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High in situ stress

Cross passage freezing

Advances in tunneling technology

Special Editorial Supplement from the publisher of Mining engineering


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COVER STORY

In this issue — WestConnex is one of New South Wales' key infrastructure projects. This 33-km (20.5-mile) long project aims to ease congestion and connect communities. Beginning on page 12, high in situ stress and its effects on tunnel design is discussed, with the WestConnex tunnels being used as an example. Cover photo courtesy of The Robbins Company.

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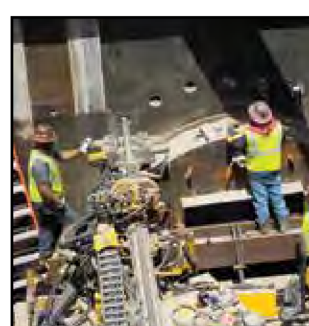

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CHAIRMAN'S COLUMN

Getting involved with the UCA Strategic Goals and objectives

I was pleased to see many of you in Atlanta for the 2018 edition of our Cutting Edge Conference. Thanks again to Greg Colzani, his team and the staff at SME for putting together another great event. During the conference, many of our members asked me how they could become more involved in the Underground Construction Association of SME (UCA). Participation with the planning and execution committees for the North American Tunneling Conference, Cutting Edge and the Fox Conference are the ones people think of first, as these are the most visible. Equally as important, yet currently less visible, is the work to be done to further the UCA strategic goals through a variety of objectives.

The mission of the UCA of SME is to promote the responsible development and use of underground space and facilities. We are working to accomplish this mission by fulfilling goals designed to address the following key areas. (Bob Goodfellow, Vice Chair of UCA, is a coauthor of this column.)

- Promote the underground construction industry.
- Educate the appropriate communities.
- Represent technical activities.
- Support the professionals involved in underground construction.

From these key areas to be addressed, three UCA Strategic Goals were developed.

Strategic Goal #1: Become the primary resource for underground construction issues and information requests.

Strategic Goal #2: Improve the image of underground construction in the minds of the public, government, owners and all key constituencies.

Strategic Goal #3: Improve the effectiveness and efficiency of the underground construction industry.

These goals led us to identify objectives specifically designed to aid in their achievement. Herein lies a multitude of participation opportunities for our UCA membership. We are seeking task force participants to work on each objective. Current task force leads are in parentheses.

Objective 1 (Mike Roach) — Identify a UCA spokesperson; develop protocols for media engagement. The primary industry spokesperson will be the chair of the UCA Executive Committee. Participants will develop media engagement protocols, and designate additional spokespersons based on subject matter expertise.

Objective 2 (Various, depending on target conference. Paul Headland for AEG) — Sponsor UCA sessions at other industry events. Task force participants will review the initial list of targeted associations and amend as they see fit. Identify liaisons for each of the associations and develop relationships on an ongoing basis for their events/conferences.

Objective 3 (Brian Fulcher) — Develop a PowerPoint presentation utilizing various images from the *History of Tunneling in the United States* book for the UCA website and targeted use by the industry.

Objective 4 (Brian Fulcher) – Distribute copies for the *History of Tunneling in the United States* book to satisfy one of the missions of this publication — to be an industry advertisement for political decision-makers. Task force participants will develop a plan and strategy for book

(Continued on page 9)

New York Governor pushes for federal funding for Gateway Tunnel project

In the past year there have been more than 300 train delays and more than 10,000 minutes of train delays because of problems with the bridge over the Hackensack River in New Jersey and with the tunnel beneath the Hudson River.

In October, New York Gov. Andrew Cuomo toured the tunnel underneath the Hudson River with a camera crew with the hope of getting federal funding for the Gateway Project, a comprehensive rail investment program that would include the Hudson Tunnel Project. That project includes the construction of a new two-track Hudson River rail tunnel from New Jersey to New York and the rehabilitation of the existing 106-year-old North River Tunnel that incurred serious damage during Superstorm Sandy in 2012.

The governor brought a camera crew along for the tour and said he plans to send the footage to President Donald Trump, *CBS New York* reported.

"I actually think if anything is going to convince the president, seeing is believing," Cuomo said. "He actually has a construction background and I think if he sees the level of damage and he sees what we're talking about, eroding steel, falling concrete, that he'll see it in a different context — that it will strip away the politics and the rhetoric and the jockeying."

The two-tube tunnel, which serves as the only rail connection between New York City and New Jersey, suffered saltwater damage from Superstorm Sandy in 2012 that is eating away at walls housing copper cables and electrical wires. Amtrak, which owns the tunnels, has estimated one or both of the tunnel tubes could fail in the next 10 to 15 years.

Cuomo pointed to a hole in the sidewall where cables, piping and metal rebar are flaking from the salt. When the salt damages the copper cables, it takes workers 12 to 14 hours to splice them back together. Much

(Continued on page 8)

Boring completed on Atlanta project

On Oct. 4, 2018, onlookers watched as a 3.8 m (12.5 ft) diameter Robbins Main Beam tunnel boring machine (TBM) completed its epic journey. The TBM, christened "Driller Mike," after local rapper and activist "Killer Mike," overcame extremely hard rock conditions along a curving 8 km (5 mile) tunnel to bolster the city of Atlanta, GA's water supply.

The new tunnel brings the Atlanta Water Supply Program one step closer to increasing the city's water capacity to between 30 and 90 days, depending on daily usage. "Our schedule for the project was very aggressive but the project team stayed together to overcome issues related to the mining of the tunnel," said Bob Huie, project director for the PC Russell joint venture (JV), the construction manager at risk (CMAR) for the project.

The unique structure of the project team is credited with the overall project success despite challenges.

The project is only the third such large construction project in the United States to use the CMAR structure. The PC Construction/HJ Russell JV was selected as the CMAR for the project, which then purchased the Robbins Main Beam TBM for the tunnel. The designer for the construction works including tunnel and shafts, JP2 — consisting of Stantec, PRAD Group, Inc., and River 2 Tap — specified the hard rock TBM. Operation and assembly of the TBM was then subcontracted to the Atkinson/Technique JV.

The robust TBM was assembled using onsite first time assembly (OFTA) at the massive Bellwood Quarry site with help from Robbins personnel. "The guys built everything per the specs to help with scheduling. It was a challenge but there was no negativity during the process," said Weslowski. Despite summer temperatures hitting 43 °C (110 °F) and 100 percent humidity, the TBM was ready to launch by October 2016.

Hard granitic rock challenged the 19-inch disc cutters from the outset. "There was ground so hard that it would take eight hours to go 1.5 m (5 ft). It was between 117 and 310 MPa (17,000 and 45,000 psi) UCS. The beginning of the job was tough," said Weslowski, but he added that once the learning curve had been overcome "they started breaking project records left and right toward the end. We got a best day of 38.4 m (126 ft)." ■

Terratec announced formal partnership with JIM Technology to produce TBMs

Following eight years of working together on numerous tunnelling project around the world, Terratec and Japan-based JIM Technology (JIMT) have announced a formal partnership in which JIM Technology will be a shareholder in the company.

The companies have delivered more than 60 tunnel boring machines (TBM) for global markets including India, Thailand, Turkey and Europe. In all these cases, Terratec has been the main contractor and JIMT its subcontractor for the provision of key components and designs for earth pressure balance (EPB) and slurry TBMs.

JIMT was created by three Japanese industrial giants: IHI Corp., Mitsubishi Heavy Industries and JFE Engineering Corp. that merged their TBM divisions. They combined their technology and experience of more than 3,000 TBMs delivered since 1936 of every type and size up to 16 m (52 ft) in diameter, for both Japan and overseas projects.

JIMT will now hold half the shares of Terratec. The other half will remain with the existing partners, who will keep running the business, since the company will keep the same structure, key managers and teams for the operation of its marketing, sales, production, after-sales and field service divisions.

"Terratec has a very efficient team working all over the world. They have achieved to become the number one TBM supplier in important growing markets like India and Thailand and achieved continued sales in established markets like Europe. We want Terratec to keep operating and expanding the business as they do, but now with JIMT's full and direct support from the engineering and production side," said Takanobu Miki, president of JIMT.

Terratec will keep its global network of regional offices and country representatives. The contact persons for clients will remain the same as before. Furthermore, the market will see Terratec expanding its global presence.

