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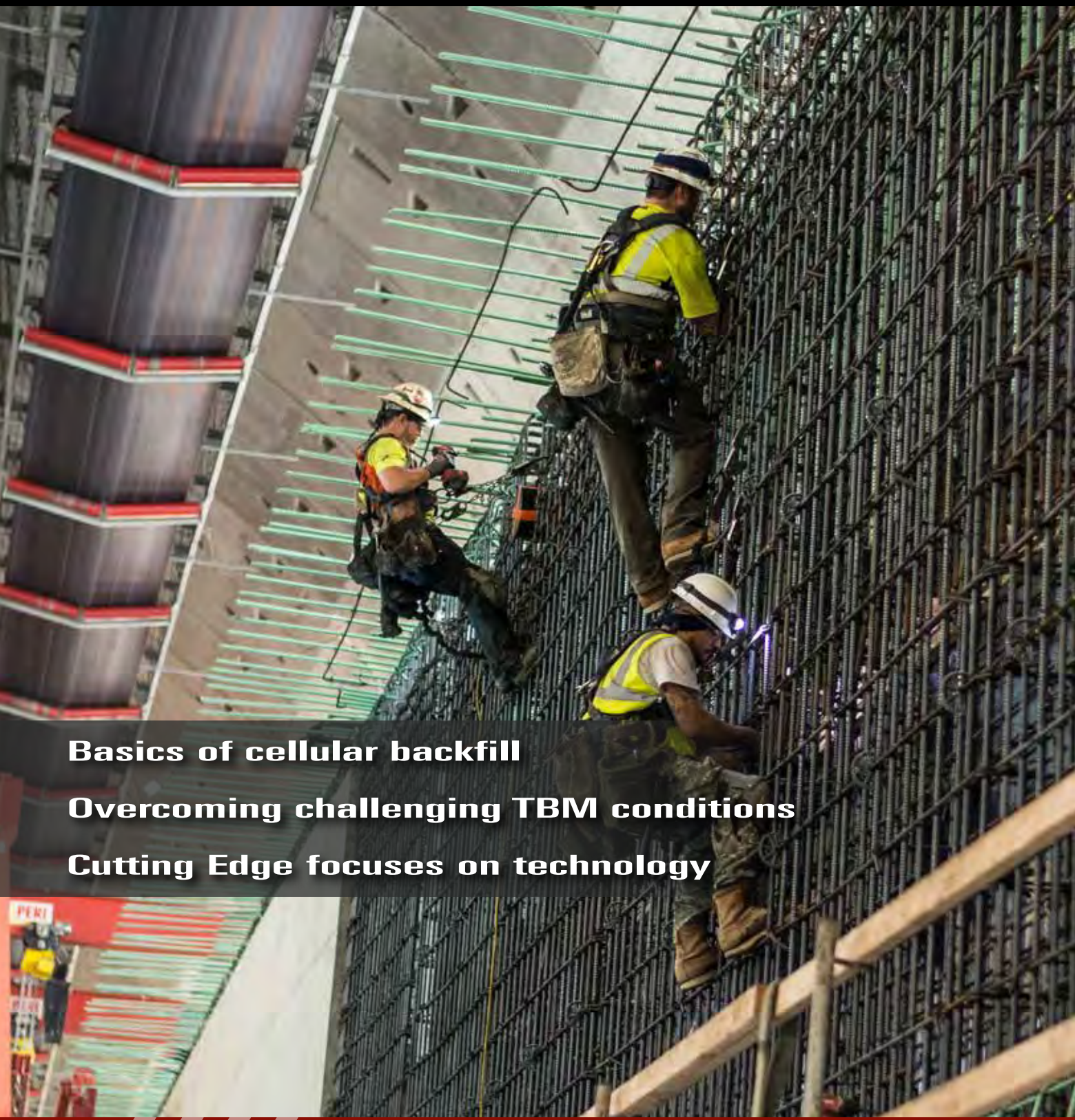

Basics of cellular backfill

Overcoming challenging TBM conditions

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COVER STORY

In this issue —
The need to fill the void space created between an excavated tunnel or shaft and the final lining system has long been a requirement in underground construction, page 10. The article on page 10 discusses the Difficult Ground Conditions system. Cover photo of the SR 99 Tunnel is courtesy of the Washington State Department of Transportation.

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CHAIRMAN'S COLUMN

UCA of SME membership soars and industry events flourish

Over the past few months, we have seen an unprecedented increase in our membership. Our current membership stands at 1,468 – the largest in UCA history. Most remarkable is that our numbers totaled 971 at the end of last May. This is a 51-percent increase in just a few short months. Thank you, and welcome to our nearly 500 new members. Your membership dues allow us to host multiple conferences per year and provide thousands in annual scholarships, all for the education and advancement of the U.S. underground construction industry.

The UCA's recent Cutting Edge Conference was again an industry success. Held in Seattle, WA, the conference included a site visit to the SR-99 Tunnel Project. This year's Cutting Edge was attended by more than 240 of our industry colleagues. Further demonstrating the growing popularity of Cutting Edge, all exhibit space and sponsorships sold out. An added feature for 2017 was the Young Member Regional Event, allowing those 35 and younger to attend to conference at a discounted cost, along with an additional visit to the Downtown Bellevue Tunnel construction site. This portion of the program was hosted by the UCA, the International Tunnelling Association (ITA) and the Tunnelling Association of Canada. It's encouraging to see so many of our next generation of leaders attending our conferences. Thanks to Joe O'Carroll, his organizing committee, and SME staff for producing another top-notch industry event.

I recently returned from the 2017 ITA's Awards event in Paris. There were three nominees from the United States.

- Blue Plains Tunnel (Project of the Year, € 50 million - € 500 million)/
- Anacostia River Tunnel (Sustainability Initiative of the Year).
- Anthony Bauer (Young Tunneller of the Year).

Shane Yanagisawa (Impregilo Healy Parsons JV) and Carlton Ray (DC Water) were on hand to accept the Anacostia River Tunnel's Sustainability Award. The 4th edition of the awards will be held in Chuzhou, China in November 2018. I am proud to announce to you that UCA has secured the 5th annual awards event for the United States, to be held in conjunction with the 2019 Cutting Edge Conference.

The George A. Fox Conference should already be on your calendars for Jan. 23, 2018 in New York City. This long-standing, annual one-day event features our industry's top professionals as speakers and attendees. Engaging technical sessions and networking opportunities make this one of our most popular events. Be sure to register soon, as this limited seating venue will sell out.

Also on your calendars should be the 2018 North American Tunneling (NAT) Conference June 24-27 in Washington, D.C. A mix of short courses and technical sessions, NAT is the premier biennial tunneling event for North America. UCA will continue to bring dozens of up and coming tunneling professionals to NAT through our cash and attendance scholarship programs. The UCA Young Members will once again host a reception for their current and future membership.

Finally, all of us on the UCA Executive Committee wish you a safe, healthy and happy holiday season. ■

Mike Roach,
UCA of SME Chairman

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Baltimore grants permit to Elon Musk for proposed hyperloop tunnel

It seems that one cannot do a Google search of tunneling or tunneling projects these days without Elon Musk's name popping up. In the past few months, the man best known as the chief executive officer of Telsa cars and SpaceX has thrown his hat into the tunneling ring.

It began, as so many things do now, with a tweet saying he was frustrated with traffic and was going to build a tunnel boring machine. Now it appears that it was more than just frustration. Since then Musk developed The Boring Co and, in October, Maryland Gov. Larry Hogan gave Musk permission to dig tunnels for the high-speed, underground transit system known as a hyperloop that Musk wants to build between New York and Washington.

The Baltimore Sun reported that Hogan administration officials said the state has issued a conditional utility permit to let Musk's tunneling firm, The Boring Co., dig a 16.5-km (10.3-mile) tunnel beneath the state-owned portion of the Baltimore-Washington Parkway, between the Baltimore city line and Maryland 175 in Hanover.

It would be the first portion of the underground system that Musk says could eventually ferry passengers from Washington to New York, with stops in Baltimore and Philadelphia, in just 29 minutes. Maryland's approval is the first step of many needed to complete the multibillion-dollar project.

Gov. Larry Hogan toured a site in Hanover that aides said could become an entry point for the hyperloop. The state does not plan to contribute to the cost of the project, aides said.

Hogan said on Facebook he was "incredibly excited" to support the project proposed by Musk, founder of the electric car company Tesla and the rocket firm SpaceX.

"This thing is real. It's exciting to see," Maryland Transportation Secretary Pete Rahn said. "The word 'transformational' may be overused, but this is a technology that leapfrogs any technology that is out there today. And it's going to be here."

The Boring Co. thanked officials for their support and declined to comment further.

Musk announced on Twitter this summer that he had received verbal approval from government officials for his giant East Coast infrastructure project.

Hogan announced his support for the project on Oct. 26. He posted photos of himself, Rahn, Boring Co. executives and Anne Arundel County Executive Steve Schuh touring the fenced-off site near the intersection of Maryland 175 and the Baltimore-Washington Parkway in Hanover where the tunneling is expected to begin.

Administration officials said they will treat the hyperloop like a utility, and permitted it in the same way the state allows electric companies to burrow beneath public rights-of-way.

"We have all sorts of utilities beneath our roadways," Rahn said. "In essence, this didn't need anything more than a utility permit."

Hogan spokesman Doug Mayer said the "vast majority" of the lines in the project will run under existing state highways.

The Boring Co. aims to reduce traffic congestion by creating a low-cost, efficient system of tunnels. The company has developed tunneling machines it says will drill quickly through soft soils at a fraction of the cost of traditional tunneling.

The hyperloop technology uses electric motors and magnets to transport train cars through a low-pressure tube.

The firm has proposed building a similar hyperloop in Southern California.

To reduce the cost of tunneling, The Boring Company says it will reduce the diameter of a one-lane tunnel from approximately 8.5 m (28 ft) to less than 4.3 m (14 ft). To make this safe for vehicles to travel in, cars would be placed on a "stabilized electric skate" and propelled through the tunnels by an electric motor. ■

Howard Steet Tunnel expansion is halted

The plan to expand the Howard Street Tunnel in downtown Baltimore, MD so that trains could pass through with shipping containers stacked two-high came to a halt when CSK Transportation, the railroad that owns the tunnel, said it could not justify its share of the $425 million project, roughly $155 million.

Maryland Gov. Larry Hogan said his administration will continue to work to advance the project, and said "It's a worthwhile project and we'll be pursuing it from every direction."

The Baltimore Sun reported that, while government officials could offer incentives such as shouldering more or all of the cost, analysts said they have little power to force the railroad to expand its century-old tunnel enough to stack shipping containers two-high on its trains — a project long sought for the port of Baltimore.

Hogan and the state's congressional delegation both said they hoped to meet with CSX management to discuss the railroad's reasoning for turning its back on the tunnel expansion.

The project, which would have raised the ceiling and lowered the floor

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California sets aggressive timeline for high-speed rail line from San Jose to Los Angeles

The California High-Speed Rail Authority has set an optimistic timetable for the proposed high-speed rail line from San Jose to Los Angeles, but a 21.7-km (13.5-mile) tunnel that would cut under Pacheco Pass has many questioning if the line can indeed be completed by 2025.

The *Los Angeles Times* did an analysis of the project and found that the timetable and the budget for the project could be hard to meet given the complex geology of the 21.7 km (13.5 mile) passage and other issues that could arise.

Under the rail authority's more recent timeline, the Los Angeles to San Francisco line will start running in 2029, requiring a 2.1-km (1.3-mile) tunnel under the heart of San Francisco and potentially 58 km (36 miles) of tunnels under the Southern California mountains.

The need to build the starter system's 21.7-km (13.5-mile) tunnel was identified earlier this year.

According the report in the *Los Angeles Times*, some of the world's top tunnel experts put the cost of the tunnel at anywhere from $5.6 billion to $14.4 billion, reflecting the high cost of boring through tricky geology and seismically active areas.

The Gilroy-to-Chowchilla route also requires a 2.4 km (1.5-mile) tunnel just east of Gilroy, itself a major infrastructure project.

State officials acknowledge that unless they demonstrate a financially successful starter system, private investors will not commit money to help build the rest of the line to Los Angeles.

At best, the rail authority's existing funds are stretched thin. It has $21 billion to build the starter system.

The funds include $6.8 billion from a 2008 bond, $3.2 billion in federal grants, $5.3 billion from California's greenhouse gas fees through 2024, and $5.2 billion from bonds issued against greenhouse gas fees after 2024.

(Continued on page 9)

Herrenknecht's apprenticeship class of 2017 includes five refugees

In the autumn of 2017, 56 young men and women began their careers with an apprenticeship at Herrenknecht AG. They are training for occupations such as mechatronics engineers, industrial, structural and machining mechanics, electronics engineers, industrial business administrators, specialists for metal technology, technical product designers or IT specialists. Altogether, Herrenknecht AG offers up to 180 apprenticeships and is, thus, at the forefront in the qualified training of urgently needed skilled workers.

More than 100 apprentices have already been in training at Herrenknecht to date. As the new apprenticeship year got under way in early September, they were joined by another 56 young men and women embarking on a dual training system apprenticeship at the Schwanau-Allmannsweier site, most of them in the industrial sector. This is precisely where there is the greatest demand for well-trained and highly qualified specialists. For the first time, Herrenknecht is also giving five refugees the opportunity to join the company and get one of the coveted apprenticeships.

World record-setting machines, imposing factory buildings and a state-of-the-art training workshop – when they first start on their new path the 30-ha (74-acres) company headquarters in Schwanau must be impressive and fascinating to the young people just launching their careers. This is especially so for the five beginners who only left their homelands of Syria, Gambia and Guinea about two years ago. For them, Herrenknecht's training is both a challenge and an opportunity for integration at the same time. At the express wish of the Board of Management, the young refugees came to Schwanau via the municipal employment program, the government employment agency, refugee aid and social workers at the vocational school in Lahr. They are now creating a future for themselves at their new domicile in the Ortenau region. All of them speak a little German already. Additional extra tuition will help them improve their language skills as quickly as possible. Wasef Katmawi, 25, wants to become an IT specialist. In contrast, 19-year-old Mohammed Hoto is training as a specialist in metal technology. In their homelands, the young men often only had incomplete schooling and kept their heads above water with odd jobs. "I am very happy about the training at Herrenknecht and hope to be taken on when I finish, and later work on international projects around the world," said Katmawi.

Herrenknecht makes it as easy as possible for beginners to get started in their careers. After initial practice workpieces they have a state-ofthe-art machine park at their disposal in the training workshop.

Herrenknecht makes the career start as personal as possible for the beginners. "We provide all our apprentices with individual support," emphasized Herrenknecht's head of training, Klaus Himmelsbach. A young team of trainers gives the junior staff practical instruction. In the training workshop a state-of-the-art machine park is at their disposal, with which practical skills and knowledge across all areas of application are taught – from practice workpieces to projects for actual production. With in-house lessons in English, professional and business studies, the apprentices are prepared for everyday working life in an international company. "If necessary, we also offer extra tuition for the challenges at the vocational school," said Himmelsbach. An annual bonus for particularly good performance creates additional incentives.

With the training, Herrenknecht gives the prospective future employees a promising perspective for their professional life. "Young people are our future. We can never do enough with regard to skilled workers, because what use is the highest level of engineering achievement if no one can build and produce it. We are, therefore, committed to supporting anyone who wants to actively work with us to build the best tunnel boring machines in the world," said company founder Dr.-Ing. E.h. Martin Herrenknecht. The dual training system is one of the success factors of the German economy and ensures the supply of new skilled workers it needs.

Herrenknecht is one of the largest trainers in the Ortenau region. In April, the company was named "Germany's best training company in the plant and mechanical engineering sector" by the magazine *Focus Money.* ■

Howard Street Tunnel: Railroad stops project

(Continued from page 4)

of the tunnel, was long considered a mutual goal of the port of Baltimore and CSX. An expanded tunnel would allow for significantly more shipping containers to be moved through the port and along the railroad.

The railroad and the state had agreed to kick in $270 million of the cost, and seek the remaining $155 million from the federal government.

