.

As you can imagine, a person raised in a single-income household in the 1950s who saw dad head to work while mom stayed home probably has a very different view of how and where work should be done than a person who has been connected to the entire world through Tik Tok since their days in middle school. For the Baby Boomers reading this, Tik Tok is a social-media platform that has stolen countless hours from my daughters with short video clips of who knows what; that, too, is beside the point.

When it comes to workforce, each generation brings its own strengths and challenges. While the Boomers offer stability, Gen Z-ers are on the cutting edge of technology. These generations also have different values and desires.

I recently spoke with Rhonda Zuraff from Pray and Co. for her thoughts about trends in the mining industry. She has been in the business of human resource management for more than 20 years and works with mining companies all over the world.

"It's a very different animal if you are an employer wanting to retain and attract top talent from the Millennial and Gen Z demographics than if you are trying to attract and retain top talent from the Baby Boomer or Gen X level," she said. "They want very different things, and compensation is not what will typically prompt them to make a move to your company or stay with your company. It's things like culture of the company and job variety. And no surprise, another key piece is time off and flexibility with time and location. The pandemic taught us that work can be done a lot of different ways and from different locations."

On page 25 the changing face of the mining workforce is discussed with Zuraff, Skylie Estep and Cayley Hoffman from South 32, Jodi Banta from the University of Arizona and Taylor Dillion from ERM. They are among the professionals meeting the workforce challenges head on, and they spoke about what the industry must do to attract and retain a qualified workforce now and in the future. ■

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

All New
Business Profiles
Inside!

Special Editorial Supplement from the publisher of Mining engineering

CLEAN RIVERS PROJECT, WASHINGTON, DC

METICULOUSLY UPGRADING THE UNDERGROUND

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

› herrenknecht.com/cleanrivers

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

PIONEERING UNDERGROUND TOGETHER

HERRENKNECHT
Tunnelling Systems

December Contents

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In This Issue

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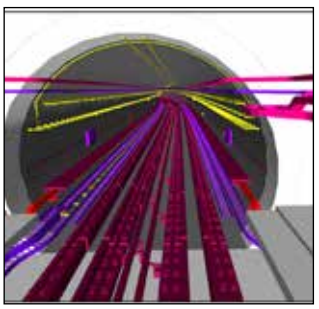
Feature Articles



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

Well, a lot …

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

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

Michael Rispin
2022-2023 UCA Chair

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

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

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BANGKOK FLOOD PROTECTION: AHEAD OF THE CURVE

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

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

TUNNELLING SOLUTIONS | UTILITIES

TERRATEC

Herrenknecht picks up prestigious innovation award at bauma trade show

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

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

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

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

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

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

(continued on page 6)

Petra acquires trenchless tunneling company Zilper

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

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

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

(continued on page 11)

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

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

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

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

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

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

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

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

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

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

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

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

Award: Herrenknecht for Machine Technology

(continued from page 4)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Largest TBM of its kind built in China

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Sydney Metro West gets greenlight for tunneling

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

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

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

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

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

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

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

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

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

TBM launched at Jefferson Barracks project

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

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

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

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

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

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

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

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

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

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

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

Chair's column: UCA aligns with ITA

(continued from page 2)

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

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

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

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

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

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

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

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

Tunnel on! ■

Petra: Combined company will de-risk projects

(continued from page 4)

investment gap.

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

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

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

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

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

Emerging safety and productivity technologies for North American tunneling

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

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

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

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

Introduction

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

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

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

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

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

Mike Rispin, Mike Walling, Rob Albinger and David Maust

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Refuge chambers

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

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

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

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

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

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

FIG. 1

Rigid, steel refuge chamber.

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

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

FIG. 2

Refuge chamber features per ITA guidelines.

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

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

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

Proximity detection and collision avoidance

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

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

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

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

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

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

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

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

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

A representative electromagnetic system is shown in Fig. 4.

Gas detection and environmental monitoring

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

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

FIG. 3

Inflatable refuge chamber.

FIG. 4

Electromagnetic PD/CA components and functionality.

FIG. 5
Wired and wireless gas monitoring systems.

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

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

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

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

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

Conveyor health monitoring

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

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

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

Conclusion

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

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

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

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Design and construction challenges for the Ellicott City North Tunnel

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

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

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

Project background

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

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

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

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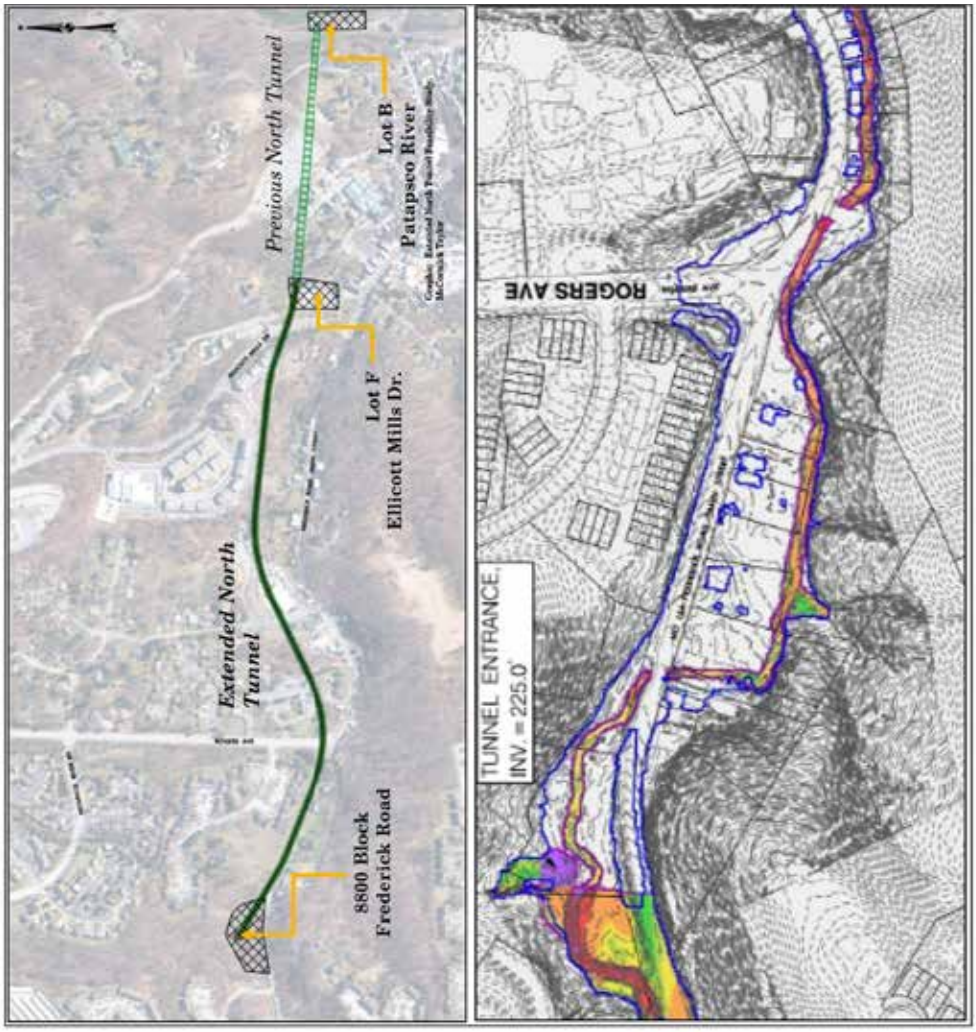
FIG. 1

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



down flash-flooding events.