As in past years, the design of the machines will continue to be carried out using JIMT's technology for the shield machines (EPB and slurry) with Terratec's team in Australia taking care of the hard rock TBMs, raise boring machines and conveyor systems.

The main parts of the TBM, such as the cutter head drive unit, will continue to be fabricated by JIMT in Japan, with the key components including electric and hydraulic systems being sourced in Japan, Australia and Europe. The assembly and testing of the TBMs will continue to be done in Terratec's plant in Guangzhou, which is now just one hour away from the company's global office in Hong Kong by the recently opened high-speed railway.

Regarding the raise boring machines and conveyor divisions, these will remain fully managed from Australia with the entire design and production being done in Terratec's facilities in Tasmania, as it has been since 1990.■

Tunneling is underway on Metro's Purple Line subway extension in Los Angeles, CA

The first round of tunneling on Los Angeles' Metro Purple Line started Oct. 16 beneath the intersection of Wilshire Boulevard and La Brea Avenue.

Twin 137-m (450-ft) long tunnel boring machines (dubbed Elsie and Soyeon) will carve out about 20 m (60 ft) of tunnel daily for the next two years, en route to the Wilshire/Western station, where Purple Line trains now turn back for downtown Los Angeles. The line will add seven new stations. Travel time between downtown Los Angeles and Westwood is expected to be about 25 minutes.

The first phase of the Purple Line extension broke ground in 2014 and is expected to open in 2023. The $2.82 billion project will add a little under 6.5 km (4 miles) of track to the subway route.

The project is being constructed in three segments.

Altogether, the extension will add roughly 14.5 km (9 miles) to the Purple Line and is expected to carry nearly 60,000 riders daily.

But the project has faced opposition from Beverly Hills residents and school officials who have sued repeatedly to block the second leg of the project, arguing that tunneling work beneath the Beverly Hills High School campus could pose a threat to the safety of students. Metro officials have steadfastly denied these claims.

Tunneling work hasn't started yet on the second phase of the project, and Metro spokesperson Dave Sotero told *Curbed* that the agency selected a route that travels beneath the high school because that route provides the greatest benefits with fewest impacts. Another proposed route along Santa Monica Boulevard would have intersected with an earthquake fault.

Sotero says Metro will continue to look for unmapped oil wells beneath Beverly Hills out of an abundance of caution.

Protests and legal challenges notwithstanding, Metro expects all three phases of the project to be complete by 2026. ■

New York: Tour highlights damage in tunnels

(Continued from page 4)

of that work is done overnight or on weekends, when one tube can be shut down without causing significant disruption to service.

Taking one of the tubes out of service for an extended time, however, would reduce peak period traffic by 75 percent, experts have said. That would have a ripple effect up and down the Washington-to-Boston corridor on which more than 700,000 people ride daily on Amtrak and several commuter lines, Amtrak has estimated.

A 2014 report by the Federal Railroad Administration estimated that the loss of rail service on the corridor for one day could cost nearly $100 million in impacts and productivity losses.

"Governor Cuomo is 100 percent right to highlight the urgent need to build a new Hudson River Tunnel, and its importance to the nation. We thank him and Gov. Murphy for their unwavering commitment to the Gateway Program. This vital Northeast Corridor rail link is too important to wait for the current 107-year-old tunnel to become unusable," Gateway Development Corporation trustees Steven M. Cohen, Tony Coscia and Jerry Zaro said in a statement. "We urge the Administration to join us in accelerating the effort to replace the critical, century-old Portal Bridge and Hudson River Tunnel with modern, 21st century infrastructure of which America can be proud."

New York and New Jersey have committed to pay for half the cost of building a new tunnel using federal loans, with New Jersey proposing to pay back its share with fare increases and New York proposing to allocate money annually from its state budget over 35 years. The Port Authority of New York and New Jersey has committed roughly $2 billion.

But Trump administration officials have rejected the 50-50 agreement the states made with the Obama administration that would have the federal government pay for the other half, calling it nonexistent.

Transportation Secretary Elaine Chao told a House committee in March that Trump was seeking to kill the tunnel project unless the states committed more money. And the Federal Transit Administration has downgraded the project's rating from medium-high to medium-low, making it more difficult to compete with other projects around the country seeking federal dollars. ■

Chairman's column: Objectives for the future

(Continued from page 2)

distribution, use and review to meet the original mission of creating this volume.

Objective 5 (Paul Schmall) – Conduct market research for better ways to contact and engage students in our industry. Preliminary market research is in progress. Participants will analyze the data and define and execute follow-on actions.

Objective 6 (Mike Vitale) – Develop and publish a listing of frequently asked questions (FAQ) about tunneling for the website. Volunteers will add to and edit existing work product. FAQs to be revised as the industry evolves.

Objective 7 (Paul Schmall) – Liaise with ASCE to visit college campuses and present to underground industry to groups of engineering students. Participants will visit local campuses, with material produced and provided by the UCA.

Objective 8 (Erika Moonin) – ASCE Legislative Infrastructure Outreach (UCA participation). Participants will work with ASCE representatives to join the ASCE legislative fly-in.

Objective 9 (Ray Henn) – Industry Guidelines for Cellular Grout Backfill Utilized in Tunneling and Underground Construction. This committee has formed, and work has begun. But Ray is always looking for good input.

Objective 10 (Randy Essex) – Guidelines for the Use of Alternative Delivery Contracting in Underground Projects. This is not an overlap of the Recommended Contract Practices for Underground Construction, currently being updated. This will be a specific road map to answer the "when and why" as well as "which form" of alternate delivery may be best suited for a given underground project.

We are constantly seeking volunteers from our membership for industry guideline documents, communications and existing activities. Whatever your interest is, as a UCA member, we have a place for you to pitch in.

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

Mike Roach
and Bob Goodfellow
UCA of SME Chair,
UCA of SME Vice-Chair

FEATURE ARTICLE

High in situ stress and its effects on tunnel design: An update based on recent project experience from WestConnex tunnels

The high virgin horizontal in situ stress field in the Sydney Basin and its impact on civil engineering projects is a well-known and accepted phenomenon found in significant literature (e.g., Pells, 2013). The prevailing high-stress effects depend on many factors — rock quality, tunnel orientation, proximity of geological features to tunnel crown, size and shape of opening, depth of excavation and stress magnitude. The behavior of the rock mass under high in situ stress conditions can cause stress fracturing and consequent dilation of the tunnel periphery, resulting in rock spalling at the tunnel crown/invert or raveling of rock blocks on the tunnel sidewall. This type of failure is of a brittle nature and may create construction and safety risks during tunnel excavation, if it occurs behind the excavation face where ground support has already been installed. Therefore, the associated risks need to be managed during construction. This paper presents the design strategy adopted to mitigate these adverse tunneling conditions for the WestConnex Project to-date.

D. Tepavac, P. Mok, D. Oliveira, H. Asche, Y. Sun and S. Simmonds

D. Tepavac, members UCA of SME , and **P. Mok** and **Y. Sun** are senior project engineer, senior project engineer and senior associate, respectively, McMillen Jacobs Assoiciates, Australia; , **D. Oliveira** is technical director Jacobs Engineering Group, Australia; **H. Asche,** member UCA of SME, is technical director, Aurecon Group and **S. Simmonds,** member UCA of SME, is design manager, L2 52-54 Railways Parade, email tepavac@mcmjac.com.

FIG.1

WestConnex Corridor (Transport Sydney, 2013)

Overview of the WestConnex M4 East and new M5 tunnel projects

WestConnex is one of the New South Wales government's key infrastructure projects. This 33 km (20.5 mile) project aims to ease congestion and connect communities and is the largest integrated transport and urban revitalization project in Australia. It was a key recommendation of the State Infrastructure Strategy released in October 2012. It brings together a number of important road projects, which, together, form a vital link in Sydney's Orbital Network. These road projects include a widening of the M4 east of Parramatta, a duplication of the M5 East, and new sections of motorway to provide a connection between these two key corridors. The WestConnex project includes a number of stages: Stage 1a: M4 Widening; Stage 1b: M4 East; Stage 2: New M5; and Stage 3: M4–M5 Link. The tunnel design referenced in this paper relates to Stage 1b and Stage 2 of the WestConnex Project (Fig. 1).

What are the underlying causes of high horizontal stress?