"We had a great plan put together with CSX, the federal government and the state government sharing in the cost of that," Hogan said during a news conference in Annapolis. "It would have a transformative effect on our economy."

The state's congressional delegation sent a letter to CSX Transportation chief executive officer Hunter Harrison requesting a meeting and an explanation for the decision. The bipartisan letter, signed by every member of the delegation, took a frustrated tone with the Jacksonville, FL-based railroad, which pledged support as recently as December for Hogan's plan.

"We seek to understand how a project that has been a top priority for CSX, multiple local, state and federal representatives and the business community for many years — to the exclusion of other local needs and projects — is suddenly no longer of importance to CSX," the delegation wrote in its letter.

The railroad said that the tunnel project "no longer justifies the level of investment required from CSX and our public partners at this time," prompting the state to cancel its federal funding request for it.

The company, which is the successor of the Baltimore & Ohio Railroad, has not explained the reasoning behind its calculation. It attributed the decision to "Precision Scheduled Railroading," the new operating plan Harrison implemented in May, which involves reviewing "use and development of existing and planned infrastructure projects."

Since CSX hired Harrison as chief executive officer in March, the company has slashed its management ranks by 950 people and spent $1.5 billion to buy back shares of its stock. Last week, it announced plans to buy back another $1.5 billion of its stock.

Baltimore is among the only ports on the East Coast that can handle the super-sized ships now transiting the larger Panama Canal carrying Asian-manufactured goods, the congressional delegation noted. Freight volumes are expected to grow significantly in the coming decades, and safety and infrastructure improvements to accommodate that growth are "critical," members wrote. ■

China tests techniques for world's largest tunnel

Chinese engineers are testing techniques to build the longest tunnel in the world to alleviate drought conditions in northwest China.

Quartz India reported that the 1,000-km (621-miles) tunnel would be a water diversion project involving Brahmaputra, one of India's largest rivers, and could become another point of tension between the two Asian neighbors.

The tunnel would divert water from Yarlung Tsangpo River in southern Tibet to Xinjiang, a barren region in northwest China, to the Taklamakan desert in Xinjiang, according to a report in the *South China Morning Post* (SCMP). The Yarlung Tsangpo River turns into the Brahmaputra once it enters India.

"The proposed tunnel, which would drop down from the world's highest plateau in multiple sections connected by waterfalls, would 'turn Xinjiang into California'," the SCMP reported, quoting an anonymous geotechnical engineer. Xinjiang, China's largest administrative division, comprises vast swathes of uninhabitable deserts and dry grasslands.

The feasibility of the proposed Tibet-Xinjiang project is being tested along a 600-km (372-mile) tunnel in China's Yunnan region.

"The water diversion project in central Yunnan is a demonstration project," Zhang Chuanqing, a researcher at the Chinese Academy of Sciences' Institute of Rock and Soil Mechanics, told the *SCMP*. Chuanqing, according to the newspaper, has played a key role in many major Chinese water tunnel projects. "It is to show we have the brains, muscle and tools to build super-long tunnels in hazardous terrains, and the cost does not break the bank," he said.

The Yunnan project comprises over 60 sections, all of which are wide enough to fit in two high-speed trains that will pass through high-altitude mountains. "Fault zones are our biggest headache," Zhang explained. "If we can secure a solution, it will help us get rid of the main engineering obstacles to getting water from Tibet to Xinjiang."

Over the years, China has developed exceptional infrastructure-building capabilities, some of which have been implemented in the Tibet region. "Nobody thought that there could be a railway line in Tibet, but the Chinese government has done so. So, there shouldn't be any doubts about China building the tunnel," Lobsang Yangtso, a research associate at the non-profit coalition, International Tibet Network, told Quartz.

But Yangtso warned that the Tibet Plateau has been witnessing climate change, with water crises in many parts of the Himalayan region.■

Robbins produces 100th continuous conveyor

On Oct. 18, 2017, a Robbins 9.26-m (30.4-ft) diameter crossover machine started up at the Akron Ohio Canal Interceptor Tunnel (OCIT) in Ohio. But the startup wasn't the only milestone. Running behind the crossover tunnel boring machine (TBM) is the 100th Robbins continuous conveyor system supplied for muck removal. The side-mounted conveyor is a design standard, but the landmark is a significant one. "With this system, we have provided more conveyors than any other TBM conveyor supplier," said Dean Workman, Robbins director of conveyors, cutters and SBUs. Counting conveyor systems the company has on order but has not yet delivered, that number is nows well above 100, Workman added.

The Akron OCIT conveyor system consists of the belt plus a main drive, splice stand, storage unit and advancing tailpiece, operating through several curves requiring patented self-adjusting curve idlers that correct themselves based on varying belt tension and belt load. The system discharges onto a customer-supplied overland conveyor, which delivers the muck to a large storage yard near the portal site. The belt was designed to handle variable geology, from soft soils to partial face rock and finally full-face shale rock.

The 100th conveyor system has been refurbished and customized for the job in a process that Robbins has been perfecting for decades. "We design our conveyor systems to last for five to 10 years, but many last for decades longer," Workman said. "We have systems utilizing components that have been in operation for 30 years. We haven't reached a limit for many of our systems — for example we had a specialized conveyor system built more than a decade ago for the Parramatta Rail Link in Sydney, Australia. Those components were refurbished for a job in Atlanta, GA, and now they are being used at the Dig Indy tunnels in Indianapolis, IN. These are long and challenging tunnel drives and the components are up to it." While the Akron OCIT conveyor is just beginning to haul muck, it is sure to be a benefit throughout the project's varying ground conditions.

The conveyor in Akron is also part of a long history for Robbins conveyors — the first of which (not counted in the list of 100) was the first ever continuous conveyor system used behind a TBM. That prototype, developed by founder James S. Robbins in 1963, was successfully used behind the 11.2-m (36.7-ft) diameter main beam TBM at the Mangla Dam project in what was then known as West Pakistan. While conveyors would not be adopted as a standard method of muck removal for many years afterward, the project laid the groundwork for future success. ■

The landmark continuous conveyor system is just the latest in a long history dating back to the first Robbins continuous conveyor used in a TBM tunnel in 1963.

California rail: Final plan to be adopted next year

(Continued on page 6)

Under the current plan, the state wants to begin the 386-km (240-mile) starter system in San Jose and end in an almond orchard south of Wasco. The state estimates the system would begin operating in 2025 and carry about three million passengers a year.

The final environmental plan, which sets the exact route, is supposed to be adopted next year, and only then can the state begin soliciting bids and awarding a construction contract.

The contract process will take at least another year.

Once a contract is issued, the builder will have to order a custom-made tunnel boring machine, which takes about one year to build and set up at the site.

The authority would need at least three years to bore the tunnel, possibly much more, and then three more to outfit it with high-voltage electrical systems, ventilation, signals and track, according to outside experts.

Meeting deadlines will depend on the geology of the route.

The rocks in the Diablo Range were left when the Pacific tectonic plate dove under the North American plate. The tunnel, which in some spots will be 300 m (1,000 ft) below ground, will have to traverse hard sandstone interspersed with weak shale, a geological structure known as the Franciscan Complex.

As the route passes near the massive San Luis Reservoir, the tunnel will cross the Ortigalata fault, which is estimated to have the potential for a magnitude 7.1 earthquake. Tunnels through faults require detailed and costly engineering. ■

Cellular backfill — a review of some of the basics

Raymond Henn and David Crouthamel

Raymond Henn, member UCA of SME, is the owner of RW Henn LLC and **David Crouthamel**, member UCA of SME, is principal, McMillen Jacobs Associates, email rhenn@rwhenn.com or Crouthamel@jacobssf.com.

The need to fill the void space or annulus created between an excavated tunnel or shaft and the final lining system has long been a requirement in underground construction. Most of those types of voids are created as a result of employing the two pass tunneling lining method. Filling of this void is called backfilling. For many years the materials used as backfill were primarily reinforced and non-reinforced concrete, sanded grout, neat cement grout, or blown-in sand/pea gravel. However, in the past 20 years the use of cellular grouts/cellular concrete as the backfill material has greatly increased. Most cellular grout is made of a mixture of water, Portland cement (with or without the addition of fly ash), a foaming agent and admixtures such as a water-reducer or superplasticizer.

It is the authors' preference to use the term cellular grout as opposed to cellular concrete since by ACI Concrete Terminology an ACI Standard (ACI CT 13), concrete contains aggregates. Normally cellular grout does not contain sand (finite aggregate), but almost never contain course aggregates.

The authors believe there are several reasons for this increased use of cellular grout as backfill, such as:

- The increase utilization of the various trenchless tunneling methods. Tunnels constructed using trenchless method tend to be smaller in size, excavated diameter or cross sectional area. Making man-entry for placing backfill from inside the secondary liner, utilizing pre-installed grout posts, more difficult if not impossible. It is these workspace restrictions that are the drivers as to when to utilize grout ports installed during the pipe/liner fabrication versus grout delivery pipes installed within the void/annulus space.
- The ability of cellular backfills to be pumped and flow longer distances.
- The unit weight of cellular grouts can be controlled by mix design and generally can range from 560 Kg/m^3 (35 lbs/CF) to 1040 Kg/m^3 (65 lbs/CF).

Keeping in mind that plain concrete has a unit weight of approximately 2,240 Kg/m^3 (140 lbs/CF). Using cellular grouts with a lower unit weight helps reduce material costs as well as reduce buoyancy (floatation) forces and loads on the final tunnel lining systems. The authors, who specialize in the design and construction of grouting programs used for tunneling and underground construction application, have noticed that within the past several years there have been problems associated with cellular backfill grouting programs in general.

This article will focus on two conditions that the authors believe can have the biggest negative impact on the quality of the in-place backfill and cause the most serious problems. These are flowing and standing water in the void space being backfilled. These conditions need to

FIG. 1

Buckled steel pipe.

Table 1

Recommended cellular backfill performance criteria.

Performance criteria	Range of values	Comment
Strength	1-5+ MPa (145-725 psi)	Dependent on external structural loads
Max heat of hydration	43-72 °C (109-162 °F)	Dependent on structural tolerance
Shrinkage	0.03-0.05% Max	Dependent on structural tolerance
Foamed density	>1040 kg/m^3 (65 PCF) or < 1040 kgm^3	Presence of water or no water

be addressed during design, when writing the specifications and in the field during preplacement/placement of the backfill. Allowing cellular grout and other types of cement based backfills to be placed in flowing water should never be allowed. However, with proper design and preplacement/placement methods, backfilling can be done to displace standing water and minimize damage to the cellular backfill during its placement.

Flowing water can be best controlled by employing techniques such as: installation of panning in combination with dewatering piping and/or a French drain system. Standing water is best handled by first removing the water and then filling in the low spots in the invert with dental concrete prior to installing the carrier pipe or other final lining systems. Allowing backfill to be placed into flowing or standing water can result in having a total absence of, or at the very least, poor quality in-place backfill behind the liner, particularly in the invert and up to the spring line areas of the tunnel. These conditions, if left uncorrected, can lead to carrier pipe failure (buckling) or liner distress which may materialize either during construction or at some point in the future after the project has been put into service. Figure 1 shows a buckled steel pipe due to damaged cellular backfill and inadequate confinement under hydrostatic loads.

Any and all of these conditions can result in a defective final product, time consuming and expensive rework, scheduling delays, disputes and even a catastrophic failure of the liner system.

It is important to understand that backfill grouting and contact grouting are two different processes (methods) performed for different reasons. The textbook AUA Guidelines for Backfilling and Contact Grouting of Tunnels and Shafts (Henn, 2003) offers definitions of these two grouting processes. This article deals only with cellular grout backfills.

Design criteria for cellular backfill

The design criteria of the cellular backfill will vary depending on the design and use of the carrier pipe or other types of final liner. It will also vary based on amount of ground load, external hydrostatic head and ground load sharing with the initial support, such as steel sets and lagging, steel casing, exposed rock, shotcrete, pre-cast concrete segments, etc. The highest risk pipe is large diameter steel pipe with external hydrostatic loads. Large diameter steel pipe becomes more flexible and sufficient restraint behind the pipe and maintaining suitable circularity is more critical. The pipe must be sufficiently restrained uniformly around the pipe.

Backfill with insufficient strength or highly variable strength, such as stratified layering of weak and stronger zones, can lead to the pipe to go out of round or buckle due to inadequate confinement.

Confinement of the pipe is also provided by limiting the amount of gap development behind the pipe. The minimum performance criteria which should be specified for the cellular backfill are presented in Table 1 that is

FIG.2

Stratified cellular backfill of variable strength and density due to the presence and damage of water.

FIG.3

Erection of intermediate bulkheads within the tunnel alignment.

typical for steel pipes. For other pipe materials, such as fiberglass pipe, Reinforced Concrete Cylinder Pipe, and others, the values will vary depending on material selection and project requirements.

In addition to the requirements described in Table 1, corrosion protection of steel pipe in aggressive ground water, including saline or high sulfide conditions by substitution of up to half of the cement with fly ash. The use of fly ash reduces the permeability of the cellular backfill, as well as the rate of development of heat of hydration.

FIG.4

Portal bulkhead.

Effects of water present during placement on cellular backfill

Water can either be flowing or standing or both within the annular space being backfilled. Fresh cellular backfill, as it is introduced into water, can be weakened by dilution as it moves through the water or if flowing water comes into contact with the backfill, the cement can be completely washed out. Dilution can cause the cellular backfill to become stratified in density and strength within the annular space. An example of this is shown in Fig. 2, where the backfill, after removing a damaged steel pipe, is not uniform in density or strength. The variability of strength is typically much less than the target strength requirements.

If the compressive strength requirements are not met, the pipe will not be restrained sufficiently to withstand external hydrostatic pressures without buckling or damage. Likewise, if the cellular backfill strength is too low, long term ground loads may not be reliably carried by the final lining without the lining distorting. The plain steel pipe is not designed to carry hydrostatic or ground loads on its own, the composite effect of sufficient cellular backfill strength and steel pipe are designed to carry these forces. If the pipe is not properly restrained, the pipe can deform, loose circularity and the factor of safety reduced relative to buckling.

The cause of damage during placement of the cellular backfill is due to the presence of water and the travel distance of the cellular backfill through the water. The travel distance can be reduced by creating closed cells or bulkheads along the length of the pipe. Figure 3 shows the erection of an intermediate bulkhead, to create a cell along the length of the tunnel. The use of intermediate bulkheads limits the distance that the backfill has to travel along the length of the tunnel and helps preserve the integrity of the cellular backfills strength. Figure 4 shows a very well designed, constructed, and organized portal bulkhead. In Figure 5 shows bottom in-place half of a tunnel backfill placement after allowing the backfill material to harden. The contractor constructed the bottom "half- bulkhead" utilizing a stay-in-place sandbag/ dry pack type wall. Doing so allowed the workers to observe the backfill placement of the bottom backfill lifts as they were being placed, this helped to ensure complete encapsulation of the carrier pipe.

In Figure 6 a section view of a tunnel shows intermediate and portal bulkheads and the backfill injection piping installed through the bulkhead and in the annulus between the excavated tunnel and the carrier pipe. If flowing water is present, panning should be placed securely on the tunnel wall or segments to shield

the water from the cellular backfill. The panning needs to drain into dewatering piping and or a French drain system. Likewise, if standing water is present, every effort should be made to evacuate the water prior to placing the cellular backfill to limit the exposure to water. Every effort should be made to minimize the exposure of the cellular backfill to standing or flowing water. If standing water is present, the mix design should have a wet density greater than water as indicated in Table 1.

Limiting gap development behind pipe

Another critical component to the performance of the placed cellular backfill is the limitation of a gap immediately behind the wall of the pipe. This assumed gap allows deformation of the steel lining in response to external pressure, forming a lobe whose stability or factor of safety is determined (Fig. 7). Two methods of analysis are Amstutz, (1970) and Jacobsen, (1974) which are based on prevention of single lobe bucking of steel pipes and apply a factor of safety of 1.5 against buckling. Both methods for plain cylinder steel pipes assume a minimum gap exists between the outside surface of the steel lining and the surrounding backfill. The magnitude of this assumed gap accounts for backfill shrinkage and thermal deformations in the steel lining due to heat of hydra-tion. To meet this requirement of minimized gap, thermal rise due to heat of hydration of the cellular backfill and shrinkage must be limited to prevent enlargement of the gap. An excessive gap growth, if not treated, can result in reduced factors of safety against buckling due to external pressures.