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

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

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

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

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

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

Geological setting

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

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

FIG. 2

Photograph of rock outcrop near eastern outfall.

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

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

Design challenges

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

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

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

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

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

Construction challenges

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

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

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

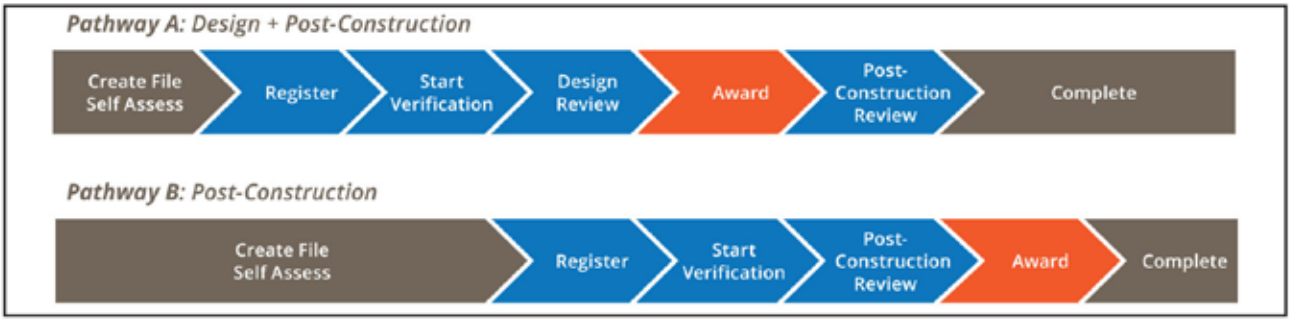
Impacts to Historic Ellicott City. The potential for construction traffic and other related impacts to the Historic Ellicott City represents a significant construction challenge. Generally, the launch and outlet sites are accessed by a single two-lane roadway (Frederick Road/ Main Street), which is designated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

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

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

FIG. 3

Envision verification pathways (ISI, 2020).



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

Sustainability

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

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

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

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

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

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

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

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

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

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

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

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

Conclusions

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

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

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

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

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

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

Building information modelling

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

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

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

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

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

Guidelines for bored tunnels

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

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

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

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

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

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

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

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

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

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

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

FIG. 1

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

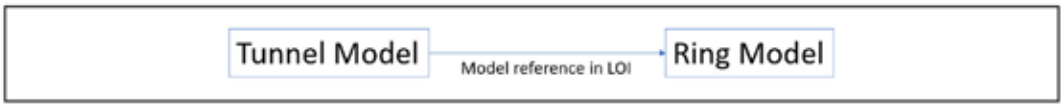
USE CASE	DESCRIPTION	Source	STRATEGIC DEFINITION	PREPARATION & BRIEFING	CONCEPT/PRELIM DESIGN	BASELINE/REF DESIGN	DETAILED/ CONTRACTOR DESIGN				CONSTRUCTION	COMMISSIONING & HANDOVER	USE/OPERATION
							30%	60%	90%	100%			
Design variants investigation	Variant investigation based on 3D models of the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

at the WTC in Copenhagen in 2022.

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

FIG. 2

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



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

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

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

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

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

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

FIG. 3

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

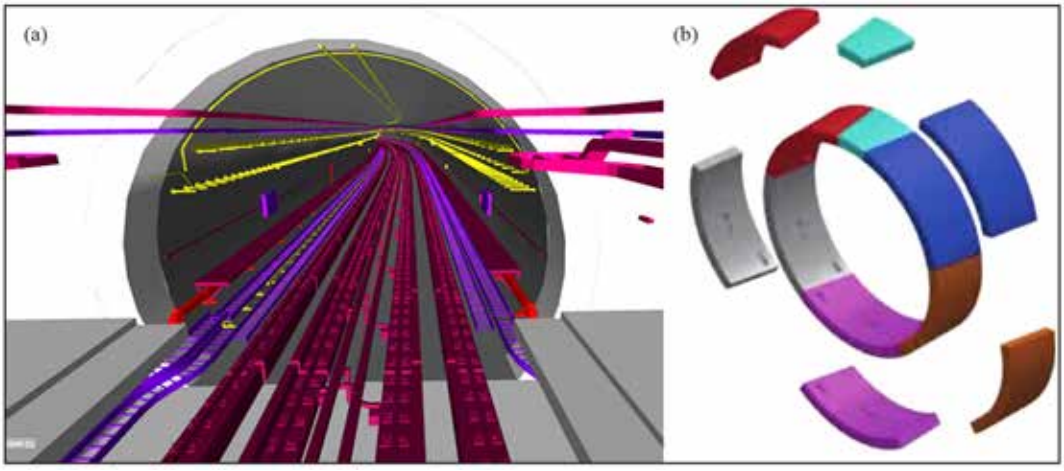


FIG. 4

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

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

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

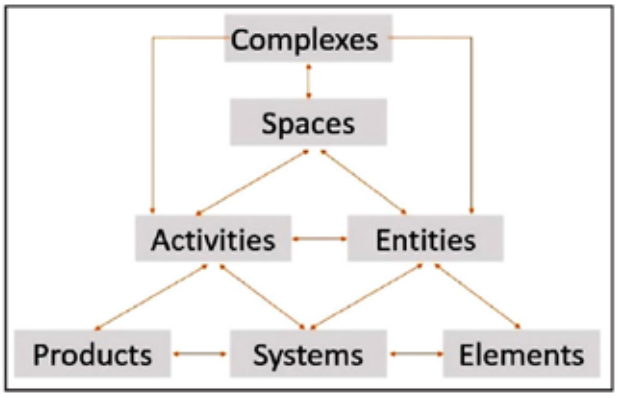
Classification systems. Objects within BIMs (i.e. the tunnel lining or tunnel segments) should be properly named or labelled so that a model may be properly queried. Classification systems are used within a BIM context to achieve this purpose. These systems provide a naming hierarchy which allows all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

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

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

FIG. 5

Uniclass object hierarchy.