The effects of high horizontal stress in tunnels and underground excavations have been well-documented in Australian literature (Pells, 1993; Oliveira and Diederichs, 2017). As discussed by Oliveira and Diederichs (2017), two rock failure mechanisms may be observed at stress levels lower than the rock unconfined compressive strength (UCS):

- Brittle failures involving crushing, spalling and or slabbing of intact rock blocks, more often associated with buckling of thin sandstone beds in Sydney.
- Shear failures associated with planes of weakness, either pre-existing or induced by the excavation process, such as faults, cross bedding partings and bedding shears.

The primary cause of such failures is associated with removal of confining rock during tunnel excavation, which causes stress redistribution and results in stress concentration around the excavated periphery. This induced stress condition can be estimated using classical solutions for stress distribution around an elastic circular opening, such as that given in Fig. 2. As shown, the horizontal stresses within the tunnel crown increase proportionally with the horizontal-to-vertical stress ratio (λ). Therefore, the effects of induced high horizontal stresses can be expected to be more pronounced with increasing depth.

Considering that rocks like sandstone may fail at stress levels of approximately 50 percent of the UCS (Oliveira and Diederichs, 2017), it can be easily demonstrated (using the classical solution of Fig. 2) that the risk of stress-induced failure increases beyond depths of 40 to 50 m (131to164 ft) in Sydney. Therefore, the excavation induced stresses estimated with recent approximations of in situ stress magnitude (Table 1) approach values of approximately 12.5 MPa, which are equivalent to 50 percent for an average Hawkesbury Sandstone UCS = 25 MPa (Table 2).

The effect of such high horizontal stresses is often altered locally by the presence of major geological features, such as valleys, fault zones, and dykes, but also varies with orientation and with respect to stronger and/or weaker bands of rock — all making for variability and unpredictability. In addition, another important factor is the presence of planes of weakness, particularly bedding partings near an excavated tunnel,

FIG.2

Stress distribution around an elastic opening.

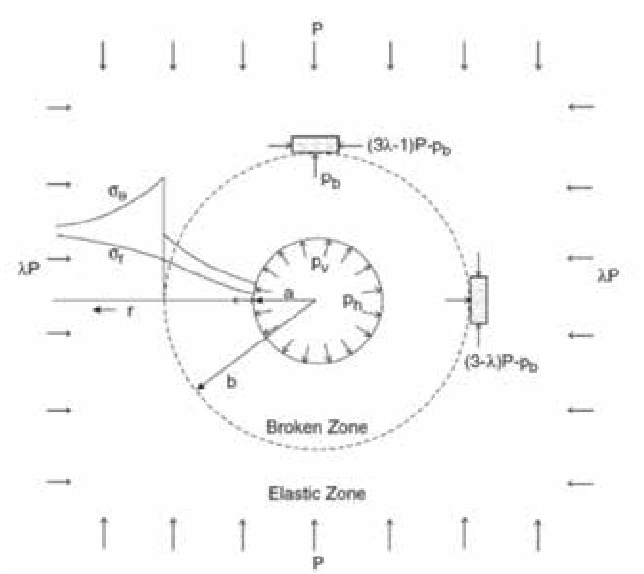


Table 1

Approximations of in situ stress magnitude in the Sydney Basin.

Horizontal stress	Bertuzzi (2014)	Oliveira and Parker (2014)
Major Horizontal Stress, σ_H	2 σV + (1.5–2.5) MPa	(3.0–3.8) σ_V + (1.0–1.2) MPa
Minor Horizontal Stress, σ_h	0.7 σ_H	0.61 σ_H
Note: σ_V denotes vertical stress.		

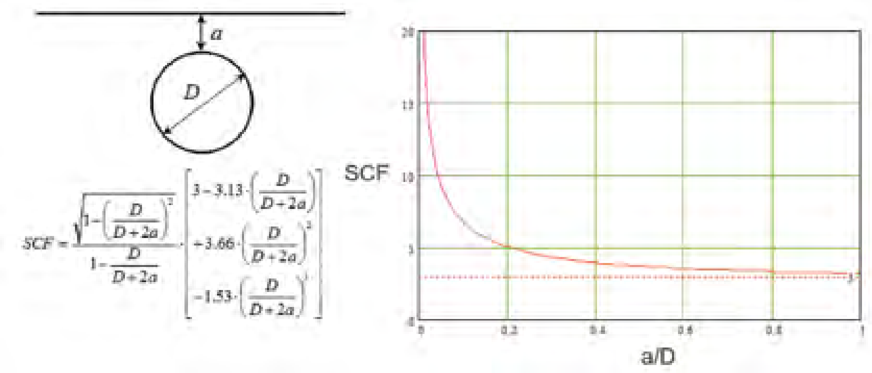
Table 2

Tunnel depth assessment for susceptibility to elevated stress condition and its effects.

In situ stress approximation	Depth of cover (m)	Vertical stress before excavation, ÓV (MPa)	Horizontal Stress before excavation, ÓH (MPa)	Horizontal-to-vertical stress ratio λ	Horizontal Stress after excavation, σ1 (MPa)
Bertuzzi (2014)	40	0.96	2 σV + 2.5 = 4.42	4.60	12.29
Oliveira and Parker (2014)	50	1.20	3 σV + 1.0 = 4.6*	3.83	12.59
* Note the lower range of Oliveria and Parker’s (2014) approximation was used, since a UCS of 25 MPa was adopted in this example. The upper range of Oliveria and Parker’s approximation corresponds to Sandstone with a UCS of 30 MPa.					

FIG.3

Stress concentration factor of a circle on an edge (after Asche and Cooper, 2002).



which magnify the induced stresses. For example, the simplified solution provided in Fig. 3 (Asche and Cooper, 2002), indicates that the stress concentration factor of SCF = 3 given in Fig. 2 may increase to approximately SCF = 7 for a low friction bedding parting located at about 0.5 m (1.6 ft) above a 7 m diameter (23 ft) tunnel.

What are the issues associated with high horizontal stress?

The immediate effect of elevated excavation induced horizontal stresses near a tunnel is the occurrence of significant shear displacements on subhorizontal discontinuities. Such an effect may cause damage to rock bolt corrosion protection, thus affecting durability, and, in more severe cases, tensile rupture of the bolts (Oliveira and Diederichs, 2017). The shear displacements may also induce local loosening of rock wedges or blocks near excavation shoulders. Because of the way the excavation stress release occurs, this can be a nuisance behind the face. In addition, such stress concentrations cause localized rock mass failures in the crown (as previously discussed), which require appropriate ground support with rock bolts and shotcrete.

An important aspect for the design of such a ground support is that the staged release of excavation induced stress means that the effect does not necessarily occur entirely at the excavation face. This becomes more pronounced when taking into account 3D effects, such as the orientation of the excavation in relation to subhorizontal discontinuities that affect stress concentration, as discussed. For instance, driving downhill means that bedding partings would typically rise into the roof, transitioning from a low stress concentration factor (SCF) to an extreme or high SCF environment where brittle failure is more likely, thus giving rise to the feeling that this is “unpredictable.” This condition is shown in Fig. 4, where the SCF transitions from low at section A-A to extreme at section B-B. A real example of this case is presented in Fig. 5, where the roadheader marks indicate failure occurred close to the face. On the other hand, driving uphill can mean that rock spalling is triggered backward from a failure initiating closer to the face when the stresses exceed the applicable spalling limit — for example, at section B-B and propagating to C-C (Fig. 6). This also gives rise to the feeling that it is unpredictable. Oliveira and Diederichs (2017) presented a simplified numerical figure to illustrate initiation of a brittle failure at a distance of 2 to 2.5 times the height of the excavation (Fig. 7).

The major implication of potential stress induced failure post excavation relates to safety risks for construction personnel who require access within the tunnels. Current tunnel construction practice is to have no personnel entry under unsupported ground because of legislative requirements. Supported ground is currently defined, within competent Sandstone on the New M5

FIG.4

Stress concentration on a downhill drive.