FIG.5

Bottom half of backfill placement after backfill material has hardened.

FIG.6

Section view of tunnel.

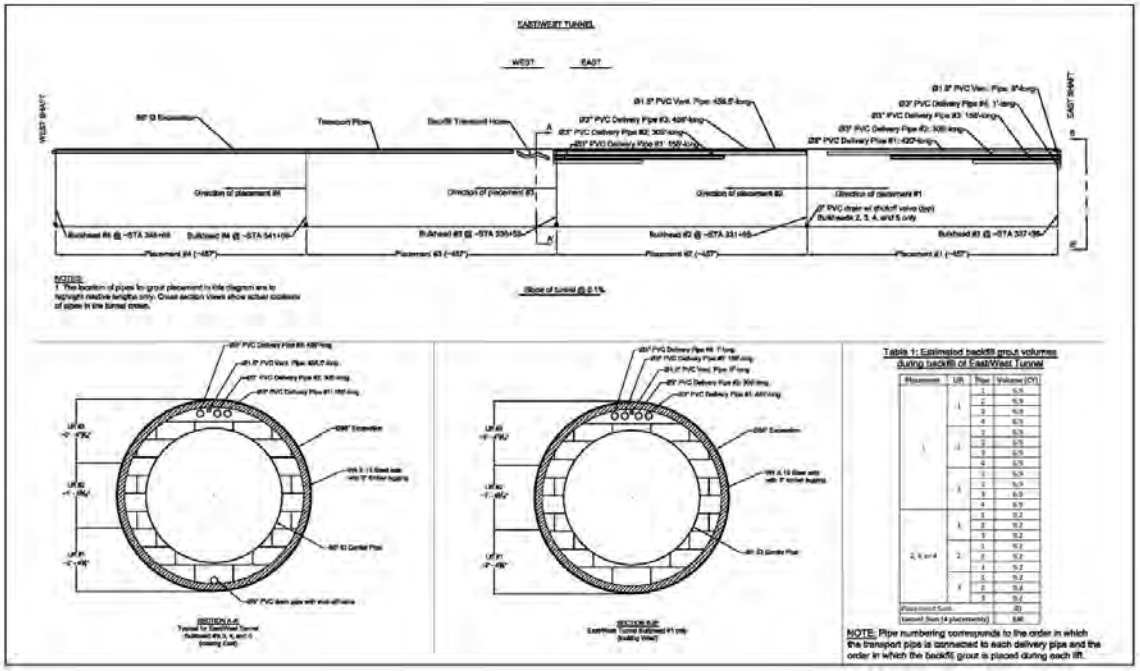
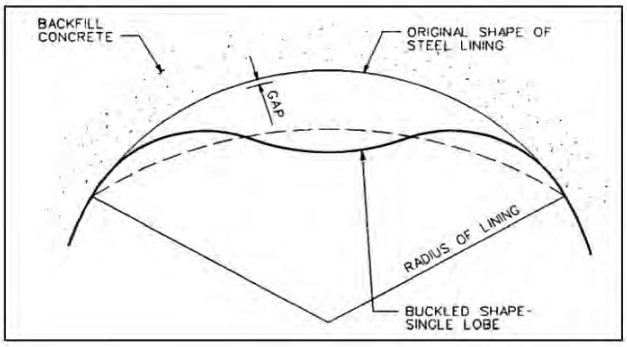


FIG.7

Single lobe buckling principal.



Mitigation of gap development should be based on specifying maximum shrinkage and heat of hydration performance requirements which should be determined based on final lining design. The specification should specify the maximum temperature rise of the placed backfill as a performance requirement. The mix designs should be tested in accordance with ASTM C186, Test Method for Heat of Hydration of Hydraulic Cement.

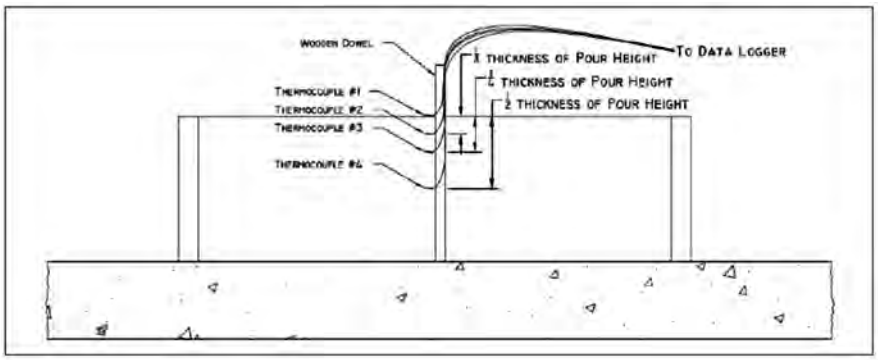
Heat of hydration (HoH) can be limited a number of ways. The most reliable methods is replacing cement content with fly ash in the mix design. Another method is to restrict or limit lift heights during placement. Another procedure, which is less effective, is using chilled water as part of the mix water, or filling the carrier pipe with water.

Testing for heat of hydration should be performed in a fashion which mimics the volume of mass cellular placement in the field. Figure 8 shows a 1 × 1 m (3 ft x 3 ft) square block with a height thickness of 375 mm (15 in.) as an equivalent lift height.

Heat of hydration should be addressed first and foremost in the mix design and lift height. Tests have shown that using a 100 percent cement and water mix designs will result in excessive temperatures. Figure 9 (top) shows a 425 mm (16 in.) lift height test with a mix design using 100 percent cement, 0 percent fly ash in the mix.

FIG.8

Heat of hydration testing arrangement.



The test shows an approximate temperature rise of 99.7° C (211° F). Figure 7 (bottom) shows a 375 mm (15 in.) lift height test with a mix design using 50/50 percent cement and fly ash. The test shows a reduced HoH of 64° C (147° F). peak value which meets a specified target of no more than 72° C (162° F).

While it can be difficult to predict the in situ maximum core temperatures, other factors will have an impact on the placed field HoH temperatures including:

- Use of fans and cooling water on the inside surface of the pipe to keep pipe/ concrete temperatures down.
- Surface temperatures of previous placed lifts.
- The effects of heat sink through either rock or precast concrete tunnel segments.
- Humidity of the curing environment and the amount of water present.
- Location of lift behind the pipe as the highest lift toward the crown produces more heat than the invert lift.

If a large gap behind the steel pipe does form, as evidenced by excessive measured heat rise and sounding of the pipe, skin grouting procedures would have to be conducted. The process of skin grouting requires the drilling and taping of holes through the steel lining, which then have to be sealed. This process should avoided by using all available tools to limit the HoH in the first place and ensure that the gap growth is limited.

Recommendations

Various possible deficiencies have been identified in the placement of cellular backfill for tunnel and shaft and the performance of various lining designs. The design of these linings is based on performance requirements of specified strength and gap limitations. These performance requirements should be highlighted in the design documents along with anticipated methodologies to meet these requirements for the installed backfill product. It is recommended that provisions should be made in the contract documents that the following requirements be made:

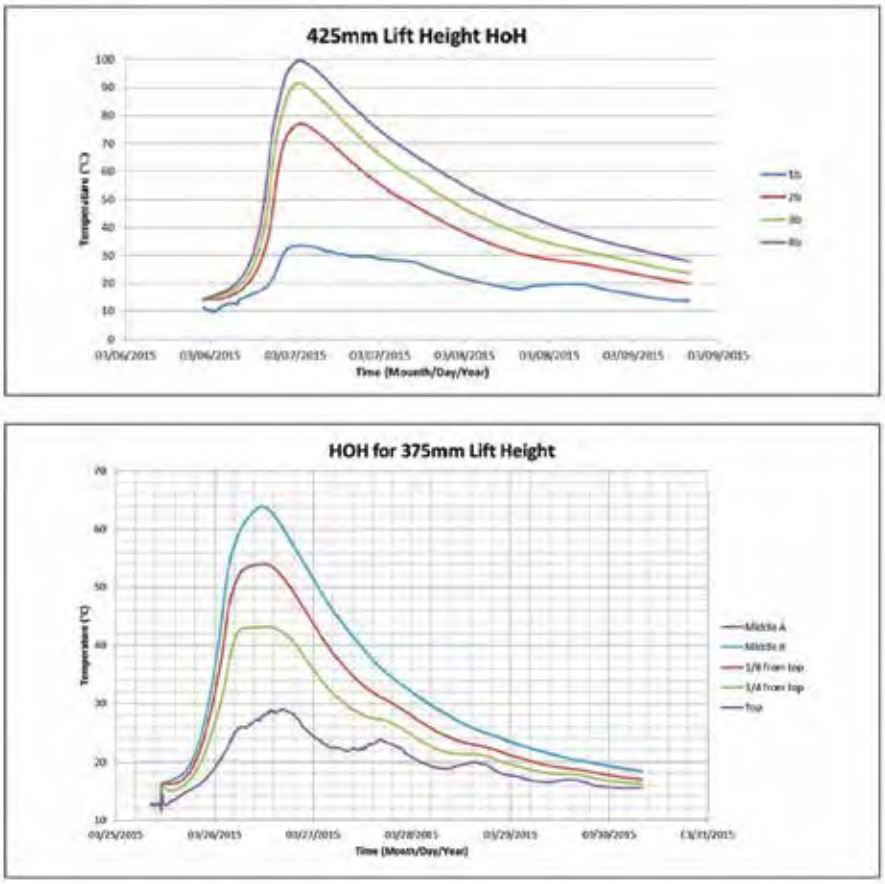
- Placement in flowing water should never be allowed. If flowing water is present some means of controlling it, such as panning, dewatering piping or a French drain system should be used.
- In the case of standing water the low spots in the invert should be filled in with concrete prior to placing the carrier pipe.
- In the presence of standing water, wet density of cellular backfill should be greater than water

throughout the ± tolerance range of its wet density. This will be necessary to displace the water.

- In the presence of standing water, placement cells should be created to limit the longitudinal travel distance of the cellular backfill through water. The spacing of these cells will depend on the ability or inability to remove the water prior to placing a lift and the amount of standing water. Spacing can range from as little as a few hundred feet to three to four thousand feet if the water depth is reduced and the backfill wet density is significantly greater than water.
- Heat of hydration rise should be specified and methods to control it including modified mix designs using upward to 50 percent fly ash and restricting lift heights. Testing procedures which mimic field conditions should be required to ensure that the selected mix designs and installation procedures will reliably meet the temperature restrictions under in situ placement conditions. ■

FIG.9

Comparison of lift height and flyash content.



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FEATURE ARTICLE

A way forward through challenging tunnel boring machine conditions

When boring a tunnel, homogeneous hard rock is the exception rather than the rule. While contractors can set goals such as meters per month and performance incentives, it is also prudent to plan for difficult ground. A properly designed tunnel boring machine (TBM) can tackle fault zones, water inflows, squeezing ground, or whatever the risk may be. The alternative is not a good one: modifying the machine in the tunnel after bad ground is encountered. Not only does this result in increased downtime, but it also needlessly exposes the crew to the tunnel conditions. In the worst case scenario, the entire operation grinds to a halt.

However, an accurate GBR cannot always be obtained, particularly for mountainous, high cover tunnels in remote locations. And even with a thorough GBR, unforeseen geological events can occur. What can be done in these situations? Difficult Ground Solutions (DGS) is ground investigation system with a suite of options that can be added to a shielded hard rock machine or dual-mode, Crossover machine to better enable advance when conditions are unknown or difficult conditions are anticipated.

Difficult Ground Solutions (DGS) enables shielded hard rock machines to get through challenging conditions.

DGS consists of a set of integrated features tailored to a specific project's geology. The main components of the system allow for ground investigation ahead of the TBM, increased monitoring and methods to keep a machine shield from becoming stuck.

In fault zones and squeezing ground

If fault zones or squeezing ground are known or suspected, or if there is even a possibility of encountering them, this can greatly affect the TBM operation. Shielded machines protect the crew from the surrounding rock, and they can bore and line a tunnel efficiently, but in fault zones and converging material their shields can be their downfall. Avoiding a stuck machine is paramount to project success. DGS employs several features to avoid the problem of a machine becoming stuck. The first of these is multi-speed cutterhead drives. These drives effectively give the machine multiple modes of operation—high speed, low torque for hard rock, and low speed, high torque for difficult ground. Designing a machine with high-torque, continuous boring capabilities allows that machine's cutterhead to restart with break-out torque in difficult ground. The net effect is that the machine can keep boring in the event of a face collapse and can bore through fault zones and running ground where the potential for cutterhead jamming exists. Going one step further, multi-speed gearboxes give the machine the ideal earth pressure balance- (EPB-) type torque if larger sections of soft ground are anticipated.

Secondly, TBMs can get through squeezing ground and faults using Continuous Shield Advance. This design utilizes a stepped shield configuration — where each successive shield is slightly smaller in diameter — to avoid becoming stuck in converging ground. External shield lubrication is an added insurance against becoming stuck, using a series of radial ports that can pump Bentonite into the annular space to act as a lubricant in squeezing material.

As a last effort, if a machine has already become stuck the TBM can utilize augmented, or "super" thrust. Additional thrust jacks can be added to supply an extra boost in a short stroke, generating enough force to break loose a trapped shield.

In conditions where large water inflows may occur

Water is an ever-present part of tunneling underground, but unexpected large inflows can damage a machine and grind a TBM operation to a halt. In the event of a large inrush of water, a guillotine gate on the muck chute can

effectively seal off the muck chamber to keep the crew safe as well as keep the machine from becoming flooded out. Additional inflatable seals can seal the gap between the telescopic shield and outer shields of a double shield TBM to keep everything water tight. This system is termed passive water protection because the TBM is stopped in place (not actively operating). During that time the crew can then work to grout off water inflows and dewater the chamber to control the flow before they begin boring again. The grouting crew also have the added assistance of back pressure to assist in grouting.

Improving visualization around the TBM

Probe drilling is an essential part of visualization, and, combined with grouting, it can also fall under the heading of water control. We've learned that, in difficult ground, more is better. Multiple probe drills, and more drill ports in a 360° radius, will typically give an advantage. Shielded machines with DGS features have been designed with this enhanced probe drilling in mind, with ports to provide probing patterns in a 360° radius. High-pressure grout injection can be done through these same ports to stabilize ground up to 40 m (130 ft) ahead of the face (or more if using specialized drills). The type of grout injected can also be specialized — for example chemical or polymer grout can be used to seal off groundwater. Lastly, a rotary forepole drill can be installed behind the cutterhead support to allow for ground consolidation around the shield periphery. The forepole drill is of particular use in fractured rock and fault zones. These drills are the mainframe of a visualization plan that can ultimately create an in-tunnel GBR as the machine advances: of particular use when no accurate GBR can be created due to topography, high cover, etc.

Other visualization tools are available as well. For squeezing ground detection, a hydraulic cylinder can be mounted on top of the shield and connected to the TBM's PLC. It measures the shield gap in the tunnel crown, so that if squeezing or collapsing ground is detected the crew can take countermeasures. These measures include using bentonite lubrication, crown or face rock conditioning, or planning ahead to use another system in the area before the machine can become stuck. For getting a better look at conditions ahead of the machine, a cutterhead inspection camera can be used to remotely inspect the boring cavity without intervention, and to check water levels ahead of the TBM. While these cameras have been used to monitor mixing chambers and perform cutterhead inspections in soft ground TBMs, their use in hard rock machines has been much more limited. In the new ground investigation system, the probe and injection holes in the cutterhead and front shield are specifically designed to accept these cameras.

Conclusions

The old adage the best-laid plans can go astray applies particularly well to tunneling. There are many unknowns, even with an adequate GBR in hand. Making an initial investment on DGS features when a TBM is still in the shop is far less costly than installing them in the tunnel after a major stoppage. These features can mean the difference between a successful operation and a stuck TBM requiring a bypass tunnel or worse. TBMs with DGS features also produce better advance rates in adverse conditions such as fault zones — recent examples of this include Turkey's Kargi Hydroelectric Project and Mexico's Túnel Emisor Poniente (TEP) II tunnel).