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

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

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

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

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

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

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

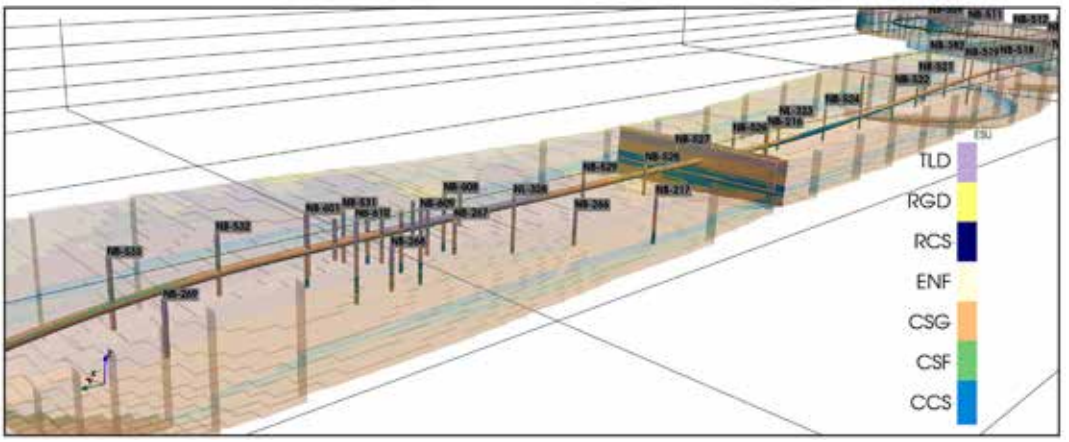
TABLE 1

Tunnel-specific examples of Uniclass object naming structure.

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

FIG. 6

Geotechnical BIM showing positions of boreholes along a tunnel alignment.



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

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

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

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

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

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

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

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

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

Conclusion

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

Acknowledgements

The authors would like to thank all the members of the ITA WG 22 for their assistance in developing the guideline. In addition, we would like to thank the UCA of SME Working group on interaction modelling in tunneling for their review on the applicability of the guideline for the U.S. market. The current members of the UCA of SME WG are Jon Berkoe, Jeff Fontana, Jacob Grasmick, Rajat Gangrade, Ivan Hee, Mark Johnson, Jay Mezher, and Eric Westergren. Former members involved in the review are Foteini Vasilikou, and Anthony Bauer. The Group is chaired by Vojtech Ernst Gall.

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

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

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

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

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

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

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

(continued on page 32)

2022 Tunnel Watch List

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

UCA's Sanja Zlatanic named to ITA Council

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

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

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

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

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

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

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

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

Sanja Zlatanic

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

Tunnel Watch List; 2022 includes new projects

(continued from page 31)

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

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

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

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

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

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

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

A call for UCA volunteers

by Genny Homyack, SME Staff

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

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

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

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

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

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

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

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

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

Executive Committee nominations

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

Paul Schmall named President of the Moles

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

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

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

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

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

Paul Schmall

COMPILED BY JONATHAN KLUG, DAVID R. KLUG & ASSOCIATES

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

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

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

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Safety Challenges in Long Rail Tunnels

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

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

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

SPECIAL SAFETY CONCEPT

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

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

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

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

SAFETY AND OPERATIONAL CHALLENGES

The specific safety risks are summarized as follows.

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

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

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

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

APPROACH TO SAFETY

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

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

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

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

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

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

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

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

FACILITY SAFETY

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

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

Important facility safety elements are as follows:

Passenger trains

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

Freight trains

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

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

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

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

ROLLING STOCK (PASSENGER TRAINS)

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

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

Lessons Learned

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

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

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

TUNNEL EQUIPMENT

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

Communication Systems

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

Signage, Emergency Lighting and Handrails

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

Camera Systems

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

Ventilation

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

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

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

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

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

Automatic Tunnel Reflexes

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

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

OPERATIONAL PROCEDURES

Signaling Systems

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

Lessons Learned:

Automatic Hazard Management System

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

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

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

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

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

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

Different way-side monitoring parameters are as follows:

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

CONCLUSIONS

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

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

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

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

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

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

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

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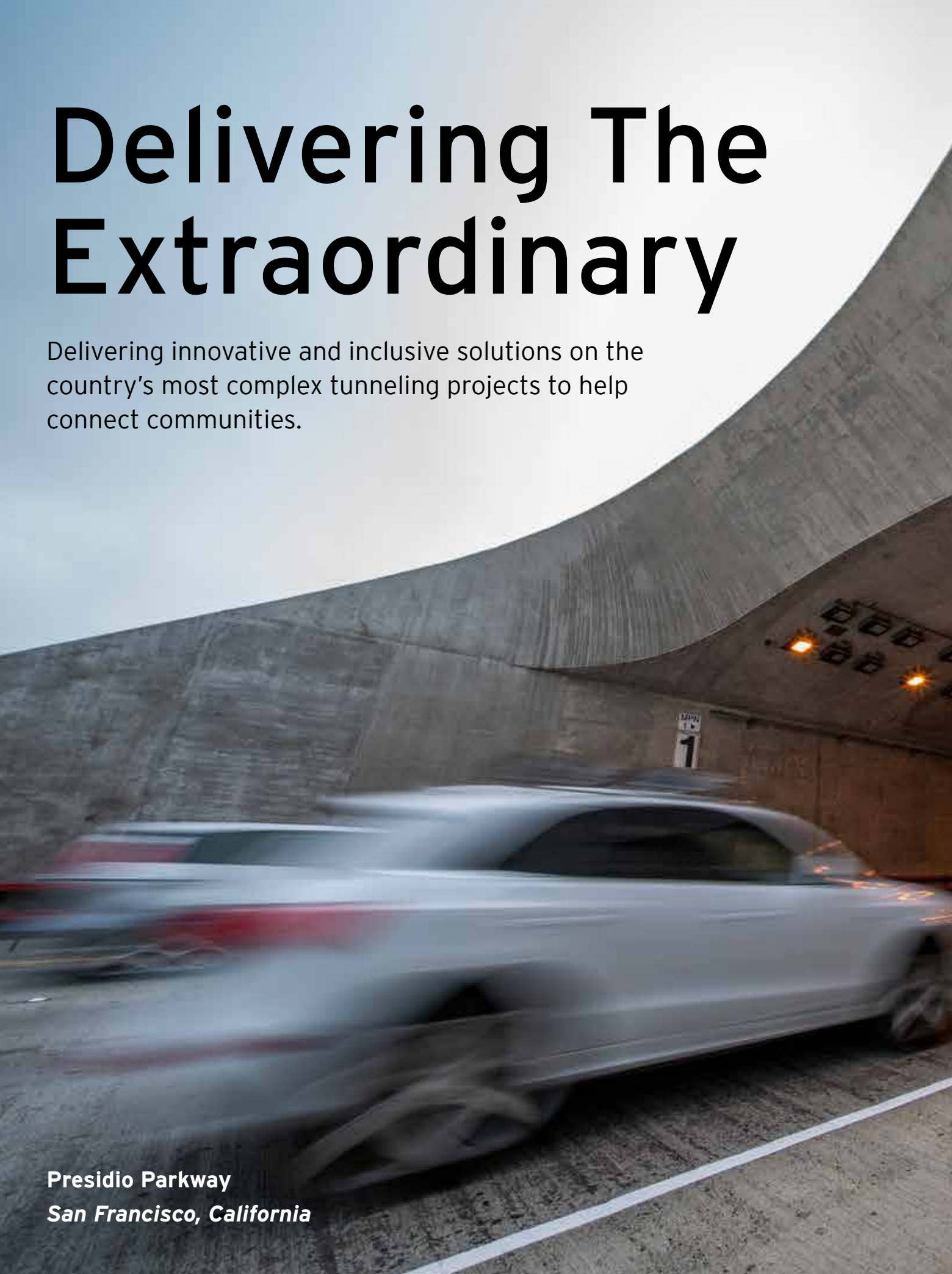