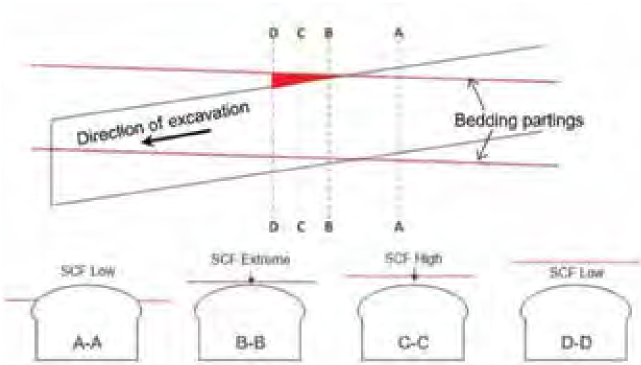


FIG.5

Stress-induced spalling in the M5 East Tunnel (after Mc-Queen et al. 2017).

and M4 East, as when both rock bolts and shotcrete have been installed, with the shotcrete having gained a certain minimum strength. Stress-induced spalling is therefore an issue if it occurs within supported ground conditions.

Given that rock bolts and shotcrete are installed soon after excavation, confinement is provided to the tunnel periphery. The level of confinement provided by the rock bolts and shotcrete is low. However, rock bolts provide sufficient retaining capacity should the spalled rock be wide enough to be captured by the rock bolts. Analysis of the results presented herein suggest that the plausible stress-induced spalled rock size rarely exceeds the extent of one rock bolt spacing. Any residual spalled rock not retained by rock bolts must, therefore, be accounted for in the design of the applied shotcrete.

However, the process of stress fracturing is complex and dependent on multiple factors. Hence, the ground-support interaction is also complex and so is the design, particularly with shotcrete applied early to the excavated rock (due to supported ground requirements). Such complexity can only be addressed by an observational approach during construction in an attempt to manage such risks.

Design strategy

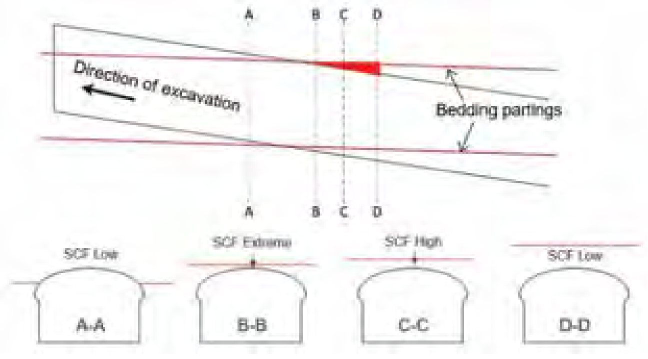
There is no practical way to avoid stress-induced spalling and other related consequences, and the associated risk of such an event occurring after support installation (i.e., under supported ground) cannot be ignored. The consequences of rock spalling on permanent shotcrete lining (particularly post installation) are that relatively large volumes of broken rock may build up behind the permanent shotcrete lining some distance behind the excavation face. This buildup of broken or spalled rock could induce fallout of shotcrete and rock. This raises a safety risk for the construction personnel as well as for the long-term end users of tunnels.

The large shear movement associated with stress-induced spalling may also impact the longevity of installed rock bolt reinforcement. The large shear movement may exceed the allowable shear limit of the rock bolts' corrosion protection (plastic sheath). The damage of the corrosion protection means that the residual design life of the rock bolts is reduced and does not meet the design durability requirement. Rebolting of sheared rock bolts will be necessary to maintain the design life requirement in this case.

The design aim is to implement controls to reduce the probability of ground support damage should stress-induced spalling occur. Given that stress-induced spalling cannot be fully avoided with reasonably practical means, the consequences are unlikely to change. The associated risks detailed above therefore remain. Based on practical risk analysis, control measures must be applied so that the likelihood of ground-support damage is reduced, and the overall risk level of a stress-induced spalling event of shotcrete and bolt shearing is thereby reduced to an acceptable level.

FIG.6

Stress concentration on a uphill drive.



The viability of any proposed control measure depends on its ability to meet the construction constraints where applicable/possible such that it must perform the following:

- Integrate and be compatible as much as possible with the already developed typical tunnel excavation and support installation sequence for tunnels without a stress-induced spalling problem.
- Incorporate either rock bolts or shotcrete as tunnel support. Support elements other than rock bolts

FIG.7

Potential spalling of a 1 m thick (3.3 ft) bed above crown behind excavation face (after Oliveira and Diederichs, 2017)

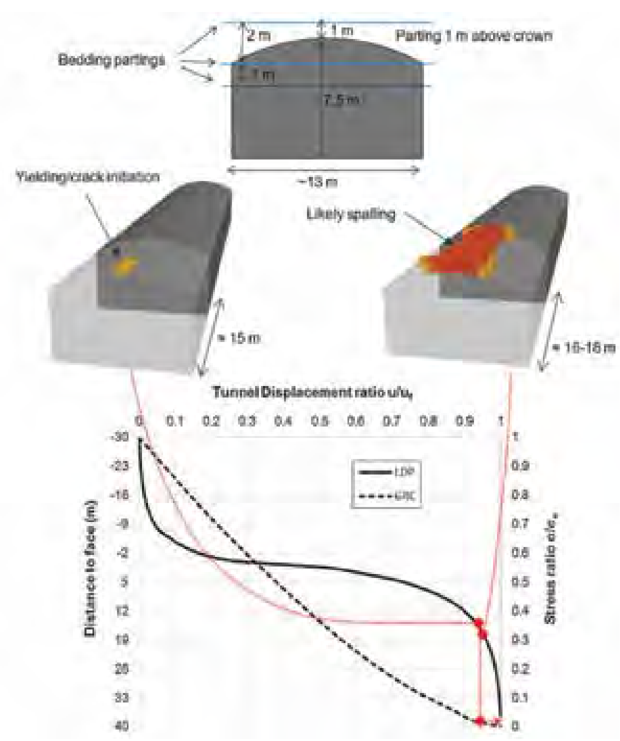
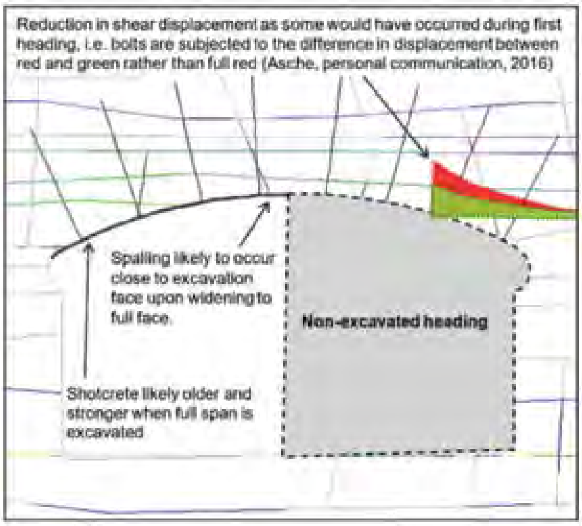


FIG.8

Benefits of split heading on tunnel support (after Oliveira and Diederichs, 2017).



and shotcrete may yield procurement difficulty and increase construction complexity.

- Conform to the protocols of the project-wide instrumentation and monitoring plan in the context of identification and transition in and out of elevated stress conditions.
- Yield tangible triggers to facilitate site-based observations. This follows, in principle, the observational approach of conventional tunneling with sequential excavation.

Site feedback, guided by in situ observational triggers, are adopted to make adjustment(s) to the already developed tunnel support design. Control measures for elevated stress conditions are thus developed as adjustments to already developed typical tunnel support with associated monitoring triggers.

Selected control measures for elevated stress condition

The selected risk control measures adopted for elevated stress conditions are:

- Mandatory split headings with minimum lag distance between headings: Typical tunnel cross sections applicable to these WestConnex projects are excavated using multiple headings. Each heading is approximately 5.5-m to 7-m wide by 6-m high (18-ft to 23-ft wide by 20-ft high). A 10-m (33-ft) minimum lag distance (approximately 1.5 times the single heading span of 7 m (23 ft)) between headings has been adopted. The main objective of the split heading (Fig. 8) is to induce the brittle failure near the face of the second heading and reduce the shear displacements within the second heading.
- Staggered rock bolt pattern: For the New M5 tunnels, the typical rock bolt pattern was adopted as square. However, for ground support against an elevated stress condition, the rock bolt pattern is altered to staggered. For the M4 East tunnels, the staggered rock bolt pattern is typical, and thus this control is less sensitive. Rock bolt spacing is also tightened where applicable. The benefits of a staggered pattern is its increased ability to contain fracture propagation within a bolt spacing. This prevents fractures from extending over multiple bolt spacings, with associated increased displacements, as would be observed for a square pattern (Fig. 9).
- Increased shotcrete thickness: The primary shotcrete developed for these projects is generally quite thin and relies on adhesion to the substrate. The thinnest crown primary shotcrete thickness is 55 mm (2.2 in.) for Sandstone Class I in the New M5 tunnels and 60 mm (2.4 in.) in the M4E tunnels. The minimum shotcrete thickness adopted for elevated stress condition is 125 mm (4.9 in.) targeting flexural capacity.