In general, contractors and owners must strive to provide geological reports that are as accurate as feasible so that TBM designers can built appropriate TBMs. In-tunnel excavation continues this geological exploration. Owners and contractors should give full consideration to building in ground investigation and treatment features when difficult conditions are a possibility. With these features, it is possible for a shielded machine to keep advancing, whether the concern is high cover mountainous tunneling with squeezing and rock bursting, water inflows, fault zones, or all of the above. ■

The Robbins Crossover machine for Túnel Emisor Poniente II is equipped with drills including a probe drill and forepole drill for ground consolidation.

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Cutting Edge conference turns a focus to advances in technology

On April 4, 2017, the largest earth-pressure-balance tunnel boring machine (TBM) ever built finally completed its 2.7-km (1.7-mile) journey beneath Seattle, WA, nearly four years after it began boring the SR-99 tunnel that will eventually replace Seattle's Alaskan Way Viaduct.

By now, readers of this publication are familiar with the ordeal that began on Dec. 6, 2016, when the machine overheated and shut down. Until that point, the TBM, named Bertha, had grabbed headlines for being the largest in the world with a 17-m (57.6-ft) diameter face. But after the incident that stopped the progress, the headlines suddenly stopped focusing on the engineering marvel of the tunnel project and began asking what went wrong. Just 300 m (1,000 ft) into the tunneling journey the machine was stuck, unable to move forward and impossible to retract.

The project's contractors, Seattle Tunnel Partners,(STP JV) – a design-build consortium comprised of Dragados - USA, Tutor Perini, say a 20-cm (8-in.) steel well-casing buried in the path of the machine caused the problems that halted the TBM. The Washington State Department of Transportation (WSDOT) disagrees, and the issue over who ultimately pays for the repairs is now with the courts.

Eventually, engineers determined the best way to get Bertha back to work was to dig a 36-m (120-ft), deep concrete lined shaft pit in front of the machine and lift the 1.8-kt (2,000-st) cutterhead out for repairs. The repairs took two years but eventually the machine resumed mining in January 2016. In April 2017, the TBM finished building the tunnel, breaking through at the tunnel's north end near Seattle's Space Needle, with little to no ground surface movement measured on the entire alignment.

While the cause of the TBM breakdown and who should pay for repairs was debated above ground, the work below ground continued. David Sowers, deputy program administrator, engineering and program management with WSDOT, told *Mining Engineering* during the 2017 Cutting Edge Conference in Seattle that in addition to the technical marvel that the tunnel became, the fact the parties involved were able to work through the unprecedented challenge is a great example of how to overcome challenges on massive projects.

William Gleason, Senior Editor

"There was a lot of work involved in building the shaft to repair the machine and it kind of took our focus away from what went wrong and the second-guessing and got us focused on fixing the machine," said Sowers. "We still had a big job to do and it got everyone galvanized around the common goal to finish the project and that continued after we completed the rescue shaft. We finished the project, we went under the viaduct and the city in a very successful way. Everyone got behind it and it was impressive. Of course, everyone is satisfied now that it

As of November, the upper deck of the SR-99 tunnel that will carry traffic southbound was nearly completed. The tunnel is expected to open to traffic in 2019. Photo by William Gleason.

After a two-year delay, the boring of the SR-99 tunnel was completed in April. The 17-m (57-m) diameter tunnel in the largest diameter tunnel in the world. Photo courtesy of WSDOT.

is completed but there were times that we wondered if we would complete the project. Hats off to everyone the contractors, the state, consultants, everyone involved."

With the tunnel bored, crews are now working to complete the double deck highway inside the 16-m (52.5-ft) diameter tube, complete with lighting, ventilation and fire detection systems.

The upper deck of the double deck tunnel, which was cast in place, was nearly completed as of November. The lower deck, which will carry traffic northbound, is made up of 1,152 precast panels that are being trucked into the tunnel and assembled. The lower deck is expected to be completed in March 2018.

Greg Hauser with Dragados USA told the 240 attendees of the Cutting Edge Conference that the northbound lower walls started late 2014 and finished Nov. 6 2017. The southbound deck, upper deck started in 2015 and should be done December 2017. Upper walls started in Feburary 2017 and are scheduled to finish in 2018 and lower northbound precast started Nov. 6, 2017.

As for all the operational and safety systems inside the tunnel, WSDOT says inspectors will test more than 7,600 components and 50 different systems over the next two years. STP's schedule shows substantial completion of the tunnel in late October 2018.

When the tunnel is substantially complete, WSDOT will then begin work to realign the existing highway to the tunnel. The new tunnel is expected to be open to traffic by early 2019.

On Nov. 13, about 100 attendees of the Cutting Edge Conference in Seattle, WA were given a tour of the project by Seattle Tunnel Partners and WSDOT prior to the conference and a good portion of the conference was dedicated to the project.

In a presentation that was part of a session titled Advancements & Success - The Alaskan Way Viaduct Replacement Project, Sowers spoke about the challenges of coordinating the project. He noted that the tunnel passed beneath a densely populated part of the city with about 160 property owners above the tunnel path.

"We had to speak to all of these people," he said. "We had to purchase the rights to the property directly underneath. And we had to come up with a way to value those pieces of property for loss of potential development."

To earn the trust of the property owners, Sowers said they were all invited to a meeting and were told that if there were any property damage due to tunneling, WSDOT would take full responsibility.

Bob Donegan, president of Ivar's, a seafood restaurant group with dozens of locations around Seattle, since 1938, also spoke about stakeholder engagement during the keynote session. He was active in many municipal matters including the Alaskan Way Viaduct and Seawall Replacement Project Stakeholders Committee, the City's Seawall Committee, and the committees to design and manage the new Waterfront Park when the project is completed and Colman Dock's

Crews were working on the lower deck of the SR-99 tunnel that will carry traffic northbound through the tunnel. Photo by William Gleason.

Citizen's Advisory Committee as well many other community committees.

Among the efforts, Donegan said it was important to educate elected officials about the project.

"We made sure we educated them early and that there were no surprises," Donegan said. "Opposition for the tunnel came from some commuters, the community of Magnolia and PWC – they were loud and vocal. We started to build a coalition of 300 different organizations to build a fence around the opponents of the project and then asked them what their problem was and how we could address it."

Cutting Edge

The Cutting Edge Conference is an annual affair hosted by the UCA of SME and *Tunneling Journal*. This year, organizers chose Seattle, not just for the SR-99 project, but for the many projects taking place along the West Coast, including the multi-billion Sound Transit light rail program that is making the Seattle area and the West Coast a hotbed of activity for the tunneling industry.

In the opening session, Joe Gildner, executive project director, Sound Transit, spoke about the $54-billion Sound Transit 3 (ST3) system plan that will expand the region's light rail system from more than 32 km (20 miles) to more than 80 km (50 miles) as part of the 25-year, $53.8 billion project that will include a new 5.3-km (3.3-mile) bored tunnel in downtown Seattle.

"In the years ahead, we will be more than doubling our service," said Gildner.

While there was a lot of discussion about the projects that are reshaping cities along the west coast the theme of the conference was Advances in Tunneling Technology and the program continued its six-year tradition of in-depth technical sessions over two days.

Within the theme of advances in technology was the Innovations in Underground Digital Technology session that focused on the rapidly growing fields of building information modeling (BIM), data management and analysis and digital technology. The session included talks that looked how BIM and 3D technology is being used on the Arenastaden, Stockholm project in Sweden and what the future of BIM might be.

The conference also had a session on advances in tunnel linings and technology and one that focused on tunneling technology and safety.

Among the talks was one that focused on the unique challenges of mining under the Chesapeake Bay, and another about the advances in high-pressure compressed air working conditions.

There were also panel discussions that focused on using technology to reach the goal of zero settlement, and another on approaches to risk management.

During the panel discussion on risk management, Bill Edgerton, McMillen Jacobs Associates; Joe Gildner, Sound Transit; Patricia Galloway, Pegasus Global Holdings; Chris Herbert, Traylor Brothers and Rob Labbe, Zurich NA discussed common risk management issues and development approaches.

The discussion about zero settlement featured Mike DiPonio, Jay Dee Construction; Glen Frank, EPC Consultants; David Girard, J.F. Shea; Daniele Nebbia, Salini Impregilo; Cody Painter, WSP and Jack Nakagawa, McMillen Jacobs Associates discussing issues such as TBM overcut, avoiding sinkholes or settlement events and soil conditioning.

The conference concluded with a presentation about the proposed multi-billion California WaterFix project. John Bednarski said the project would include 96 km (60 miles) of tunnel to transport water from Northern California to the south.

Bill Hansmire gave the final presentation, a West Coast Project update in which he looked at current and potential future projects in California, Washington and Oregon.

The Cutting Edge Conference has established a tradition of moving to locations where there is vibrant and important tunnel projects in the works. Look for more information about the 2018 conference in the coming months. ■

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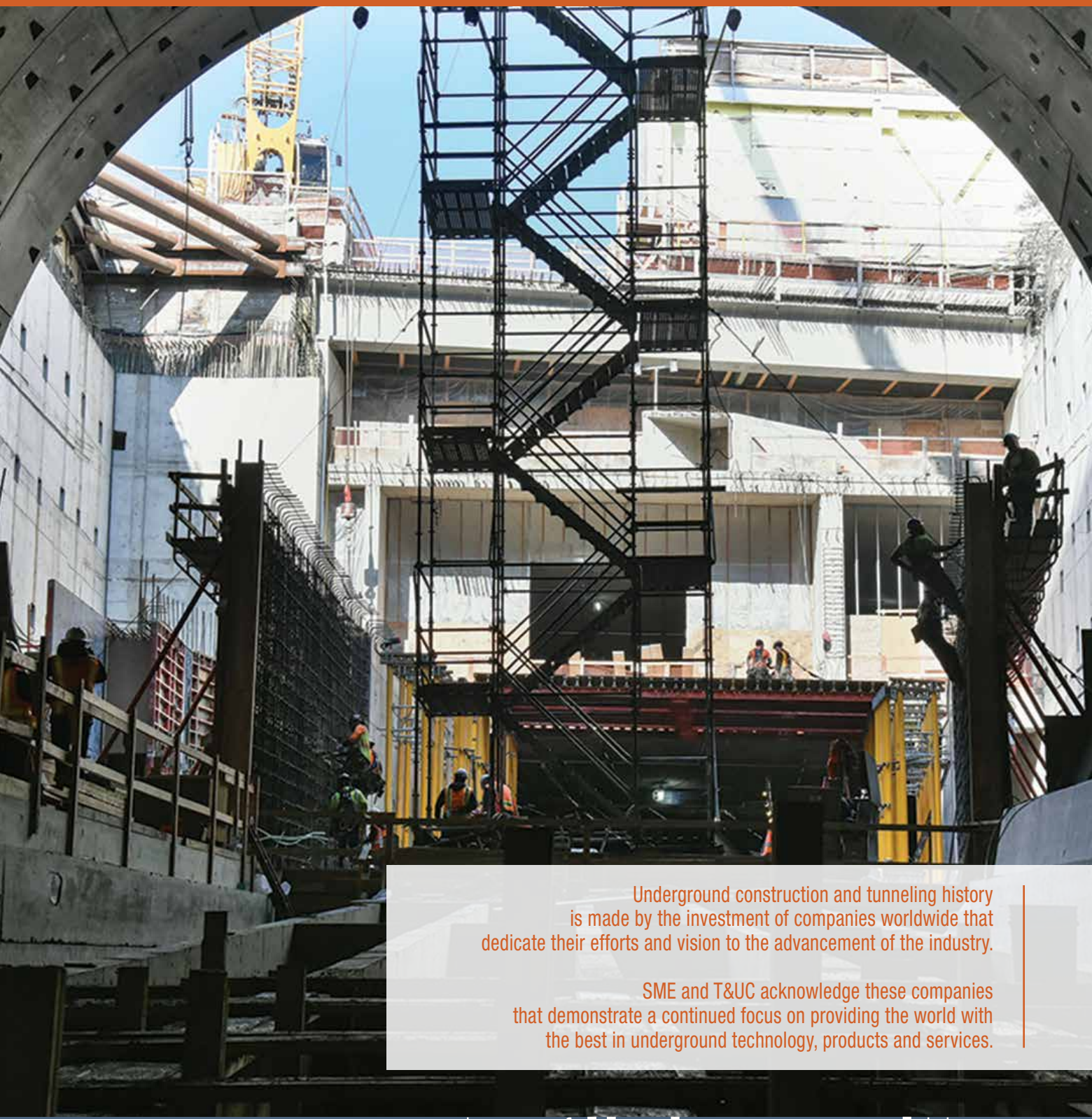

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For more information, visit us at: **www.frontierkemper.com**

T&UC

HNTB: Innovative tunnel solutions

With growth in the urban core and increased demand for more efficient transportation, reliable power, water and wastewater conveyance, and communication systems, many cities are opting to add infrastructure underground. Modern technology makes that solution possible and preferable. Impressive, sophisticated underground structures can help solve current and future urban congestion and development challenges.

HNTB Corporation has more than 50 years of experience in the design, construction and restoration of tunnels and underground structures in various grounds in the highway, transit, rail, aviation and water resources markets. Our experts have the insight and knowledge to provide innovative solutions on a wide range of tunnels, including cut-and-cover, tunnel boring machine (TBM) tunnels, conventional tunneling, NATM, immersed tube tunnels, shaft construction and micro-tunneling. Our long history in planning, program management, design, construction management and technical services for tunnel structures includes award-winning projects on some of the country's most complex tunneling projects.

HNTB provides full service in tunneling and underground engineering including:

- Program and construction management
- Design of soft ground tunnels, rock tunnels, caverns, shafts, New Austrian Tunneling Method, cut-and-cover structures, immersed tunnels, micro-tunneling and pipe jacking
- Condition survey and rehabilitation
- Geotechnical and engineering geology
- Excavation support, protection of existing facilities, and underpinning
- Settlement analysis and mitigation
- Seismic design and retrofit
- Geotechnical and structural instrumentation
- Ground improvements and groundwater control
- Tunnel ventilation and fire-life safety design
- Tunnel security and hardening

Among its recent notable projects are:

- Istanbul Strait Road Crossing in Turkey (2016 ENR Best Global Projects, Bridge/Tunnel)
- Midtown Tunnel in Norfolk, Virginia
- Amtrak's B&P Tunnel in Baltimore
- Crenshaw-LAX subway line in Los Angeles
- The Alaskan Way SR99 Tunnel in Seattle
- Tom Lantos Tunnels at Devil's Slide in California
- Structural assessment and rehabilitation of several subway tunnels and stations in New York in the aftermath of Super Storm Sandy

HNTB
www.hntb.com

WORLD CLASS **TUNNELING EXPERIENCE**

TOP CLOCKWISE: Istanbul Strait Road Tunnel Crossing *Istanbul, Turkey* | Elizabeth River Tunnels *Norfolk, Virginia*
Tom Lantos' Tunnels *California* | Alaskan Way Tunnel *Seattle, Washington*

Sanja Zlatanic
National Tunnel Practice Leader
Chief Tunnel Engineer
szlatanic@hntb.com
(212) 294-7567

HNTB

The HNTB Companies
Infrastructure Solutions

hntb.com

Moretrench

The challenges inherent in tunneling operations are well known. What is perhaps not so well known is that only one geotechnical contracting company has the in-house range of ground improvement tools to resolve even the most complex subsurface conditions. That company is Moretrench. Whether the issues are known in advance or occur unexpectedly, call Moretrench because when it comes to the complexities of underground construction, no one has seen more.

Delivering liquid nitrogen to the Port Mann off-shore working platform.