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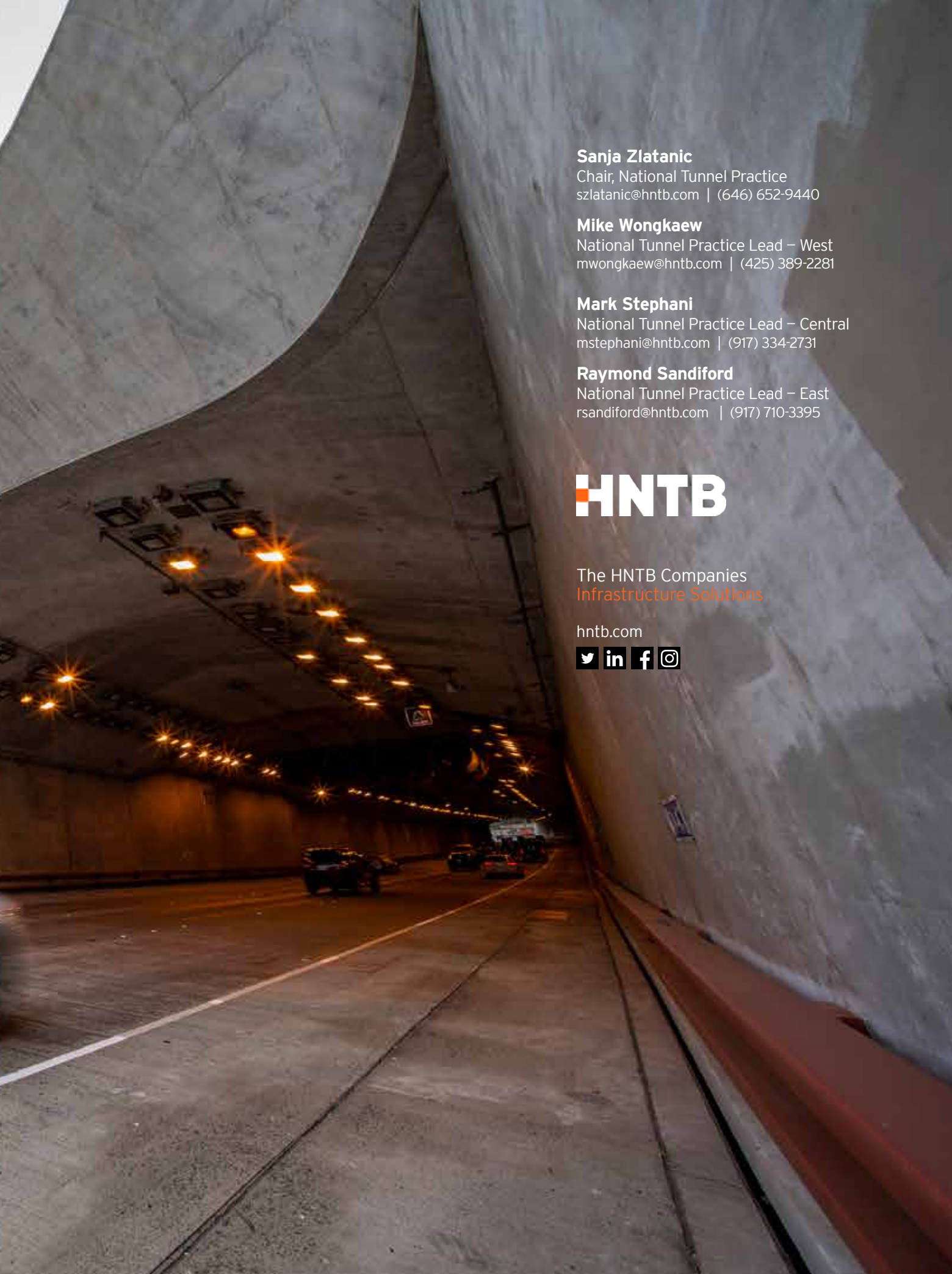

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DC Clean Rivers Project, Washington, DC: Division A - Blue Plains Tunnel, reinforced concrete slurry diaphragm wall shafts (pictured); and Division I Diversion Structure, jet grouting for underpinning, support of excavation, and groundwater control



PIONEERING UNDERGROUND TOGETHER

With the experience of more than 5,700 projects, Herrenknecht is a technology and market leader in the area of mechanized tunnelling technology. Herrenknecht is the only company world-wide to deliver cutting-edge tunnel boring machines for all ground conditions and in all diameters – ranging from 0.10 to 19 meters. The product range includes tailor-made machines for traffic, supply and disposal tunnels, technologies for pipeline installation as well as drilling equipment for vertical and inclined shafts and deep drilling rigs.

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

As a reliable project partner, Herrenknecht supports its customers with an extensive range of services from the beginning of the project to breakthrough. From the initial project idea through manufacturing, transport, assembly, tunnelling support and spare parts service to disassembly, Herrenknecht accompanies the process at the customer's side. Even personnel solutions for the temporary supplementing of jobsite crews are provided if required. With competent service specialists and more than 45 years of experience in the tunnelling industry, the company regularly supports around 300 jobsites worldwide and offers customized service packages tailored to individual project requirements.