FIG.9

Square (a) vs Staggered (b) reinforcement pattern performance during brittle failure (after Villaescusa et al., 2016)

Numerical analysis

Numerical analyses were undertaken to assess responses of the rock mass and installed tunnel support subjected to elevated stress conditions. These numerical analyses include continuum (utilizing FLAC2D and FLAC3D) and discontinuum analyses (utilizing UDEC and RS2). The studies undertaken utilizing these analyses aided development of the adopted control measures for elevated

Table 3

Tunnel depth assessment for susceptibility to elevated stress condition and its effects.

Rock mass properties		Ground types		
		Type 1	Type 2	Type 3
Unconfined compressive strength, MPa	UCS	30	25	20
Unit weight, kN/m³	□	24	24	24
Rock mass modulus, MPa	E_m	6,000	4,000	3,500
Poisson's ratio	□	0.2	0.2	0.2
Peak parameters	m	0.750	0.625	1.250
	s	0.063	0.063	0.063
	a	0.25	0.25	0.25
Residual parameters	m	9	9	9
	s	0.0001	0.0001	0.0001
	a	0.75	0.75	0.75

stress conditions.

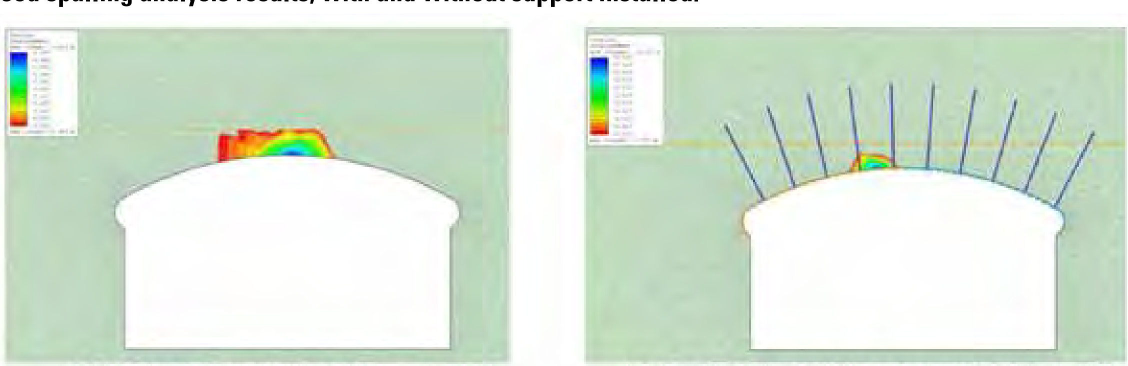
To assess the tunnel support performance when the support is subjected to elevated stress condition, additional rock material modelling was undertaken. Recent research development has shown that to better capture the stress-induced spalling zone and extent around a tunnel, a modified failure criterion for the rock mass should be used (Diederichs et al., 2010; Oliveira and Diederichs, 2017). Table 3 presents a set of modified Hoek-Brown rock mass material parameters adopted for these projects.

Figure 10 presents the analysis results as part of the evaluation of the stress-induced spalling effects. Two heading excavations followed by bench excavation have been adopted for the analysis results shown. A single bedding parting set at 1 m (3.3 ft) from the tunnel crown has been analyzed, with and without support installed. Rock spalling is likely to extend toward the full depth of rock bounded by the tunnel excavated periphery and bedding parting. With support installed, the rock spall size is much reduced. This confirmed the beneficial confinement effects provided by the rock bolts and shotcrete.

By adopting the same excavation sequence and material model, the effect of rock bolt shearing was assessed. Twin mainline tunnels were analyzed within the same cross section to capture the effects on the adjacent tunnel (Fig. 11). The results showed that potential rock bolt shearing is only likely to be confined to the lead heading of the first excavated tunnel. The magnitude of shear displacements is likely to exceed the shearing limit for corrosion protection, but does not exceed the ultimate structural capacity of rock bolts. That is, if elevated stress conditions are observed, rebolting for long-term reinstatement will be required and is likely to be limited to the rock bolts installed within the lead heading of the first excavated tunnel. This concludes that if there is sufficient

FIG.10

Stress-induced spalling analysis results, with and without support installed.

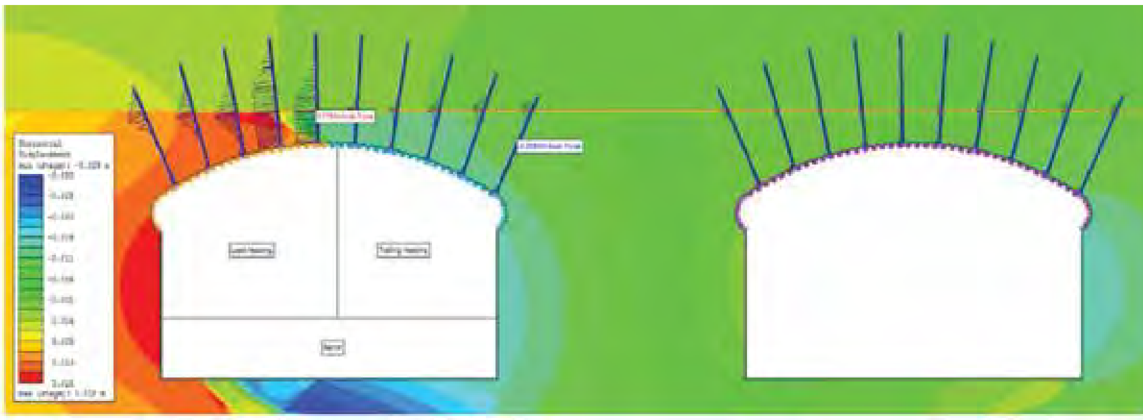


(a) Rock spall prediction with no support

(b) Rock spall prediction post-support installation

FIG.11

Rock bolt shear assessment.



lag distance between the lead and trailing headings of the first tunnel, the extent of rebolting required will likely decrease. Confirmation of the extent of rebolting typically is done using endoscope observations.

Based on the spalling analysis results, it was assessed that the most likely rock spall depth ranges from 0.5 m to 0.7 m (1.6 to 2.3 ft); subject to different ground conditions. Rock spall extent is slightly greater than a one-bolt spacing (Fig. 10). Staggered rock bolt patterns were then adopted/confirmed to better arrest and contain spalling rock as discussed above. With the rock bolts arranged in a staggered manner, the longitudinal strip of spall rock is arrested and contained. The staggered rock bolt pattern is therefore considered more suitable for elevated stress conditions.

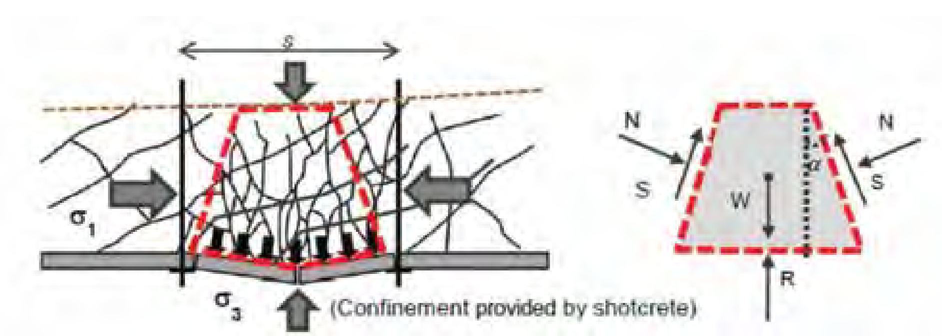
Additional analyses were undertaken to evaluate the performance of the primary shotcrete lining. The prevalence of rock spall within a one-rock-bolt spacing suggests that the shotcrete needs to provide retaining capacity to retain the rock spall. Stress-induced spalling is a fracture process that likely induces multiple fractures within the rock spall, especially when the spall rock size is relatively small (Fig. 12). The mechanism involves a load transfer of the spall rock weight to the shotcrete, which in turn transfers to the rock bolts through the connection between the shotcrete and the rock bolt. A typical rock bolt–shotcrete connection is facilitated using handle bar plates. The primary shotcrete lining is therefore critical for containment of the rock spall.