Port Mann Water Main: Ground Freezing
Mining of the new, 3,280-ft long Port Mann Water Main was well underway deep below the Fraser River in Vancouver, British Columbia, when an unanticipated mechanical failure occurred in the cutter head, halting mining operations. When initial more conventional approaches to allow access for repair were ruled out, the tunneling contractor contacted Moretrench. Moretrench developed a liquid nitrogen ground freezing solution that would not only allow safe access for inspection and repair but could also be implemented quickly. The remote TBM location, 160 ft below river mud line and 650 feet from the exit shaft, meant that all equipment and materials, including liquid nitrogen storage tanks, had to be ferried to the pile-supported work platform. Pinpoint drilling for freeze pipe installation was critical to ensure freeze build up exactly as designed. After just 12 days of freezing, the freeze was sufficiently formed to allow safe entry into the cutter head for repairs to begin.

High mobility grouting of karstic rock enabled dry excavation of the OARS CSO shafts.

OARS Relief Sewer Phase 2 Shafts: High Mobility Grouting
Drill and blast installation of three deep shafts through highly variable karstic conditions was the challenge facing the design and construction teams for Phase 2 of the CSO project in Columbus, OH. The shafts extended through shale underlain by three distinct strata of karstic limestone. With the water table 20 ft below the surface, and the high hydraulic conductivity of the rock evident from pumping tests, it was estimated that inflows of thousands of gallons per minute could be anticipated during shaft excavation under hydrostatic head of up to 150 ft. Pre-grouting was therefore required. A Moretrench-designed alternate to the original in-shaft staged grouting plan allowed all grouting to be accomplished around the shaft perimeter from the surface. A suite of four, balanced-stable grouts developed by Moretrench catered to the highly variable subsurface conditions. With grouting complete, excavation proceeded with only minimal shaft inflow.

Jet grout cut-off for installation of the Mulry Square vent plant.

Mulry Square Vent Plant: Jet Grouting:
The Mulry Square emergency vent plant is designed to serve a portion of both the 8th and 7th Avenue subway lines in Manhattan, New York. With offsite groundwater drawdown during construction prohibited, a perimeter cut-off was required. This was designed as secant pile walls, with jet grouting specified for closure where the vent plant penetrated the wall of the subway tunnel. Groundwater modeling by Moretrench demonstrated that the jet grouting would need to extend only to a minimum depth of 53 ft to achieve cut-off, rather than the 100 ft originally anticipated, reducing the quantity of secant piling and jet grouting required. Subsequent groundwater monitoring during excavation to full depth within the secant pile/jet grout cut-off structure confirmed the accuracy of the groundwater modelling and offsite drawdown did not exceed the specified limits.

For more on these and other tunneling projects, visit us at:
www.moretrench.com.


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Deep Foundations
Grouting
Ground Freezing

ANTRAQUIP CORPORATION – your reliable, innovative partner

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

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

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

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

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

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

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

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

AQ6 Hydraulic Cutting Attachment

AQC180 on CAT336

Antraquip AQM175 Roadheader

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ANTRAQUIP® CORP

Kiewit

As a construction, mining and engineering leader, Kiewit is a FORTUNE 500 company with 2015 revenues of $9 billion. Kiewit, through its operating companies, brings a wealth of diverse resources and a track record for delivering the highest quality results — on budget and on schedule. Kiewit's size and experience provides the stability, predictability and know-how our clients and partners expect — and the flexibility and overall best value they deserve.

Kiewit has been constructing underground facilities for over 50 years, offering some of the most highly skilled and experienced teams in the industry. We have completed more than 100 underground related projects totaling more than $1 billion. Our tunneling portfolio includes projects related to transportation, water / wastewater facilities, power, mining, and telecommunications. In addition, Kiewit has the resources to construct cut-off walls, structural slurry walls, drilled shafts and ground improvement. We perform these operations with our fleet of specialty equipment and the management resources of one of the top builders in North America. Through the use of cutting-edge technology, industry-leading safety performance and a wide range of capabilities, we offer our clients an innovative, one-stop shop for all their tunneling needs.

Our projects range from fast-track mining jobs to a $1 billion undersea rail tunnel. No project is too large or small when it comes to meeting our clients' needs. Our clients in these markets have come to expect the industry's safest work environments, the highest-quality delivery and superior compliance with requirements of all types. Behind it all are the core values that have shaped how we manage our business — for our clients and other key constituents.

Kiewit Infrastructure Co.
302 South 36th St., Suite 400
Omaha, NE 68131
402-346-8535

Kiewit

KIEWIT FOUNDATIONS GROUP

Keeping safety in the forefront, Kiewit Foundations Group performs complex geotechnical projects across North America. We deliver innovative and cost-effective solutions tailored to the specific needs of each project. Our range of services include:

- Diaphragm Walls
- Slurry Cutoff Walls
- Ground Improvements
- Drilled Shafts

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KIEWIT.COM

Putzmeister Shotcrete Technology, Your Worldwide Partner for Quality and Innovation

Putzmeister Shotcrete Technology provides you with one source for the world's most complete offering of solutions and equipment for sprayed concrete.

Since purchasing Allentown Equipment with its more than 100 years of shotcrete expertise, and combining it with Putzmeister's innovative concrete technologies and experience, Putzmeister Shotcrete Technology can provide world-class support for contractors' needs in the Refractory, Underground, Mortar and Civil industries.

In the early 1900s, Allentown's pioneering technology was first developed for taxidermy purposes when its originator Carl Akeley, a famous hunter and professor, devised a method for spraying plaster onto a wire frame. The outcome was a strong, thick plaster coating that didn't slump from the frame or set before being fully placed.

Forty years later, a new process was developed involving the use of pressure tanks to force stiff mortar through a hose. This new wet-process became known as shotcrete - and the rest is history.

"In this day and age, very few companies are able to succeed in business for over 100 years," says Patrick Bridger, president of Putzmeister Shotcrete Technology. "We are very proud of our longevity, and see it as a

Mixkret 4 - Low Profile Concrete Mixer

testament to our reputation for quality, and the value we have brought our customers for more than a century."

Since the 1950s, the Allentown name has been synonymous with the process of spraying mortar at high velocity onto surfaces in the refractory, underground, mortar and civil industries. The equipment line has expanded to include a wide range of Gunning Machines, Pre-dampeners, Dosing Pumps, Pumps, Combination Mixer-Pumps, Mixers, Chemical Additive Pumps, Nozzle Carriers, Mortar Machines, Concreting Machines and parts and accessories.

Throughout the years, numerous milestones have been achieved:

- 1900s - Carl Akeley develops method for spraying plaster onto wire frames.
- 1910 - First Cement Gun introduced at New York Concrete Show.
- 1911 - Patents and trademarks issued for the Cement Gun and its Gunite process.
- 1950s - Wet-process shotcrete application developed.

SPM 307 Nozzle Carrier

- 1960s - Dry-process rotary gun developed.
- 1970s - Swing-tube technology used on wet-process shotcrete equipment, making application and use more practical.
- 2007 - Company acquired by Putzmeister America, Inc., resulting in most comprehensive line of sprayed concrete equipment. Name changed from Allentown Equipment to Allentown Shotcrete Technology, Inc.
- 2008 - Allentown becomes exclusive United States distributor of the Sika/Aliva family of wet- and dry-process shotcrete equipment.
- 2009 - Putzmeister America's Special Application Business forms partnership between Allentown, Esser Pipe Technology and Maxon Industries, Inc., creating a comprehensive systems approach for tunnel and mining, dam and power generation, transportation, marine and off shore projects. MacLean Engineering, in partnership with Allentown, develops new self-contained shotcrete spraying machine.
- 2010 - Allentown Celebrates 100th Anniversary.
- 2012 - Allentown Shotcrete Technology, Inc. is re-branded Putzmeister Shotcrete Technology.

With Putzmeister's reputation for excellence and expertise built on our commitment to application-oriented engineering and customer service – put the strength of Putzmeister to work for you. Contact us at (800) 553-3414 or visit PutzmeisterShotcrete.com.

Putzmeister SHOTCRETE TECHNOLOGY

Putzmeister Shotcrete Technology
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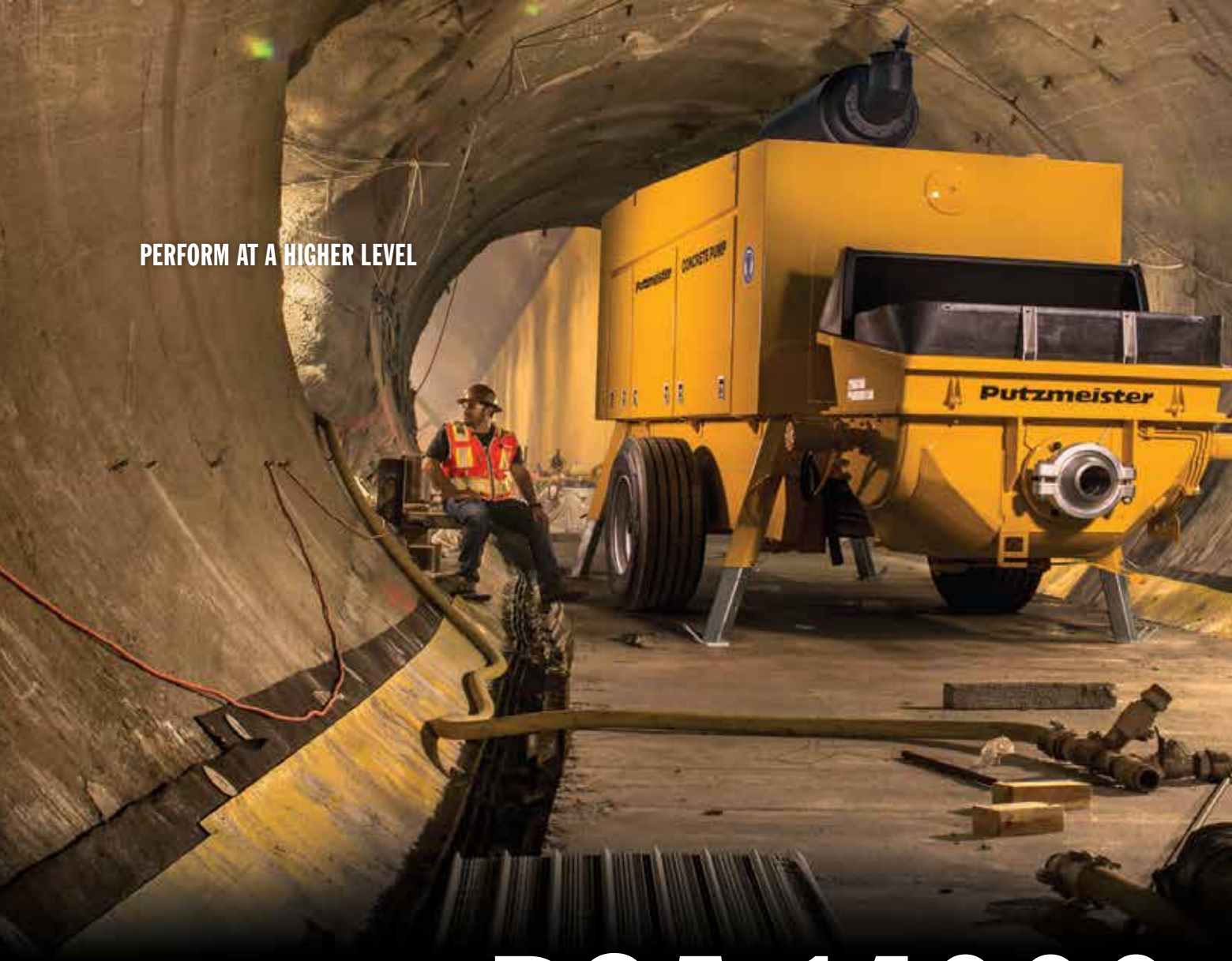

BSA 14000

Putzmeister

Trailer-Mounted Concrete Pump

The Putzmeister BSA 14000 Trailer-Mounted Concrete Pump delivers superb, powerful performance over a long lifespan, making quick work of tough mixes in long-distance concrete applications. It provides smooth and reliable pumping, superior durability, unbeatable flexibility and exceptional convenience to meet the needs of even your most demanding job. Only Putzmeister has the technology to combine high output and high pressure in one state-of-the-art unit.

At Putzmeister, exceeding your expectations isn't a goal – it's mandatory.

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Derrick Equipment Company

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

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

SERVING THE DRILLING AND TUNNELING INDUSTRIES

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

Throughout this time, Derrick has remained dedicated to complete in-house manufacturing of every machine, screen panel, and tank system. Each unit is created and assembled at Derrick's Buffalo, New York headquarters facility.

EQUIPMENT MAKES THE DIFFERENCE

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

- 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

CIVIL CONSTRUCTION

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

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

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Leading-Edge Solutions

Since 1988, Derrick has manufactured innovative technologies for the Civil Construction industry. Derrick's separation technology offers unmatched solids removal performance. Using this equipment and innovative screen technology, customers continuously recycle and re-use drilling fluid, while also controlling drilled solids and impact on the environment. Our civil construction solutions are currently used worldwide by companies that require high-efficiency separation and slurry dewatering in environmentally sensitive and urban environments.

Reducing:

- **Disposal Costs**
- **Chemical and Dilution Costs**
- **Total Operating Costs**
- **Environmental Impact**

Increasing:

- **ROP (Rate of Penetration)**
- **Fluid and Solids Handling Capacity**
- **Project Profits**

North America's Leader in Geotechnical Construction

Hayward Baker handles geotechnical challenges both large and small. Our extensive experience with the full range of ground modification techniques has been applied to hundreds of tunneling projects. Commonly applied tunneling services include earth retention, underpinning, waterproofing, soil improvement, and ground stabilization.

Seattle, WA
Brightwater Conveyance System

Construction of the Brightwater Conveyance System required surgical jet grouting to facilitate tunneling operations. Utilizing their proprietary jet grouting equipment, Hayward Baker created soilcrete blocks outside of four deep vertical shafts to assist with both TBM and hand-mined tunneling operations. The ground improvements allowed TBMs to be launched or received into and out of the shafts without the risk of water and ground run-in. Overlapping columns to depths of 94 feet compose the soilcrete blocks.

Brightwater Conveyance System

Los Angeles, CA
Lower North Outfall Sewer Rehabilitation Project

Rehabilitation of the 82-year-old Lower North Outfall Sewer included grouting around the outside of the tunnel to densify and strengthen the soil above the tunnel in order to protect the overlying structures from settlement. Hayward Baker performed permeation and fracture grouting through over 3,500 holes from within the tunnel, stabilizing the overlying structures. State-of-the-art survey technology and proprietary grouting instrumentation allowed Hayward Baker to first probe the soil to determine existing conditions, and then observe the soil response during grouting, while monitoring the ground surface in real time.

Los Angeles, CA
Metro Gold Line C800

Construction of twin subway tunnels for the LA Metro's Gold Line would cause ground loss, endangering overlying structures unless the soils surrounding the tunneling zone were treated prior to excavation. Using conventional horizontal drilling to install steel and PVC sleeve port grout pipes, Hayward Baker performed chemical grouting to stabilize soils, and fracture grouting to protect overlying structures. Heave and settlements were monitored by exterior remote robotic total stations and interior wireless tiltmeters.

St. Louis, MO
Baumgartner Tunnel Alignment

Water-bearing rock formations in the path of the Baumgartner Tunnel Alignment needed to be sealed. Unsafe levels of hydrogen sulfide forced the grouting to be performed from the surface in advance of the tunneling operation. Hayward Baker drilled and grouted the water-bearing rock formations along a 1,200-foot-long segment of the proposed 20,000-foot-long, 12-foot-diameter combined sewer tunnel. A total of 40,000 feet of grout holes was drilled to complete the project. Depths of the drill holes were approximately 170 feet from ground surface.

Big Bend Tunnel Improvement
Big Bend, WV

Big Bend rail tunnel, constructed in 1932, required extensive ground and wall improvements over a 1,200 foot stretch due to its age and frequent use. Hayward Baker stabilized the tunnel walls with cement-bentonite structural grout, several rows of rock bolts and dowels, and compaction grout underpinning. Epoxy and cement grouting were utilized to repair an existing fracture of the tunnel liner along the spring line. Hayward Baker also stabilized the invert with compaction grouting at approximately 4,000 locations.