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

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

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

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

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ANTRAQUIP CORPORATION – your reliable, innovative partner

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

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

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

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

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

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

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

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


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Terratec

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

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

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

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

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

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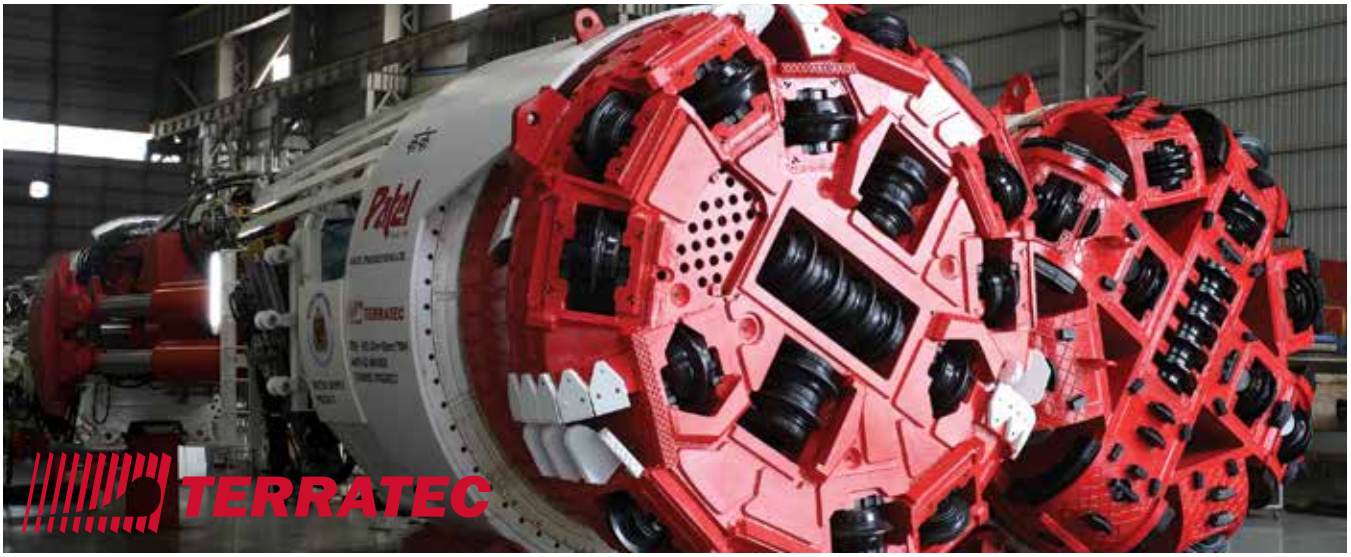

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JENNMAR continues to grow, but our focus will always be on the customer. We feel it is essential to develop a close working relationship with every customer so we can understand their unique challenges and ensure superior customer service. Our commitment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

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

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

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

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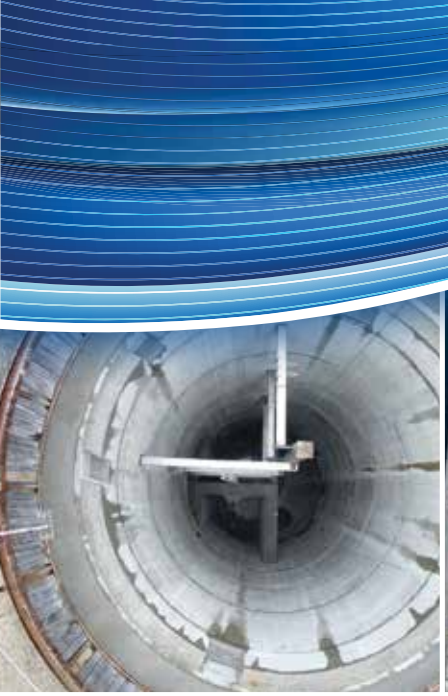




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MAPEI Corporation

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

The UTT group is a successful division of MAPEI Group, which has provided proven construction system solutions for more than 80 years. Established in 1937, MAPEI Group is a global corporation, based in Milan, Italy, and with 91 subsidiaries that include 84 plants in 35 nations. MAPEI is the world-leading manufacturer of mortars, grouts and adhesives, as well as complementary products for installing floor and wall coverings. MAPEI manufactures chemical products for building, including waterproofing products, admixtures for concrete and repair products, and decorative and protective exterior coatings — as well as the UTT product line.

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

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

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

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

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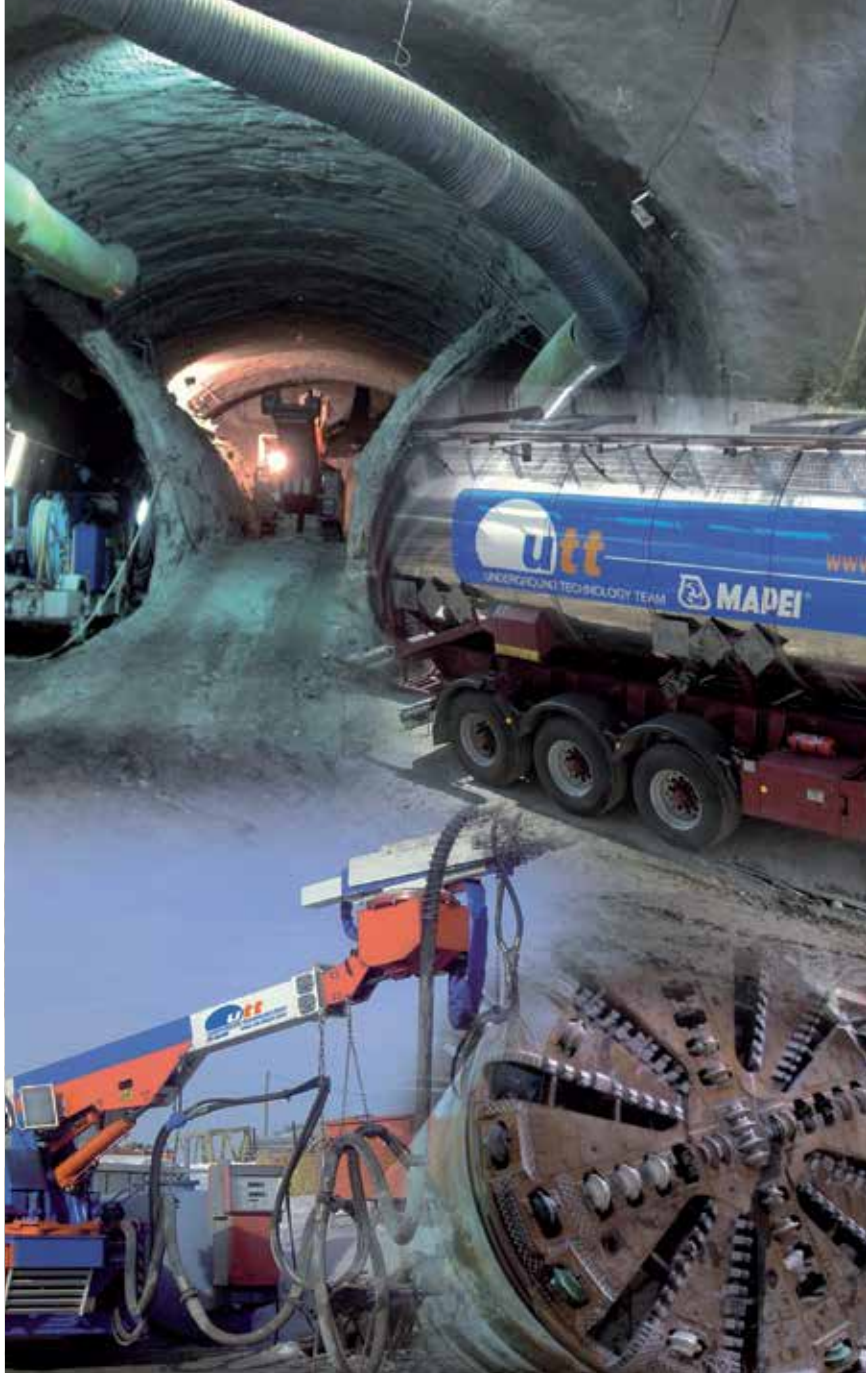