Deterministic structural analysis based on Barret and McCreath (Oliveira and Diederichs, 2017) was then undertaken to assess the mechanical response of the shotcrete. This analysis assumes that the process of stress fracturing is associated with ground stress dissipation (i.e., stress transfer from the rock mass movement to the shotcrete is reduced to a negligible magnitude). However, it was also realized that some level of in situ stress remains within the spall rock boundary, providing frictional restraint (Fig. 12). The overall rock spall weight was then adjusted accordingly when applied to the deterministic analysis to determine an appropriate shotcrete thickness.

The assumption of stress dissipation used in the deterministic analysis is not definite. There is limited evidence or in situ experience available to confirm this assumption. The complexity of the stress fracturing process and the associated ground stress transfer/dissipation to the shotcrete is not completely understood. The implication is that the risk of shotcrete failure is further increased, regardless of shotcrete thickness (reasonably practical thickness), because of the magnitude of plastic strain experienced during stress fracture. The primary shotcrete was analyzed using numerical analyses to confirm adequacy of the adopted shotcrete thickness.

FIG.12

Assumed shotcrete mechanical response to support stress-induced spalling rock (after Oliveira and Diederichs, 2017).

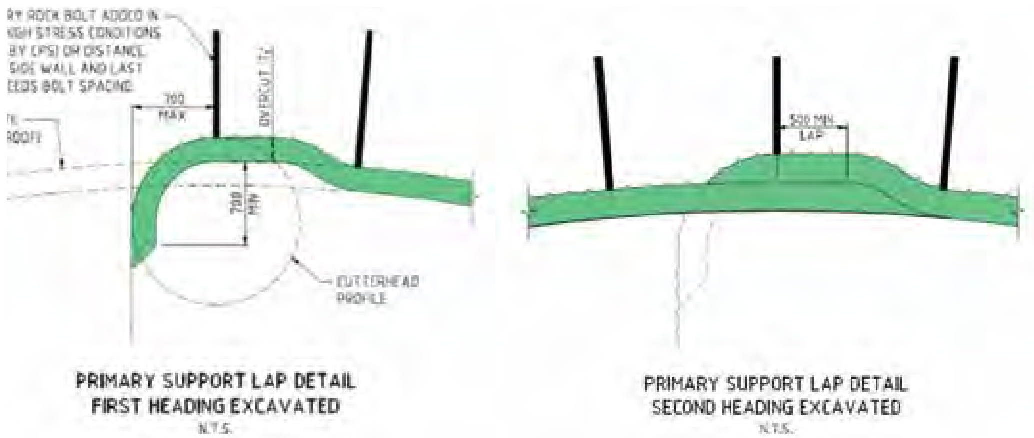


Design outcomes

The different analyses

FIG.13

Lap detail adopted for addressing spalling risks between lead and trailing headings.



undertaken indicate the adequacy of the control measures adopted for the elevated stress conditions in these projects. To facilitate implementation of these control measures, a set of observational criteria was developed:

Elevated stress condition susceptibility definition. Tunnel sections defined below shall be classified as areas subject to potential rock spalling risk:

- First bedding ≤ 1.5 m (4.9 ft) above crown.
- Presence of any seams or shears ≤ 1.5 m (4.9 ft) above crown.
- Presence of shale lens or mudstone facies ≤ 1.5 m (4.9 ft) above crown.

Note the first bedding distance of 1.5 m (4.9 ft) from tunnel crown was set to provide an early alarm to initiate in situ observations earlier. This was to better react and to implement control measures in advance.

Elevated stress condition observational triggers/ identifiers. High stress conditions are evidenced by a combination of (but not limited to):

- Ground cover greater than 45 m (148 ft).
- Higher horizontal ground movement measurements (above 75 percent of the amber level of the typical conditions).
- Spalling or cracking of shotcrete within two weeks of application.
- Higher horizontal movements detected in endoscopes (more than 9 mm or 0.4 in.).
- Presence (or predicted presence) of a subhorizontal discontinuity or adverse feature(s) within 1.5 m (4.9 ft) of the tunnel crown. This can be predicted:
  - o If the bedding is rising in the face — from geological face mapping.
  - o If the bedding is falling toward the crown — from geotechnical endoscope mapping.

The above observational triggers/identifiers were also adopted to aid removal of elevated stress control measures.

The strategy of the elevated stress control measures is:

- To promote stress-induced spalling to occur at the lead and trailing heading interface. This is to permit/aid removal of spall rock during trailing heading excavation, and constrain spall rock to unsupported or less trafficked supported ground.
- To reduce the uncertainty related to rock bolt shearing. Endoscope installation density is also increased (doubled) to better define the affected extent of rock bolts.
- To give time for shotcrete strength gain to provide support to spall rock.
- To control spall rock failure after support installation with increased shotcrete thickness and tightening of rock bolt spacing such that tangible damage (i.e., not sudden brittle failure fallout) can be observed and minimized.

It should also be noted that, although the M4 East project incorporated a few of these key control measures, the majority were developed as part of the New M5 project given that, on average, the tunnels are located at greater depths.

Construction observations to date

Limited construction data are available to date from these projects that may indicate stress concertation. However, anecdotal observations to date across both projects indicate larger overbreak in sections that are deeper than 45 m (148 ft). Additionally, lead heading shotcrete near the central temporary haunch has exhibited a slightly higher frequency of cracking than in other parts of the tunnel. Although this correlates well with spalling analysis results, a new lap detail at the lead and trailing heading interface was developed to mitigate risks associated with overstress of the primary shotcrete lining (Fig. 13).

Conclusions

Limited construction data are available to date to provide sufficient validation to the design implemented for high stress condition for the WestConnex Project. Construction observations are ongoing to provide feedback to the performance of the selection system. However, the construction data collected to date show that the expectation for elevated stress conditions perceived from the design analysis presented in this paper holds. This concludes that an observational based approach allows for selection of adequate tunnel support design to manage the risks associated with elevated stress conditions. Coupled with engineering judgment, the design principles discussed in this papers although developed for Sydney Sandstone, are applicable to other conventionally excavated tunnels in horizontally bedded strata of similar stress states. ■

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Cross passage freezing from the ground surface

The Northgate Link Extension project is the third phase of the Sound Transit master plan to extend light rail throughout the greater Seattle metropolitan area. When completed, the Northgate Link Extension will extend the existing light rail system north by about 7 km (4.3 miles) from the University of Washington to the Northgate neighborhood. A general overview of the project alignment is provided as Fig. 1. The project was funded by a combination of federal grants and allocations from local taxes. The general contractor on the project was JCM Northlink LLC (JCM), a joint venture between Jay Dee Contractors, Frank Coluccio Construction Company and Michels Corp. SoilFreeze, Inc. was retained as a subcontractor to provide ground freezing design and construction services.