Big Bend Tunnel Improvement

Hayward Baker
Geotechnical Construction
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Fax: +1-410-799-3786
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Herrenknecht Tunnelling Systems

Herrenknecht is a technology and market leader in the area of mechanized tunnelling systems. As the only company worldwide, Herrenknecht delivers cutting-edge tunnel boring machines for all ground conditions and in all diameters – ranging from 0.10 to 19 meters. The Herrenknecht product range includes tailor-made machines for transport tunnels and supply and disposal tunnels. Under the umbrella of the Herrenknecht Group, a team of innovative specialists has formed to provide integrated solutions around tunnel construction with project-specific equipment and service packages upon request: these include separation plants, conveyor belt systems, navigation systems, rolling stock systems and segment moulds right up to turnkey lining segment production plants. The range of products also includes services in the area of technical consultancy, planning and supervision for tunnelling projects as well as personnel solutions to complement construction site crews on a temporary basis.

Traffic Tunnelling for efficient traffic arteries.

By the middle of this century, the world's population is expected to have reached nine billion. To keep people and goods on the move, the way for new efficient infrastructures is leading underground. With state-of-the-art technologies, even in cramped and complex jobsite conditions efficient infrastructures are created exactly where they are needed.

For the construction and expansion of urban metro systems Herrenknecht TBMs have built new tunnels in more than 700 projects. German high-tech machines from Herrenknecht are creating underground arteries for the American cities, just like in Los Angeles. Tunnel boring machine »Harriet« successfully completed her drive in for the Crenshaw/LAX Transit Project in April 2017. »Angeli« just finished digging the first of two tunnels for the Regional Connector Transit Corridor in July. From spring 2018 onward, for each of the "Purple Line Extension Sections 1 + 2", two more Herrenknecht TBMs will be working their way through the difficult ground.

Worldwide, construction companies have built a total of more than 2,800 kilometers of new tunnels in the diameter range > 4.80 m with Herrenknecht technology. In 2016 alone Herrenknecht supplied around 60 large tunnel boring machines.

Utility Tunnelling for underground supply and disposal systems

As the world's population grows the need for underground supply tunnels is also increasing. 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, Internet and telephone lines. Here, trenchless tunnelling technology offers a range of advantages compared to conventional construction procedures: transport, business and environment remain mostly undisturbed when Micromachines, HDD rigs or shaft sinking equipment are being used.

Herrenknecht international.

In the year 2016, the Herrenknecht Group achieved a total output of 1,208 million euros. The independent family-run business employs around 5,000 members of staff worldwide including up to 180 trainees. With 76 subsidiaries and associated companies, like Herrenknecht Tunnelling Systems founded in 1998 in Washington, Herrenknecht is able to provide a comprehensive range of services close to American project sites and customers, quickly and in a targeted way.

www.herrenknecht.com

River crossing realized with the Herrenknecht Direct Pipe technology

Two Herrenknecht Machines for the LA Metro during workshop acceptance in Germany

TBM for the Anacostia River Tunnel as part of the DC Clean Rivers Project

The Robbins Company

Your Partner in Tunneling

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

The Crossover Solution

Have a challenging project? Robbins offers the ideal machine for mixed ground conditions that might otherwise require multiple tunneling machines. Robbins supplies three types of Crossover machines: the XRE (Crossover between Rock/EPB), the XSE (Crossover between Slurry/EPB), and the XRS (Crossover between Rock/Slurry). Today's tunnel boring machines must adapt to shifting conditions, and Robbins Crossover TBMs do just that by combining the most powerful features from different machines.

An 8.7 meter (28.5 ft) diameter Robbins Crossover (XRE) TBM, made its final breakthrough in June 2017 and set multiple national records while boring Mexico City's Túnel Emisor Poniente (TEP) II Project. The TBM navigated fault zones, variable ground, low cover, and more to achieve a national record of 57 m (187 ft) in one day as well as maximum rates of 231 m (758 ft) in one week and 702 m (2,303 ft) in one month. The 5.8-kilometer (3.6 mi) tunnel will supplement an existing and overtaxed wastewater line built in the 1970s. The deep drainage tunnel will serve to prevent recurrent flooding in three key areas of Valle Dorado, benefiting a population of 2.1 million inhabitants.

Another Robbins Crossover (XRE) TBM, measuring 9.26 m (30.4 ft), is the first of its kind in the U.S. The TBM has recently begun boring the Ohio Canal Interceptor Tunnel (OCIT) in Akron, Ohio. The TBM was launched from a 12 m (40 ft) deep portal site and will build the first 68 m (226 ft) in soft ground, transitioning to a 183 m (600 ft) long zone of partial face shale before switching to hard-rock mode for the remainder of the drive in full face shale. Probe drilling will be done continuously using two probe drills to determine which mode the TBM should be in.

Milestone for Continuous Conveyors

The startup of the Akron machine was a milestone, but not the only one: running behind the Crossover TBM is the 100th Robbins Continuous Conveyor system supplied for muck removal—more than any other TBM conveyor supplier. The conveyor in Akron is part of a long history beginning with the first system developed by James S. Robbins in 1963. The prototype conveyor was successfully used behind an 11.2 m (36.7 ft) diameter Main Beam TBM at the Mangla Dam project. Today, conveyor systems are capable of spanning dozens of kilometers and hauling 1,800 metric tons (2,000 US tons) an hour or more. It's a legacy that Robbins will continue to grow.

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

GROSVENOR PROJECT, AUSTRALIA

FOCUSED FORWARD

FORWARD INNOVATIONS

Every technological breakthrough Robbins has ever made has been an answer to one of our client's challenges. From minimizing downtime in mixed geology with our Crossover TBMs to maximizing safety and performance with our latest ground investigation solutions, Robbins is committed to keeping your project moving forward.

Robbins
RELIABLE | RESPONSIVE

Local Presence. Global Competence.

DSI Tunneling LLC offers a complete selection of ground control solutions for the Civil, Mining and Foundation markets. We have been a leader in the underground support business in North America since 1920.

We are a global leader in tunnel and shaft construction, focused on engineered and tailored products to support our customers and industry.

DSI Tunneling is proud to bring an expanded group of products to the job site:

- **ALWAG** – Support Systems
- **Biomarine** - Tunnel Rescue Equipment
- **Boart** – Probe and Roof Bolting Equipment
- **CBE** – Segment Moulds – Precast Segment Moulds, Related Equipment and Plants
- **ChemGrout** - Grouting Equipment
- **Condat** – Ground Conditioning Chemicals and Lubricants
- **Cooper & Turner** – Bolts and Sockets for Precast Segments
- **DSI** – Steel Ribs, Liner Plates, Lattice Girders, Lagging and Miscellaneous Support Items
- **Dywidag** – Bolts and Accessories including DSI Threadbar, Friction Bolts and Omega Bolts
- **ES Rubber –** Segment Gaskets
- **Geodata** – Monitoring Equipment
- **Hany** – Grouting Systems
- **Montabert –** Excavator Drilling Attachments and Replacement Drifters
- **Promat International** – Fire Protection Products
- **Strata Worldwide** – Safety and Communication Equipment
- **VikOrsta** – CT-Bolts – Double Corrosion Protection
- **Weldgrip** – Fiberglass Bolts and Dowels
- **WIRTH** – Pile Top Rigs

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in the Design, Development, and Production of Underground Steel Supports in North America.

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We offer full service support:

- Engineering Estimates
- Design Collaboration
- Contractor Shop Drawings
- Construction Support

ABC Industries, Inc.

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

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

Schnabel Engineering

Schnabel Engineering, formerly Lachel & Associates, specializes in design and construction management services for tunneling and other heavy civil construction projects in the areas of transportation, water and wastewater infrastructure, and hydroelectric power. Our goal is to meet the needs of clients by providing fully integrated management and technical services that are objective, thorough, and effective.

We combine our expertise in the design and construction of underground structures with a keen understanding of nuances and interrelationship of geology, hydrogeology, and geotechnics on underground projects. From inception, through design, risk assessment, estimating, construction, and operations, we provide time-critical answers to difficult questions that help make certain the project comes in on time and within budget.

Founded in 1956, Schnabel has a long history of providing tunnel design services for constructors, owners, and other A/E firms for project across the United States. Some of our recent projects include:

- DC Water Clean Rivers Program, Washington, DC
- Loudon Water Raw Water Supply Tunnel, Leesburg, VA
- East End Crossing Tunnels, Louisville, KY
- Waller Creek Flood Tunnel, Austin, TX

TUNNEL DESIGN SERVICES
Some of our design services for tunnels and underground projects include:

- Feasibility Studies
- Alignment Optimization
- Assessment of Geotechnical Conditions
- Tunnel Initial and Final Support Design
- Numerical Methods for Design
- SEM / NATM
- Cavern Design
- Shaft Design
- Constructability Review and Cost Estimating
- Geotechnical Baseline Reports (GBRs)
- Construction Documents/Design Reports

www.schnabel-eng.com

Schnabel ENGINEERING
formerly Lachel & Associates

- Tunnel Engineering
- Geotechnics
- Constructability and Cost Estimating
- Risk Management
- Construction Engineering
- Construction Management
- Trenchless Technology
- Tunnel Inspection and Rehabilitation

MORRISTOWN, NJ FAIRFAX, VA DALLAS, TX LAS VEGAS, NV

schnabel-eng.com

Schauenburg

Schauenburg International originated in Germany as a traditional organization that quickly discovered innovation is the key to growth and flourished into a modern international group of technology companies. In 1974 Schauenburg Flexadux Corp. was established in the U.S. as a manufacturer of flexible ventilation ducting.

By embracing that spirit of innovation Schauenburg Flexadux Corp. expanded into a multi-faceted manufacturing company that creates Turn-Key solutions to all mining, tunneling and related industries throughout the continental USA and beyond.

We are proud to have new cutting-edge machines that will further assist us in creating better rigid and flex ventilation products. Our rigid now has an even smoother internal surface; reducing friction while providing superior durability. Our flex now accommodates a wider range of diameters for both positive and negative pressure systems.

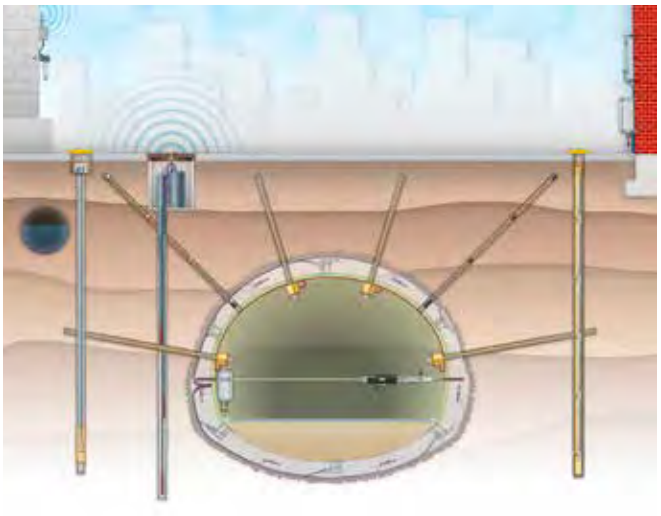
SCHAUENBURG
Flexadux Corp.

Geokon, Incorporated

Geokon, Incorporated, is a 38 year-old company based in Lebanon, New Hampshire, USA. It operates on a worldwide basis through a network of over 45 agencies for the manufacture and sale of geotechnical instruments. Founded in 1979, Geokon currently has over 100 experienced employees, many of whom have been with the company for over 25 years. Geokon, Inc. has emerged as The World Leader in Vibrating Wire Technology™ and one of the major global instrumentation companies due to our high-quality products, responsive customer service and industryleading designs.

In addition to almost all major cities in the USA, our instruments have been used in tunnels and subway systems around the world, including those found in Seoul, Taipei, Guangzhou, Istanbul, Hong Kong, Singapore, London and the Channel Tunnel.

Tunnel-specific instruments include NATM-style concrete pressure cells for monitoring stresses in shotcrete linings; convergence meters and tape extensometers to measure tunnel closures; multiple-point borehole extensometers and instrumented rockbolts to monitor the stability of the surrounding ground; piezometers to monitor ground water pressures and displacement gages to measure movements across cracks and joints. Dataloggers are used to take readings at programmed intervals and transmit real-time data (and any triggered alarm signals) to local stations or to remote readout locations using web-based software.



Geokon's experienced staff is at your disposal to assist in instrument design, selection and installation. For more information please visit www.geokon.com, e-mail us at info@geokon.com or call 1-603-448-1562 and speak to a sales representative.

Geokon, Inc.
Telephone: + 1-603-448-1562
Email: info@geokon.com

CDM Smith

CDM Smith provides lasting and integrated solutions in water, environment, transportation, energy and facilities to public and private clients worldwide. As a full-service engineering and construction firm, we deliver exceptional client service, quality results and enduring value across the entire project life cycle.

CDM Smith's underground construction staff includes geotechnical, structural, and civil engineers and geologists located worldwide. Our staff has extensive experience in providing the full range of tunnel and geotechnical related services. Our tunnel related work includes planning, feasibility and design, including both 2D and 3D FEM analyses. We offer construction services including construction and program management, inspection and geotechnical instrumentation monitoring and interpretation for soft ground and rock tunnels. Design and construction includes all types of ground modifications including ground freezing, grouting, and dewatering.

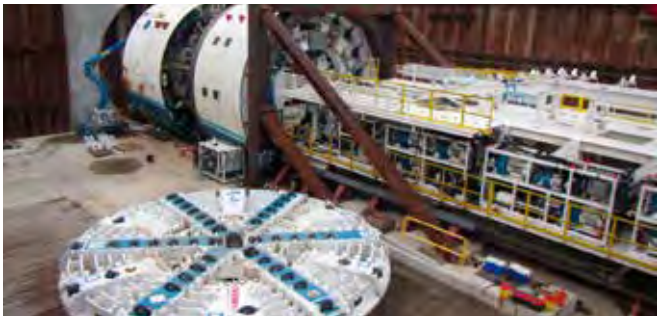
Our field equipment includes geotechnical instrumentation and construction data acquisition equipment. Our field personnel are NICET, OSHA and NRC certified. CDM Smith's tunnel services include:

- Shaft Design: Ground Freezing, Slurry Wall and Secant Pile Wall
- Conventional Soft Ground and Rock Tunnel Design, Microtunneling, Pipe Jacking and Directional Drilling
- Evaluation and Rehabilitation of Existing Tunnels
- Ground Investigation, Testing and Evaluations
- Groundwater Control System Design

CDM Smith
www.cdmsmith.com

CDM Smith
cdmsmith.com

Industry leaders. Delivering innovative solutions.



Parsons is a technology-driven engineering services firm with more than 70 years of experience in the engineering, construction, technical, and professional services industries. The corporation is a leader in many diversified markets with a focus on infrastructure, defense, and construction. Parsons delivers design/design-build, program/construction management, systems design/engineering, cyber/converged security, and other professional services packaged in innovative alternative delivery methods to federal, regional, and local government agencies, as well as to private industrial customers worldwide.

We have successfully delivered some of the largest and most complex tunneling and underground construction projects in the world. From planning and design through construction management and operations, Parsons provides a complete range of services for water, wastewater, and transportation tunnels. Whether your project involves soft ground, rock, or mixed-faced conditions, our dedicated staff of more than 100 tunnel professionals have the experience and skills to manage the risks and deliver safe, economical, and innovative solutions. Our recent award-winning projects, such as Lake Mead Intake No. 3 and the Sheikh Zayed Road and Tunnel, demonstrate Parsons' position as an industry leader and our dedication to delivering on challenging projects.

Learn more at parsons.com.

Premier Pipe Systems Manufacturer for Over 90 Years

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

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

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

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

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

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

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

Quotations are immediately available on inquiry.

Naylor Pipe Company
1270 East 92nd Street
Chicago, IL 60619 USA
Tel: 1-773-721-9400 Fax: 1-773-721-9494
Email: sales@naylorpipe.com
www.naylorpipe.com

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

Brokk Inc.

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

Brokk recently introduced the new Brokk 500, which includes 40 percent more demolition power than the Brokk 400 as well as the Brokk SmartPower™ electrical system, a more powerful breaker, extended reach and industry-leading serviceability.