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Reliable technology and expertise for underground construction

- 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

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MAPEI®
ADHESIVES · SEALANTS · CHEMICAL PRODUCTS FOR BUILDING

Reliable Automatic Sprinkler Co., Inc.

Protecting the 'New M4' East Tunnel

About the Tunnel

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

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

About Deluge Systems

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

About the TNL280 Nozzle

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

Project Quick Facts:

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

Learn More:

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

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

Disruption is not an option

Reliable® Tunnel Deluge Systems protect your most critical infrastructure assets

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

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

TNL280

Over 100 Years of Reliable Experience

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

Reliable®

Manufacturer and Distributor of Fire Protection Equipment

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

reliablesprinkler.com/tunnels

DSI Underground

Reinforcing Progress - DSI Tunneling LLC.

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

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

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

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

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

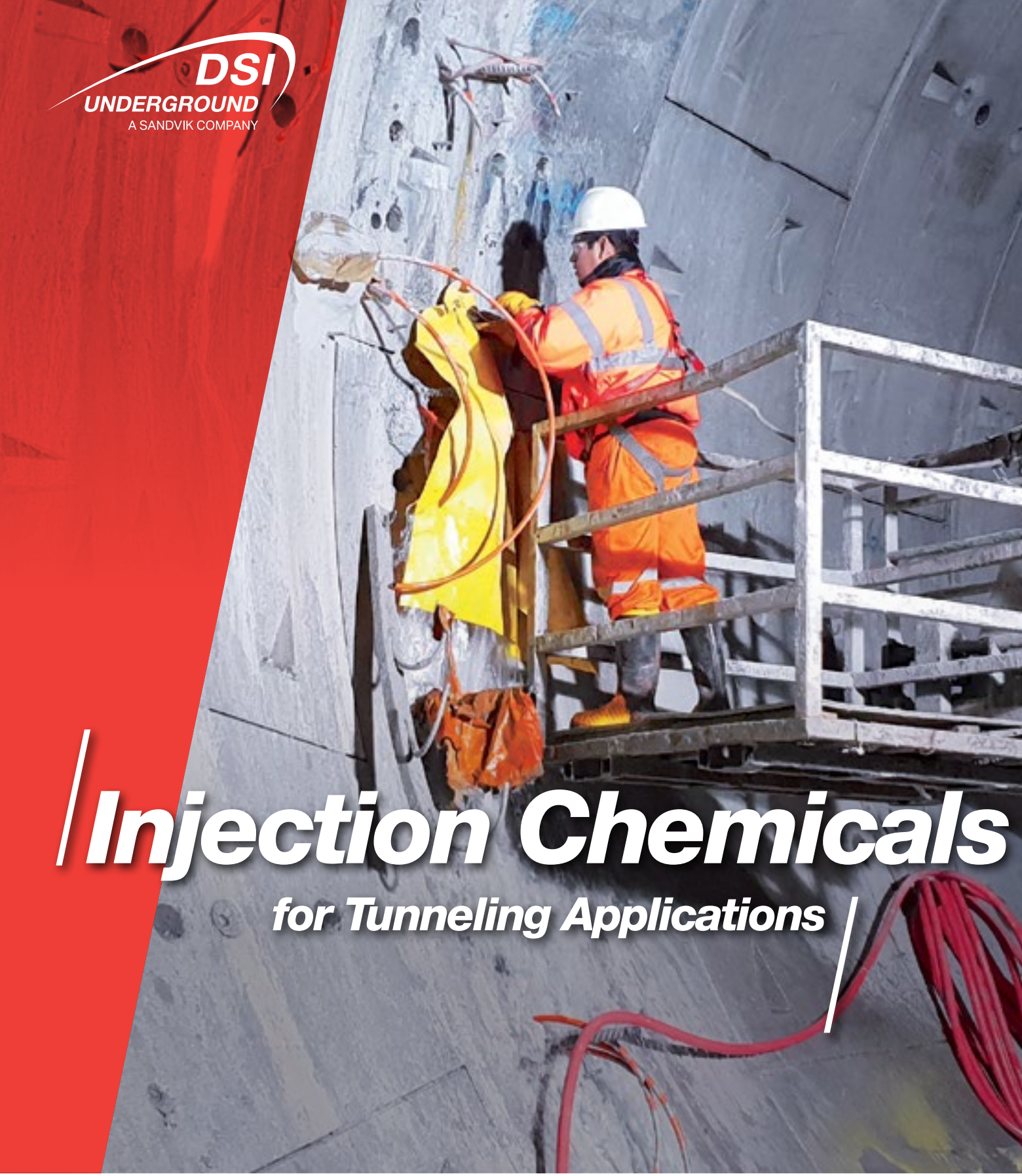
When you're tackling a seemingly insurmountable objective, facing tons of rock and earth, and need the skills and knowledge to achieve it, we're with you. We understand the complexities and considerations, the depths and dangers far below the ground - and we work with you to navigate them, taking you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

DSI Tunneling LLC. Reinforcing progress.