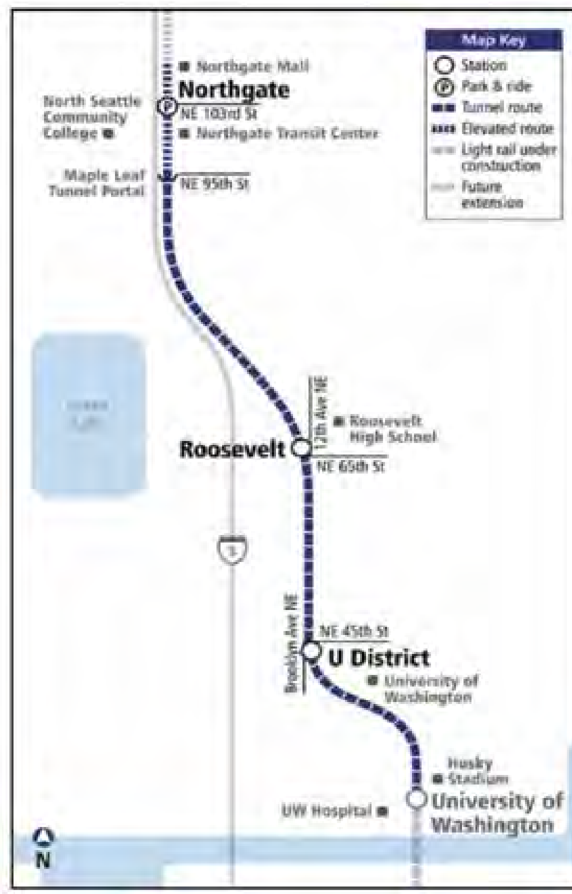
The project involved the construction of two parallel 5.5-m, 25-cm (18-ft, 10-in.) (inside) diameter tunnels using earth pressure balance (EPB) tunnel boring machines (TBM) and precast segmental concrete tunnel liners. The two tunnels maintained roughly the same elevation along the alignment and were spaced roughly 12 m (40 ft) apart (centerline to centerline). A total of 23 cross-passages connecting the two tunnels were included at approximate 244-m (800-ft) intervals. Cross passage excavations were elliptical in shape with dimensions of approximately 5.6 m (18.5 ft) in height and 5.3 m (17 ft) in width. The cross-passages were 5.8 to 6.1 m (19 to 20 ft) long as measured between the exterior of the tunnels at springline elevation. Cross passages were intentionally located directly beneath public right-of-ways thus avoiding buildings. Many of the cross passages were located beneath narrow roads in residential neighborhoods with mature vegetation, existing utility structures and piping and limited parking areas. Excavation and support for each cross passage was completed using the sequential excavation method (SEM).

The subsurface soil and ground water conditions at the cross-passage locations were described in the Northgate Link Geotechnical Baseline Report (GBR) prepared by Jacobs Associates and the Northgate Link Geotechnical Data Report (GDR) prepared by Shannon and Wilson, Inc. Soils along the project alignment were glacially overridden and characterized as very dense or hard. Subsurface soils consisted of cohesionless sand and gravel (CSG), cohesionless silt and fine sand (CSF), cohesive clay and silt (CCS) and till and till-like deposits (TLD).

The contract documents identified three categories of ground support systems for the cross-passage excavations based on the soil conditions identified at each location. Category 3 ground support systems required ground improvement before excavation could begin. Category 3 cross passages were typically the most difficult

FIG. 1

General overview of the Northgate Link Extension project (image credit: SoundTransit)



Aaron K. McCain, Brenton Cook, Nate Long and Larry Applegate

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soil conditions located near a transition between very permeable sandy CSG and the less permeable CCS or CSF. The boundary between the two dissimilar soils would have rendered dewatering efforts ineffective, as sufficient ground water drawdown could not be achieved. Initially five cross passages were identified as Category 3, but freezing was used to stabilize the soils for an additional five after soil explorations identified difficult soil conditions at those locations.

The five cross passages initially requiring Category 3 ground support and frozen from the ground surface are as follows:

- Cross Passage No. 21 (CP 21): The center line of the excavation was approximately 34 m (113 ft) below the ground surface (bgs).
- Cross Passage No. 29 (CP 29): The center line of the excavation was approximately 39 m (125 ft) bgs.
- Cross Passage No. 30 (CP 30): The center line of the excavation was approximately 37.5 m (123 ft) bgs.
- Cross Passage No. 31 (CP 31): The center line of the excavation was approximately 35 m (114.5 ft) bgs. In addition, CP31 was located at the low point of the tunnel alignment and included a sump pit which extended about 5 m (16 ft) below the centerline of the cross passage.
- Cross Passage No. 32 (CP 32): The center line of the excavation was approximately 23 m (76 ft) bgs.

Ground freezing for Category 3 cross passages

Ground improvements for Category 3 ground support systems were originally specified to be jet grouting or ground freezing. JCM was concerned with community and environmental impacts of the jet grouting in the densely populated urban/residential environment. In addition, freezing presented a more flexible schedule than jet grouting as the work could be done before or after the TBM had passed the location. As a result, JCM opted to pursue ground freezing as the preferred method to improve soils conditions.

Ground freezing involves circulating calcium chloride brine, chilled to -15 °F (-26 °C) or colder, through an array of steel pipes installed within the subsurface. Heat is extracted from soils immediately around each chilled steel pipe, freezing ground water within the soil matrix. As soils freeze radially outward from individual chilled pipes, the frozen soils from adjacent pipes eventually overlap to form an impermeable barrier with increased strength and stiffness. Ground freezing only needs to change the temperature of in-situ soils in contrast to more intrusive methods such as injection, permeation or replacement. Advantages of ground freezing include: the ability to pinpoint the location of the freeze pipes and thus the extent of the ground freezing; the ability to verify the extent of ground freezing through ground temperature monitoring; and minimal disturbance and spoils management at the ground.

At the request of JCM, SoilFreeze provided an approach that installed the majority of freeze pipes from the ground surface so that larger freeze equipment would be located out of the tunnels. Smaller freeze systems installed within the tunnels would supplement the primary freeze system elements from the ground surface. JCM felt that freezing from the ground surface would achieve two principal goals: 1) limit the work and equipment that needed to be located within the tunnels and 2) remove the bulk of the freeze system installation off the critical path of the project by installing the freeze pipes independent of the completion of the tunnels.

Design and installation of the ground freeze system

The choice to freeze from the ground surface contained technical and outreach challenges that were successfully addressed and mitigated through careful, innovative design and progressive, forward-thinking during the construction process. The primary challenge of freezing from the ground surface was to maximize the benefit of freezing for successful excavation of the cross passages while minimizing impacts to existing near surface infrastructure and the newly installed tunnels. Specific challenges can be categorized in these two areas: 1) within the freeze around the tunnels and 2) at the ground surface.

Specific challenges within the freeze zone included:

- Development of a frozen soil zone within time frames required by the construction schedule.
- Coordinating freeze pipe installations to minimize the number of pipes intersecting the path of the cross-passage excavations.
- Freezing the areas in the “shadow” of the tunnel, beneath the tunnel haunches where freeze pipes from the surface cannot access.
- Ensuring that frozen soils sufficiently adjoin to the extrados of the warmer tunnel liner segments.
- Ensuring that sufficient freeze continues during excavation and subsequent construction of the cross passage.
- Methods to manage and/or mitigate pressures that develop on the tunnel liner segments.

The specific challenges at the ground surface included:

- Optimize the freeze system to minimize electrical demands due to power supply restrictions.
- Coordination with utility entities to protect, maintain, and not interrupt, existing infrastructure crossing through work zones.
- Mitigating potential impacts to nearby residences resulting from equipment noise, limited vehicular access, and damage to landscaping.

- Methods to manage and/or mitigate ground movement associated with freezing activities.

Design of the frozen soil shoring system

In general, the design of a frozen soil shoring system requires two types of analysis. The first is a thermal analysis where the freeze pipe spacing, extent of frozen soil with time and frozen soil temperatures within the frozen soil shoring are determined. This information is then used to estimate frozen soil geometry and strengths to be implemented in a constitutive geotechnical analysis. The constitutive geotechnical analysis assesses deformations, stresses and strength-based factors of safety that could be anticipated within a given frozen soil shoring system.

Highly specialized two-dimensional (2D) engineering software was used for the thermal analysis. The thermal software utilizes finite element methodology to accurately evaluate thermal variations in the ground. Specifically, the thermal software calculates transient (time-dependent) frost growth around chilled freeze pipes within a 2D plane.

Three-dimensional (3D) constitutive geotechnical analyses were calculated using finite element software. This computer software is capable of analyzing stress and strain behavior for complex 3D soil geometries under static or dynamic loading conditions. Soil-structure interaction between unfrozen soils, frozen soils, ground water and structural elements can be effectively analyzed.

Iterative thermal analyses were used to conclude that a grid of 30 freeze pipes was sufficient to freeze the soils between the two tunnels within a six- to eight- week time frame. This time frame was governed primarily by the cohesive soils that were present at each location. Cohesive soils typically have a higher moisture content, and therefore, a higher latent heat. Freeze pipes were arranged in a grid pattern consisting of six columns of five pipes as shown in Fig. 2. The profile of the approach is provided as Fig. 3. The spacing between each column of freeze pipes was approximately 1.4 m (4.5 ft) while the spacing between rows of freeze pipes was about 1.2 m (4 ft).