The Brokk 500 delivers 1,086 foot-pounds with each blow of its 1,510-pound hydraulic breaker. On top of that, it adds more length to Brokk's signature three-part arm system, now reaching 24.3 feet vertically and 23 feet horizontally.

Weighing 11,464 pounds, the Brokk 500 is only slightly heavier than the Brokk 400, and the width of the machine is the same. It also is "backward compatible," so all the tools and attachments used for the Brokk 400 can also be used on the new Brokk 500.

The Brokk 500 comes with Brokk's new intelligent electrical system, Brokk SmartPower, which is a key part in creating the machine's performance improvement. It maximizes the power output of the machine at any given time based on both environmental and operating factors.

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

Brokk features the Brokk 500, which includes 40 percent more demolition power than the Brokk 400 as well as the Brokk SmartPower™ electrical system, a more powerful breaker, extended reach and industry-leading serviceability.

The Brokk 500 delivers 1,086 foot-pounds with each blow of the 1,510-pound Atlas Copco SB 702 hydraulic breaker. On top of that, it adds length to Brokk's signature three-part arm system, which now extends 24.3 feet vertically and 23 feet horizontally.

Mott MacDonald

Tunnel engineering is one of Mott MacDonald's core services. For public and private clients, we have engineered transportation tunnel solutions for roadway, passenger rail, freight rail, subway, pedestrian, cable and communications projects. Our expertise spans a broad range of capabilities from the planning and implementation of new facilities to the inspection and rehabilitation of existing facilities.

Our involvement in tunneling began more than a century ago, dating back to our founders' involvement with London's underground road and rail systems in 1902, and Toronto's subway system in 1954. Our association with these clients continues today — a testimony to the trust, confidence, and professional relationship we build with our clients and to the quality of our work.

With more than 60 offices throughout North America, Mott MacDonald offers services to handle any size project — from a small inspection assignment to world-class, multi-billion-dollar transit programs.

Our goal is to deliver clients projects in an environmentally responsible manner, with value-added design and construction methods — minimizing programmatic risk along the way.

www.mottmac.com

East Side Access, New York, NY

David R. Klug & Associates, Inc.

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

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

Grindex

Get the job done

Grindex is a world leader in electrical submersible pump technology for demanding applications such as construction, mining, and heavy industry, with more than 400,000 pumps delivered. The company combines 75 years of engineering experience with endless efforts to help their customers get the job done, despite the toughest conditions. Known worldwide for their high reliability, durability and dependability, pumps are designed to be used in the most challenging environments imaginable - without compromise for our professional users.

Pump designs range from 0.6 to 140 HP. Solids handling capability of up to 3.2", capacities of up to 750 feet and 5100 GPM. Both single and three phase pumps can be equipped with built in float switches and other options. Stainless steel options available. Unique features: air valve and SMART electronics. These features prevent overheating, incorrect motor rotation, and single phasing.

Grindex
www.grindex.com
Email: info.us@grindex.com

Gall Zeidler Consultants

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

The company specializes in mastering difficult ground conditions by using cutting-edge ground improvement methods such as dewatering, grouting, and ground freezing. GZ employs over 50 staff worldwide, and has a history of over 170 miles (275 kilometers) of successfully completed international tunneling projects. The company's expertise has consistently been sought after by major contractors and project owners in the industry developing tailored tunnel solutions and to assist with the mitigation of risks associated with tunneling.

GZ's ongoing projects include East Side Access, New York, Northgate Link Extension, Seattle, Crossrail, London and Riyadh Metro. GZ was involved in the recently completed Caldecott Tunnel Fourth Bore and Devil's Slide Tunnels in California, Dulles Metrorail Extension, Washington, D.C., Cable Tunnels in London and Singapore and multiple underground station upgrades in London.

Surecrete Inc.

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

Our product lines include Nittetsu SuperFine ultrafine cement, rheology modifiers, admixtures, and a complete selection of packaged wet and dry shotcrete, concrete and grout mixes.

We also represent several major equipment manufacturers focusing on the mixing and placing of shotcrete, concrete and grouts.

Surecrete Inc.

155 NE 100th St., Suite 300
Seattle, WA 98125
Phone: (206) 523-1233
Fax: (206) 524-6972
Email: jeff@surecrete.com
For more information, visit our website at www.surecrete.com.

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

Comprehensive safety training for both new and experienced tunnel professionals is provided through the Safety and Hazard Awareness for Tunnels (SHAFT) program.

The curriculum, developed by the Northwest Laborers-Employers Training Trust with input from a team of industry experts and stakeholders, is comprised of a blend of classroom discussion and interactive use of materials and mockups. Classes focus on tunnel safety, rail, and utilities.

The training facility, located in Elma, Washington, features a TBM mockup, 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.

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

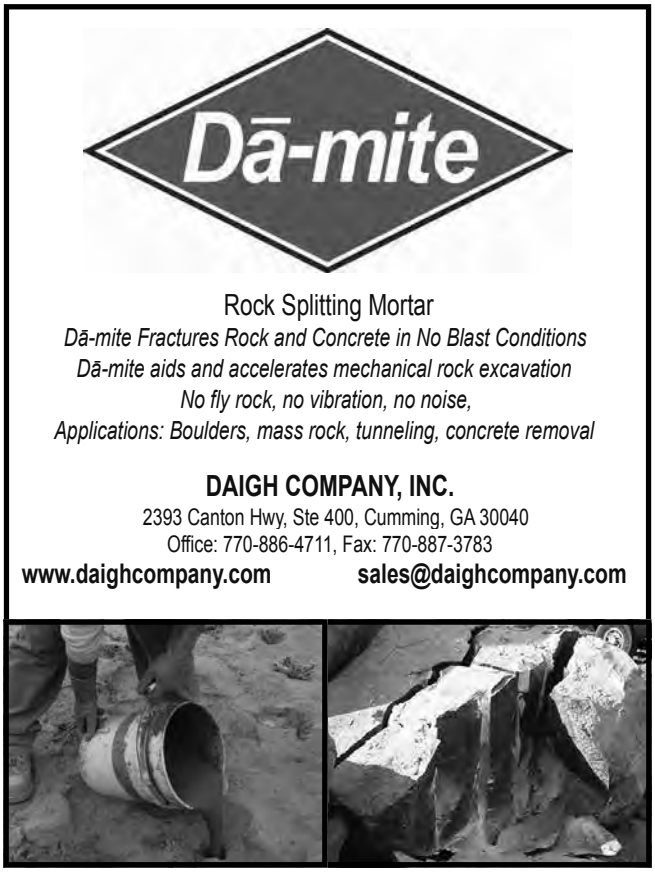
Brookville

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

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

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

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



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

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

Daigh Company, Inc.
2393 Canton Hwy., Ste. 400
Cumming, GA 30040
Telephone: +1-770-886-4711
Fax: +1-770-887-3783
Email: sales@daighcompany.com
www.daighcompany.com

Dā-mite®
Rock Splitting Mortar

The Heintzmann Group

The Heintzmann Group, which has been in business approximately 165 years, manufactures support systems in the tunneling and mining industries. In the last decade, we have greatly expanded our line of products, as well as our regions of service. We currently have offices located in Virginia, West Virginia, Alabama, Colorado, and Illinois. Our range of products and services include but are not limited to standing supports, pumpable roof support, arches, square sets, pre-stressing devices, heat treated beams, polyurethane grout injection, shaft rings, lattice girders, two flange liner plates and four flange liner plates.

The goal of the Heintzmann Group is to provide resources to make the tunneling and mining environments safer and to achieve the highest level of customer satisfaction by providing our customers with a variety of support options.

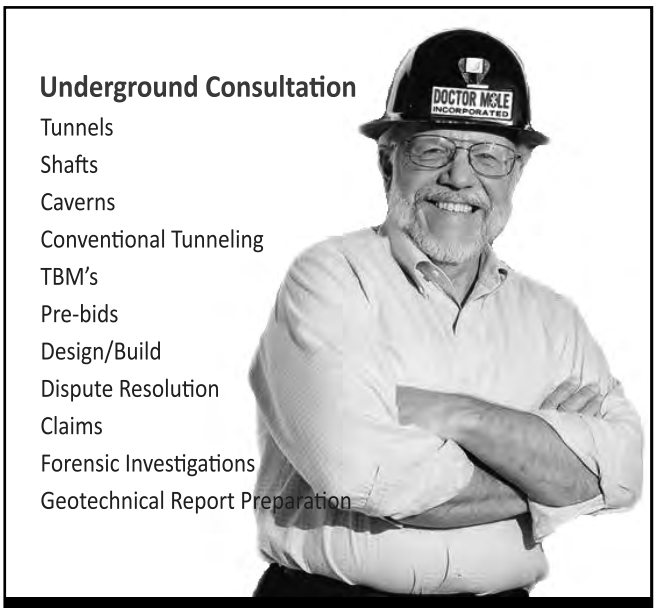
The Heintzmann Group
Telephone: +1-276-964-7413
www.heintzmann.com

Announcing Doctor Mole Incorporated

Dr. Gary S. Brierley started operating as an independent consultant under the corporate name of Doctor Mole Incorporated (DMI) on January 1, 2013. Doctor Mole Incorporated is a one-stop-shopping-center for the design of all types of underground openings in all types of ground conditions. DMI can help clients meet their underground design and construction needs. No job is too small and it is our intention to help owners, designers, contractors, geotechnical engineers, and developers create successful underground projects from start to finish. Based in Denver, Colorado, DMI is strategically located and available to help with projects across the United States. Give us a call at 303.797.1728 or visit us on the web at www.drmoleinc.com.

Doctor Mole Incorporated
990 S. Broadway, Suite 222
Denver, CO 80209 USA
Telephone: +1-303-797-1728
www.drmoleinc.com

DOCTOR MOLE INCORPORATED



Babendererde Engineers and Tunnelsoft

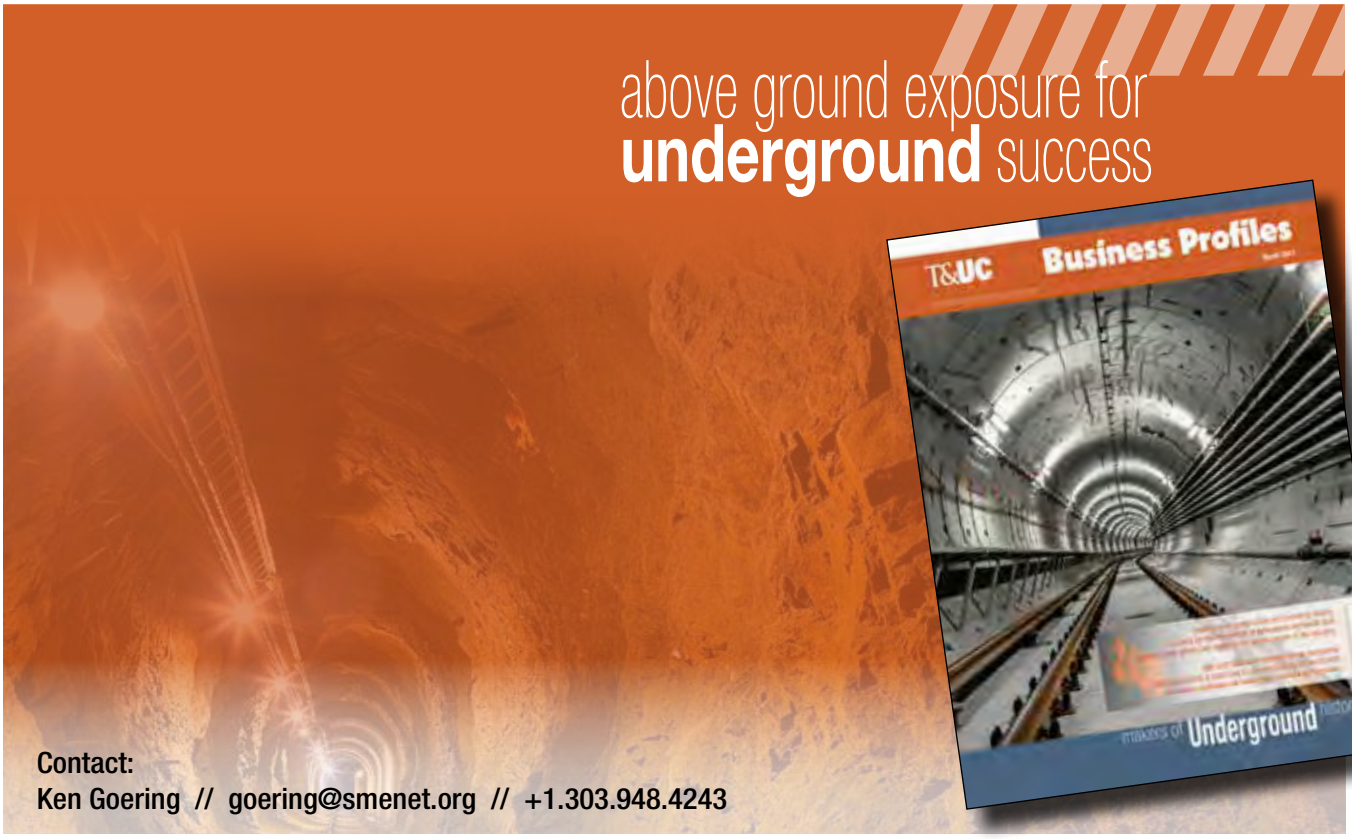
BABENDERERDE ENGINEERS is a worldwide engineering and consulting company specializing in underground works.

We support projects involving tunnel boring machines (TBMs), whether for highly mobile pipe jacking projects or for large diameter traffic tunnels in challenging geological conditions, during all phases – from feasibility study to design & from construction to contract closure.

Thanks to this hands-on experience of our qualified engineers, our division TUNNELSOFT has developed and constantly refines our software TPC (Tunnelling Process Control).

Its unique flexibility, combined with powerful automatic reporting and notification tools makes it the leading solution for data management and excavation monitoring in the market.

www.babeng.com | tpc.tunnelsoft.com



McMillen Jacobs Associates

McMillen Jacobs Associates is the combination of two rich histories creating one great future. In December 2014, Jacobs Associates, Inc. and McMillen, LLC merged to bring together the combination of over 75 years of technical engineering design and construction expertise in the conveyance (water, wastewater, stormwater), dispute resolution, energy and power, transportation, underground, and water resources industries.

We offer a full range of design, design-build, self-performing construction and construction management services. We work closely with our clients at every stage of a project, assisting them with planning, design expertise, project management, construction, and start-up. Our 21 offices in North America and Australasia and more than 400 staff serve clients locally and worldwide.

McMILLEN JACOBS ASSOCIATES

Design with Vision, Build with Integrity
www.mcmjac.com

Mueser Rutledge Consulting Engineers

Mueser Rutledge Consulting Engineers (MRCE), founded in 1910, is a leading engineering firm focused on the below-ground disciplines of geotechnical engineering and structural foundation design for all structures.

Providing design solutions for tunnels and shafts is an MRCE specialty and involves the firm in a wide array of tunnel projects in both soft ground and rock for railroads, highways, subways, pedestrians, utilidors, CSOs, interceptors, as well as water and wastewater treatment.

MRCE's recent tunneling projects include LIRR East Side Access, NYCT 2nd Avenue Subway, CSX Virginia Avenue Tunnel, VDOT Midtown Tunnel, DC Water's Blue Plains and First Street Tunnels, Toronto Subway Yonge-Eglinton Station, and NYCDEP's Catskills and Delaware Aqueduct Rondout-West Branch Tunnel and Brooklyn to Staten Island Harbor Siphon Tunnel.