DSI UNDERGROUND

www.dsiunderground.com
502.473.1010

DSI
UNDERGROUND
A SANDVIK COMPANY



Injection Chemicals

for Tunneling Applications

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

DSI Tunneling LLC
502-473-1010

dsitunneling.com
dsiunderground.ca

Derrick Corporation

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

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

SERVING THE CIVIL INDUSTRIES

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

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

EQUIPMENT THAT MAKES THE DIFFERENCE

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

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

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

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

SCREENING TECHNOLOGY THAT MAKES A DIFFERENCE.

DERRICK®

CONVENTIONAL FLAT SCREEN
SOLIDS IMPEDE FLUID FLOW

CORRUGATED PYRAMID SCREEN
ENHANCED PERMEABILITY

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

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

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

www.Derrick.com

HYPERPOOL® SHAKERS

Miller Contracting

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

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

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

MILLER

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

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

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

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

for more information please visit our website: millercontracting.us

Innovative Onsite Concrete Production Equipment for Rent

OUR SERVICES, EQUIPMENT & PARTNERSHIP

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

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

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

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

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

Premier Pipe Systems Manufacturer for Over 95 Years

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

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

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

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

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

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

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

Quotations are immediately available on inquiry.

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

Drill Tech Drilling & Shoring, Inc.

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

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

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

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

Crux Subsurface - New Look, Same Innovative Solutions

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

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

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

Kiewit

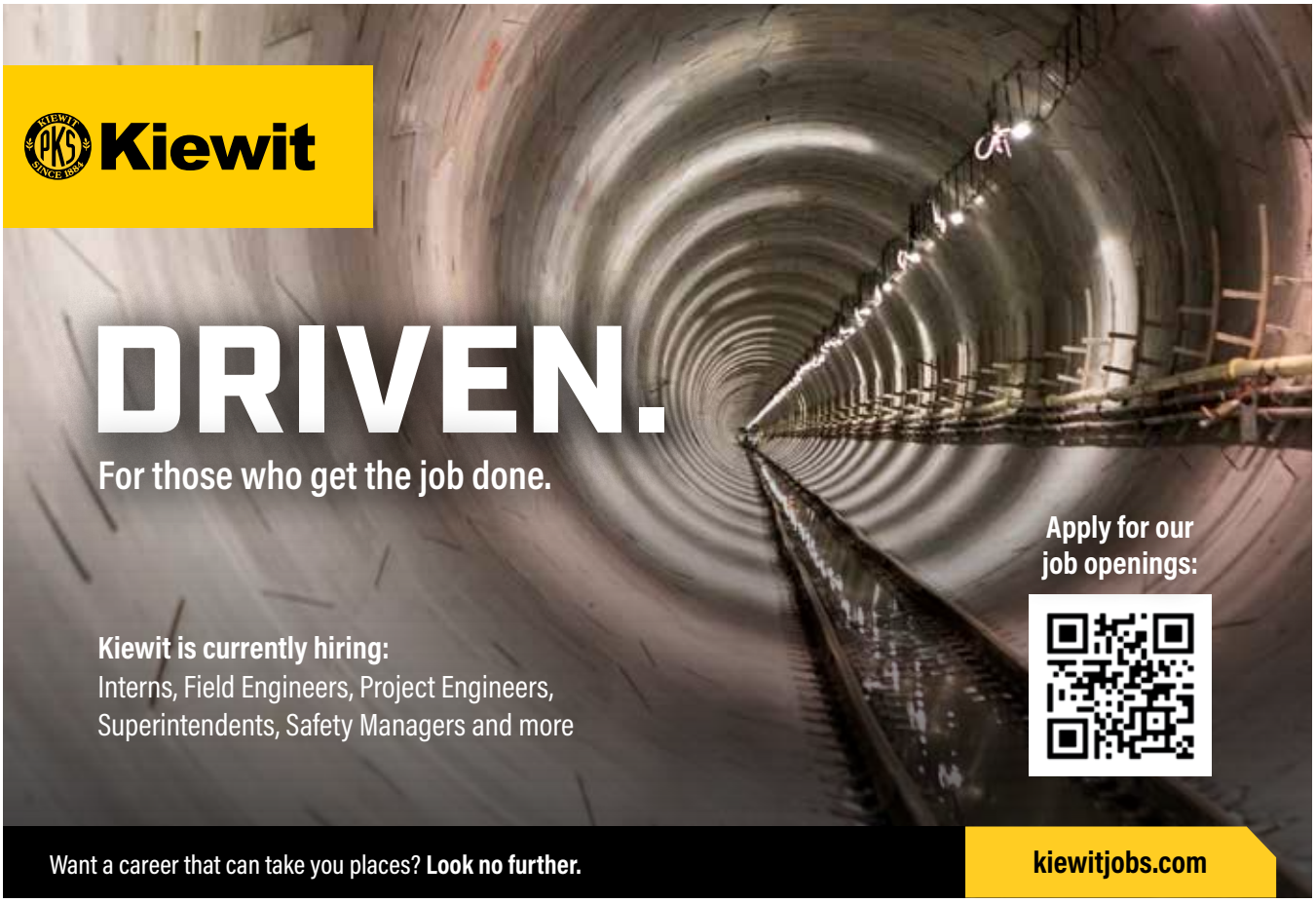
As a construction, mining, and engineering leader, Kiewit is a FORTUNE 500 company consistently ranking in the ENR's Top 10 Contractors. Kiewit is owned by active employees, creating a level of motivation that keeps the company on top. Kiewit, through its operating companies, brings a wealth of diverse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

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

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

Kiewit

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



CDM Smith – A Leader in Tunnel Engineering

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

Tunneling Expertise

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

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

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

Market Sector Experience

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

- Transportation
- Environment
- Water/wastewater
- Mining

Award-Winning Projects

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

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

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

Contacts:

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Mining Equipment Ltd.

Mining Equipment Rolling Stock for Columbus, Ohio

"Rolling for more than 35 years"

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

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

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

Mining Equipment 10 Ton Locomotives for Columbus, Ohio

Normet - Defining the Future Underground.

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

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

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

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

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

Normet has a broad underground offering:

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

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

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

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

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

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

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

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

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

STRATA WORLDWIDE BRINGS BORAID® DIRECTLY TO TUNNEL BUILDERS

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

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

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

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

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

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

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

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

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

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

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

www.strataworldwide.com/tunneling

BORAID

STRATA WORLDWIDE

David R. Klug & Associates, Inc.

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

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

Michels Construction, Inc.

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

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

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

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

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

EOE/AA/M/F/D/V

Infrastructure. Delivered.

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

Challenging projects require the dedication and skill of true pioneers.

That's what we deliver.

MICHELS®
CONSTRUCTION, INC.

An Energy & Infrastructure Contractor

www.Michels.us

Reliable hands free charging

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

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

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

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With its innovative connector for high power charging systems the QCC by Stäubli provides a universal solution for automatic charging of various kinds of electric vehicles (Mining equipment, AGVs, buses, trucks, etc.). The automated connection device (a so-called ACD) makes it possible to transfer high levels of power, which ensures fast recharging of energy storage devices such as Li-Ion batteries and super capacitors. The QCC offers high efficiency and low maintenance requirements. The amount of stored energy required is reduced due to quick recharging stops, which enables the vehicle to better serve its purpose – transport of the weight of goods, not the weight of batteries.

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

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Brookville

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

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

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

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

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

Bradshaw Offers Innovative Tunnel Engineering and Construction Technology

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

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

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Gall Zeidler Consultants

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

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

Our tunnel and geotechnical engineering services cover all stages of a project:

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

GZ Gall Zeidler Consultants

Kelley Engineered Equipment

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

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

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

HAGER-RICHTER GEOSCIENCE, INC.

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

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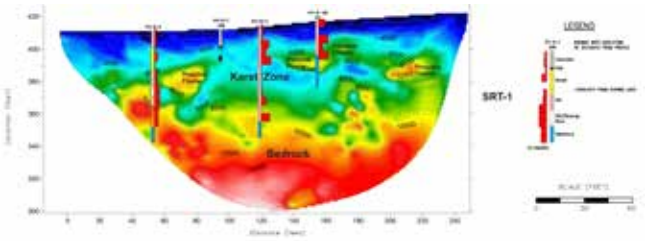

HRGS
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Geophysics for the Engineering & Environmental Communities

Kilduff Underground Engineering

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

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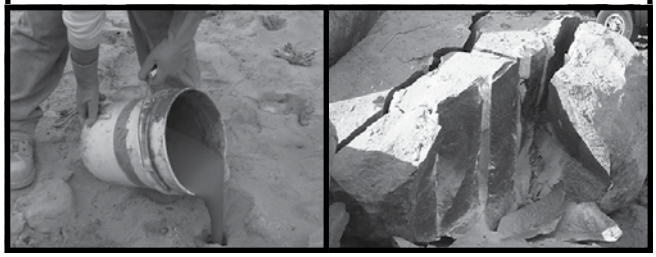

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Daigh Co. is the supplier of Dā-mite Rock Splitting Mortar. Dā-mite is used to fracture rock and concrete in "no-blast" conditions. Dā-mite is an ideal and effective tool for fracturing mass rock, boulders, trench rock, dimensional stone, concrete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

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Dr. Sauer & Partners

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

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

www.dr-sauer.com

Dr. Mole, Incorporated

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

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

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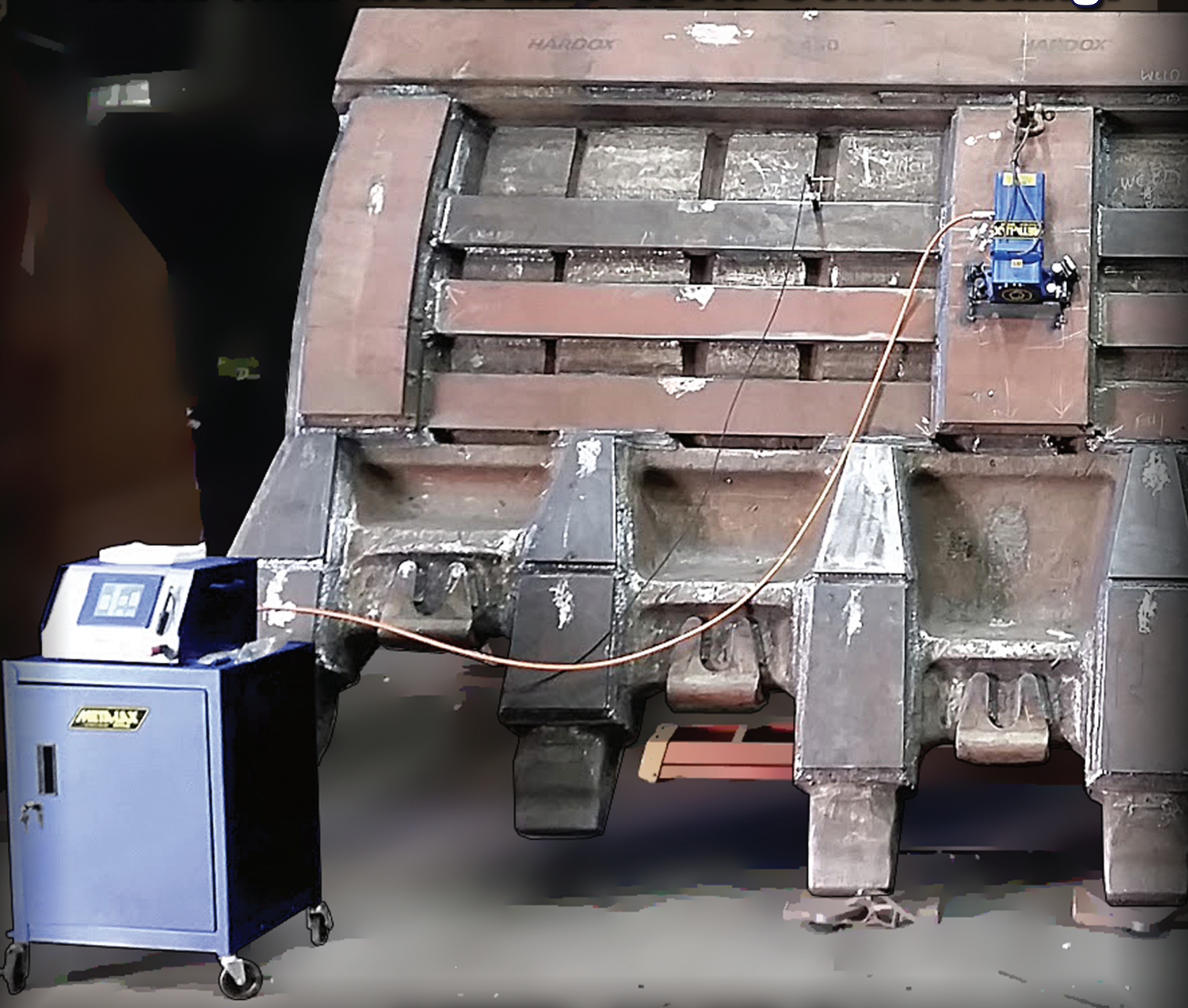

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