Mueser Rutledge Consulting Engineers
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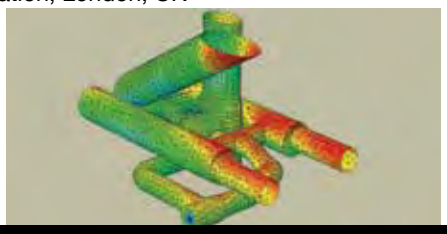
Telephone: 917-339-9300
Fax: 917-339-9400
Email: farland@mrce.com
www.mrce.com

Dr. Sauer & Partners

Dr. Sauer & Partners is an independent consultancy specialised in providing the full range of design and construction management services for SEM tunnels, shafts and caverns. The firm delivers innovative, cost-effective and environmentally-aware design solutions and has over 30 years of experience providing design and construction for more than one hundred of the world's most complex tunnelling projects (Metro, Highway, Water, Rail and Mining). Dr. Sauer & Partners designs tunnels in urban and rural locations and in any type of geology. Current and recent projects include: Chinatown Station (San Francisco, USA), Ottawa Light Rail (CAN), Bank Station Capacity Upgrade Project (London, UK), Crossrail (London, UK), Red Line (Tel Aviv, Israel), Eglinton Crosstown LRT (CAN)

The image shows: 3D FE Model of Step Free Access at Green Park Station, London, UK

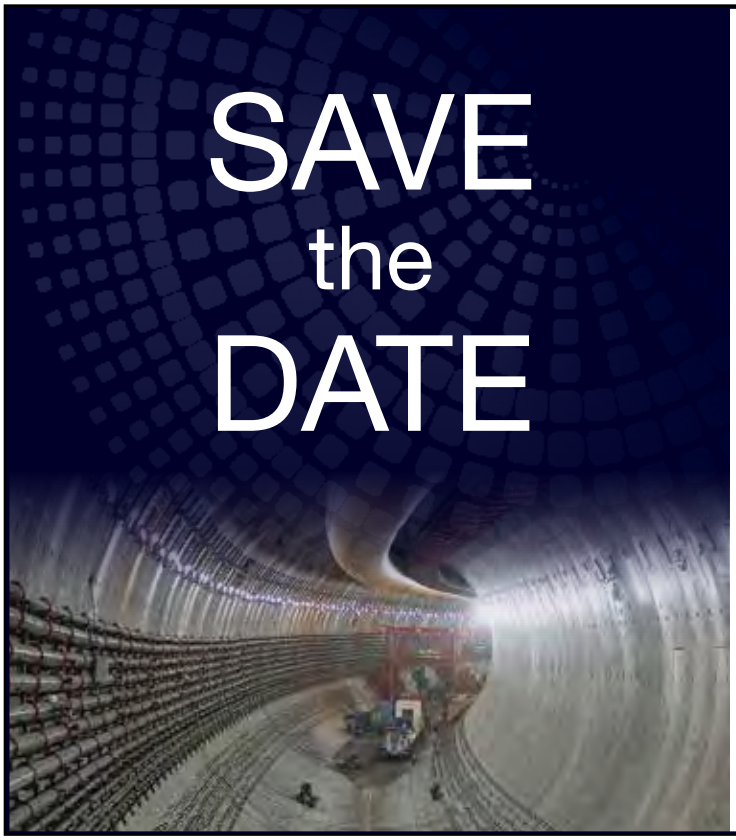


COMPILED BY JONATHAN KLUG, DAVID R. KLUG & ASSOCIATES

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Gateway Tunnel	Amtrak	Newark	NJ	Subway	14,600	24.5	2018	Design study
2nd Ave. Phase 2	NYC-MTA	New York	NY	Subway	16,000	20	2020	Under design
2nd Ave. Phase 3-4	NYC-MTA	New York	NY	Subway	105,600	20	2017-22	Under study
Water Tunnel #3 Stage 3 Kensico	NYC-DEP	New York	NY	Water	84,000	20	2020	Under study
Bergen Point Wastewater Outfall	Suffolk Co., DPW	Babalon	NY	Sewer	14,200	12	2017	Judlau/OHL JV awarded
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Rail	25,000	30	2022	Under study
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	Rail	10,000	30	2018	Under design
Thimble Shoal Parallel Tunnel	Chesapeake Bay Bridge & Tunnel Dist.	Chesapeake	VA	Highway	5,700	45	2016	Dragados/ Schiavone awarded
Hampton Roads Bridge-Tunnel Project	Virginia DOT	Hampton Roads	VA	Highway	7,500	42	2018	Under design
Northeast Boundary Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	17,500	23	2017	Impregilo/Healy JV awarded
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	4,500	33	2022	Under design
Olentangy Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2017	Under design
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	Sewer	 30,000 21,000	 18 14	 2018 2019	 Under design Under design
Doan Valley Storage Tunnel	NEORSD	Cleveland	OH	CSO	10,000/ 9,400	18/18.5	2017	McNalley/ Kiewit JV awarded
Westerly Main Storage Tunnel	NEORSD	Cleveland	OH	CSO	12,300	24	2020	Bid date 1/16/18
Shoreline Storage Tunnel	NEORSD	Cleveland	OH	CSO	16,100	21	2021	Under design
Shoreline Consolidation Tunnel	NEORSD	Cleveland	OH	CSO	11,700	9.5	2022	Under design
ALCOSAN CSO Ohio River Allegheny River Mononghahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	 10,000 41,700 53,900	 30 30 30	 2019 2020 2021	 Under design Under design Under design
Three Rivers Protection/Overflow	City of Fort Wayne	Fort Wayne	IN	CSO	26,400	12	2016	Salini/Impreglio/ Healey awarded
Louisville MSD Tunnel	Lousville MSD	Lousville	KY	CSO	13,200	22	2018	Shea/Traylor low bidder
Blacksnake Creek Tunnel Project	City of St. Joseph	St. Joseph	MO	CSO	6,650	10	2017	Super Excavators awarded
KCMO Overflow Control Program	City of Kansas City	Kansas City	MO	CSO	62,000	14	2018	Under design

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
Mill Creek Peaks Branch Tunnel	City of Dallas	Dallas	TX	CSO	5,500	26	2014	Southland/Mole JV low bidder
Ballard to Wallingford Tunnel	Seattle Public Utilities	Seattle	WA	CSO	14,250	14	2018	Under design
L.A. Metro Westside Phase 2 Phase 3	Los Angeles MTA	Los Angeles	CA	Subway	 26,500 26,500	 20 20	 2016 2017	Tutor Perini/O&G JV awarded Proposals 12/11/17
Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2018	Under study
Northeast Interceptor Sewer 2A	LA Dept. of Water and Power	Los Angeles	CA	Sewer	18,500	18	2014	Delayed indefinitely
River Supply Conduit - Unit 7	LA Dept. of Water and Power	Los Angeles	CA	Water	13,500	12	2015	Advertise 01/18
JWPCP Effluent Outfall Tunnel project	Sanitation Districts of LA	Los Angeles	CA	Sewer	37,000	18	2015	Bid date 1Q 2018
Two Mile Bar Tunnel	Oakdale Irrigation	Oakdale	CA	Water	5,950	11.5x13	2017	SMCI low bidder
Freeway 710 Tunnel	CALTRANS	Long Beach	CA	Highway	26,400	38	2016	Re-design activated
BDCP Tunnel #1 BDCP Tunnel # 2	Bay Delta Conservation Plan	Sacramento	CA	Water	26,000 369,600	29 35	2018 2019	Under design Under design
SVRT BART	Santa Clara Valley Trans Authority	San Jose	CA	Subway	22,700	20	2016	Redesign activated
Silicon Valley Clean Water Tunnel	Silicon Valley Clean Water	Silicon Valley	CA	CSO	17,500	13	2017	Barnard/Bassac JV awarded
Coxwell Bypass Tunnel program	City of Toronto	Toronto	ON	CSO	35,000	12	2015	Bid date 12/20/17
Highway 401 Rail Tunnel	Metrolinx	Toronto	ON	Subway	580	35x28	2017	EllisDon/Strabag JV awarded
Keswick Effluent Outfall	City of Toronto	Toronto	ON	CSO	11,600	23	2018	Under design
Yonge St. Extension	Toronto Transit Commission	Toronto	ON	Subway	15,000	18	2016	Under study
Taylor Massey Tunnel	City of Toronto	Toronto	ON	CSO	20,000	18	2018	Under design
Inner Harbour West	City of Toronto	Toronto	ON	CSO	18,400	19	2021	Under design
Scarborough Rapid Transit Extension	Toronto Transit Commission	Toronto	ON	Subway	25,000	18	2018	Under design
REM Transit Tunnel	City of Montreal	Montreal	QC	Subway	27,000	22	2017	Bidders selected
Newfoundland-Labrador Fixed Link	Gov. of Newfoundland/Lab	Newfoundland	NL	Transit	56,000	40	2020	Under study
Green Line LRT	City of Calgary	Calgary	AB	Transit	26,250	20	2018	Under design
Second Narrows Tunnel	City of Vancouver	Vancouver	BC	CSO	3,600	14	2013	Under design
Annacis Island Outfall	City of Vancouver	Vancouver	BC	Water	8,000	10	2017	Under design
Burnaby Mountain	Kinder Morgan	Vancouver	BC	Oil	8,000	12	2017	Under design
Broadway Sky train extension	Trans Link	Vancouver	BC	Subway	25,000	18	18	Under design
Northern Gateway Hoult Tunnel	Enbridge Northern	Kitimat	BC	Oil	23,000	20	2014	Under design



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AWARDS

Boyce receives Bechtel Pipeline Engineering Award

Glenn M. Boyce P.E., F.ASCE, a principal with McMillen Jacobs Associates, received the ASCE 2017 Stephen D. Bechtel Pipeline Engineering Award. The prestigious award honors Boyce for his "numerous contributions to the engineering profession as a seasoned practitioner, educator and author, expanding design and construction realms of utility pipelines, tunnels, shafts, geotechnical engineering, and all aspects of trenchless technologies."

Boyce is a supervising tunnel and geotechnical engineer with more than 30 years of professional experience covering every aspect of tunnel, shaft and geotechnical engineering, including exploration and assessment. He has published book, manuals and articles about trenchless technology and was chosen as *Trenchless Technology* magazine's 2009 Trenchless Technology Person of the Year. He holds a Ph.D. in geological engineering from University of California, Berkeley.

The ASCE Pipeline Division Award of Excellence was established in 1988 to recognize outstanding achievements in pipeline engineering. It honors individuals who have made a definitive contribution to the advancement of pipeline engineering in research, planning, design, or construction. ■

Glenn Boyce (l) accepts the 2017 Stephen D. Bechtel Pipeline Engineering Award from Tennyson Muindi (r).

PERSONAL NEWS

JAMES E. PARKES, PE (SME) has joined Schnabel Engineering as a senior associate in the new position of technical tunneling director. Based in Baltimore, MD, he will be responsible for positioning and growing the company's national tunnel and underground engineering services practice. Parkes was most recently with WSP | Parsons Brinckerhoff and brings to his new role 18 years of experience in technical leadership, operations and personnel management, strategic planning, and business development. He has has a diverse portfolio of high-profile tunnel, shaft, dam, water resources, light rail and transportation infrastructure projects located throughout the United States.


PARKES

Hayward Baker, Inc. has announced promotions for several staff members. **JUSTIN LEWIS**, PE, was promoted to division manager of structural support in the company's Chicago, IL office and will have the overall responsibility for estimating, design and management of earth retention, and deep foundation projects in Hayward Baker's Midwest area. **MIKE MINTON**, PE, was promoted to division manager of ground modification in the Chicago office. Minton has held the role of project manager within the ground modification division since 2010, with a focus on aggregate piers and vibratory improvement technologies. **RAYMOND FRANZ**, PE, D.GE, was promoted to vice president in the Chicago office. Franz has more than 31 years of extensive and varied experience in the design and construction of specialty geotechnical projects, including the Louisville-Southern Indiana Ohio River Bridges project and the Thornton Composite Reservoir. **SHANE FARR,** PE, SE, was promoted to vice president in Hayward Baker's California structural support offices, after previously holding the position of division manager of structural support in the Chicago office. Farr is responsible for all structural projects and will focus on expanding Hayward Baker's design-build capabilities in California. **KYLE CAMPER**, PE, was promoted to senior vice president for the company's Western region. He has 25 years of in-depth experience in the geotechnical industry, 20 of which have been spent with Hayward Baker. Camper previously held positions of senior project manager, division manager and vice president in the Midwest area.

SAM SWARTZ, PE, has opened the Chicago, IL office of McMillen Jacobs and will be providing design leadership on regional projects, as well as providing business development for major underground projects. He relocated from the firm's Seattle, WA office. Swartz is currently the lead tunnel and shaft designer for the Second Narrows Water Tunnel in Vancouver, BC, Canada. He was also the discipline lead for tunnel structural design for the dual light rail tunnels on the University Link Extension and provided design support services during construction. ■

NEW PRODUCTS

Trelleborg displays tunnel segment gasket at 2017 RETC

Tunnels are getting larger, deeper and excavated in more challenging conditions. There is also growing pressure to successfully complete these projects while meeting increasing demands for performance, on-schedule delivery and safety.

However, on many projects, concrete tunnel segments are fitted with rubber gaskets onsite and secured using adhesive, which can lead to time-consuming and cost-intensive repair work as a result of displacement between segments that are not accurately positioned. This can reduce the gasket's ability to withstand water pressure, exerting negative effects on the outcome of a project.

To combat the issue, the Trelleborg sealing system is precast into the tunnel segment during manufacturing, removing the need for adhesive on installation, which enables installers to save significant time and money.

The gasket forges a superior bond connection with the segment to improve installation accuracy and ensure increased water tight performance. ■


Tunnel segment with Trelleborg sealing gasket.

www.trelleborg.com/engineeredproducts

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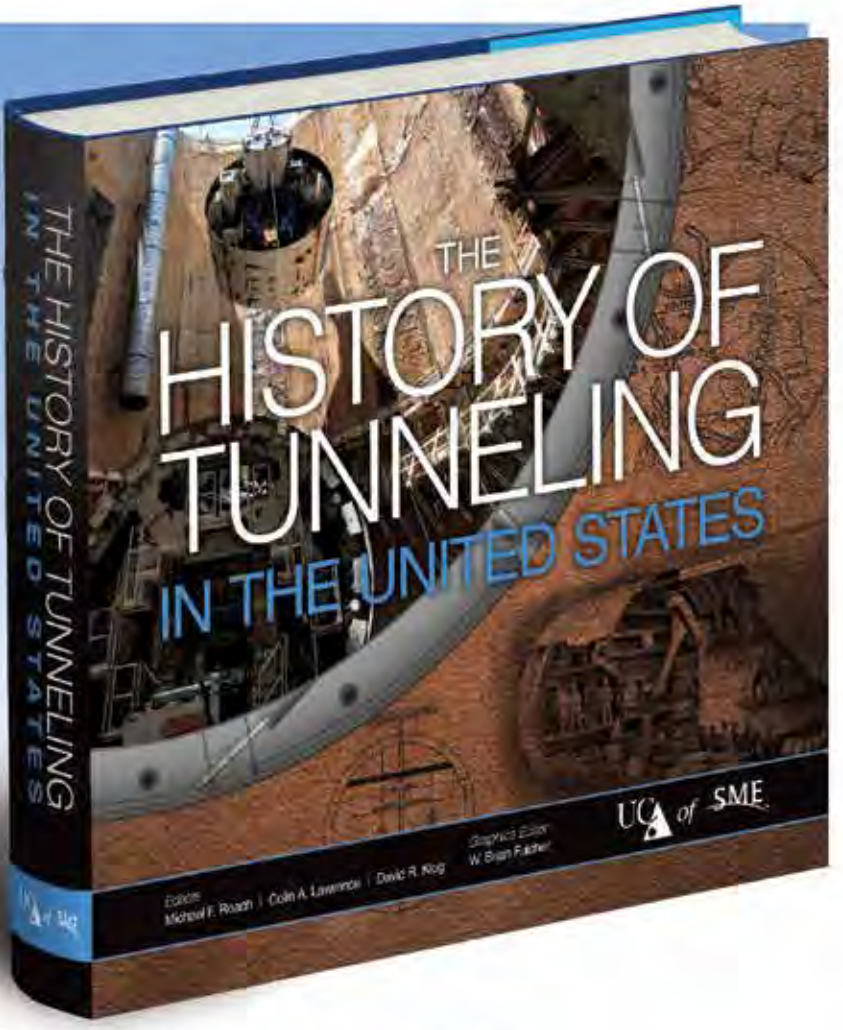
New Book Chronicles 200 Years of Tunneling in the United States



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