The outermost columns of freeze pipes, in the plan, were positioned outside the excavation limits of the cross passages. This left approximately 20 pipes that would be encountered during excavation for each cross passage. A grid pattern with fewer pipes would not adequately freeze the soils above and below the cross passage within the project schedule.

The circular shape of each tunnel restricted access from the ground surface to soils below the springline elevation of the tunnels directly adjacent to the extrados of either tunnel liner, thus forming a freeze shadow.

FIG.2

General plan view of freeze pipe grid pattern.

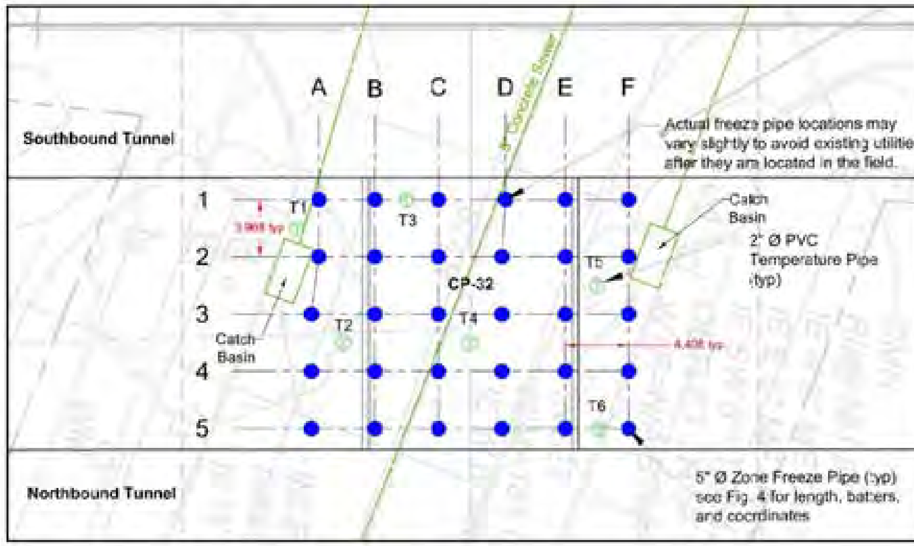


FIG.3

General profile view of freezing approach.

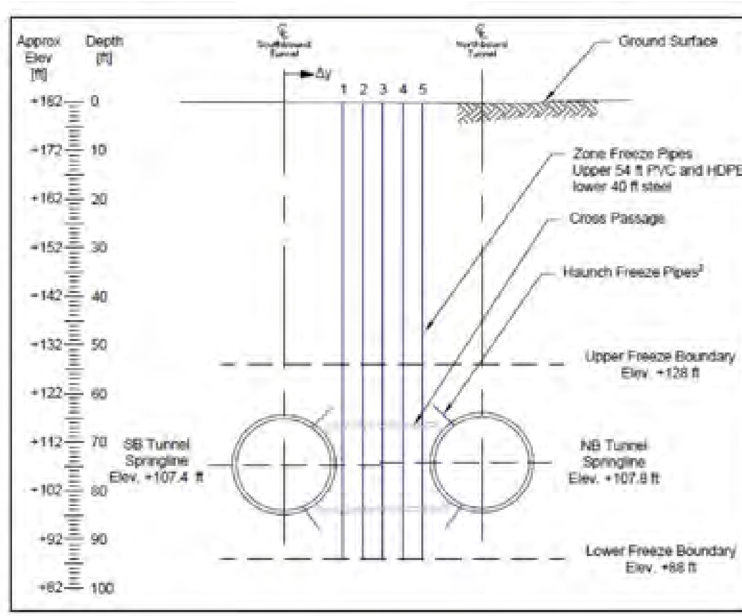


FIG.4

In tunnel haunch and interface pipe layout.

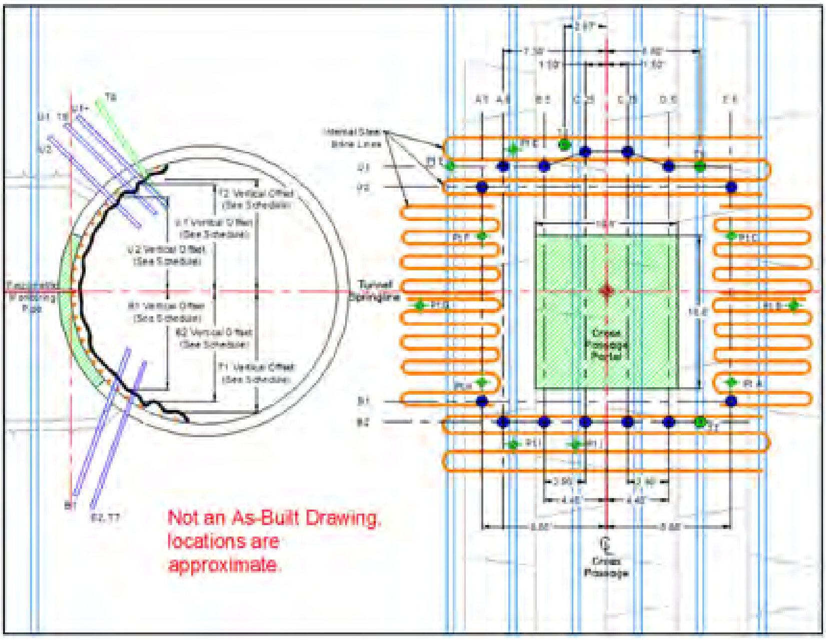


FIG.5

In tunnel freeze system operation.

Short haunch freeze pipes were installed through the tunnel liners below the springline of both tunnels to freeze just beyond the limits of the excavation. Although a shadow did not exist above the tunnels, it was decided that haunch freeze pipes would also extend above the springline of the tunnels instead of drilling additional freeze pipes from the ground surface.

Typical locations of haunch freeze pipes are shown in Fig. 4. The number and location of the haunch freeze pipes varied at each location based primarily on the potential for ground water gradients following the tunnel alignments. Installation of the haunch freeze pipes did require a chiller to be installed in each tunnel, however the size of the chiller was significantly smaller than one that would be required to freeze the entire freeze zone. The in-tunnel chillers were placed on elevated platforms installed along the interior the tunnel liners, near springline elevation. The in-tunnel chillers did not impede traffic or work within either tunnel.

A final design hurdle involving freeze pipe positioning was to develop a system that would ensure that frozen soils would remain frozen directly adjacent to the tunnel liner extrados. This interface represented the weakest point of the frozen soil shoring. Ventilation systems actively circulating air through the tunnels warmed the interior face of the segmental concrete tunnel liners. This air circulation acted to create a warm internal boundary that could generate enough of a thermal gradient through the concrete liner to thaw a thin layer of soil and induce a seepage path into the excavation. To combat the warmth imparted by the ventilation system, steel pipes circulating chilled brine were affixed to the interior face of the tunnel liners surrounding the proposed cross passage portals, as shown in Figs. 4 and 5. Chilled brine was supplied to these pipes using the same chiller systems that were installed for the haunch freeze pipes. Additionally, insulation blankets were affixed to the interior surfaces of the tunnel liner to limit warm air exposure.

The system of vertical freeze pipes installed from the ground surface in combination with the in-tunnel freeze pipe systems, were analyzed using both the thermal and constitutive geotechnical models previously discussed. Thermal models predicted a zone of ground improvement significantly smaller than the specified ground modification extents presented in the project drawings. Despite the frozen soil zone being smaller than specified, constitutive models indicated that maximum frozen soil deformations during excavation would be less than 1.3 cm (0.5 in.) at the crown of the cross passage, with little to no deformation at the invert of the cross passage. In addition, the calculated strength-based factor of safety for the frozen soil shoring generally exceeded 5.0 at each cross-passage location. Reviewers eventually allowed for a reduction of the modified soil zone extents for three reasons: 1) the location of each freeze pipe would be known; 2) the radius of frozen soil around each pipe is relatively uniform and predictable using thermal modeling and 3) the extent of the frozen soil could be verified and monitored using thermocouple sensors placed at key locations.

SoilFreeze employed zone freeze pipes as the primary freeze elements that would be installed from the ground surface. Zone freeze pipes are a patented system designed to isolate freezing within a targeted zone at depth. Zone freeze pipes work by circulating chilled brine through a 10-cm (4-in.) steel vessel with high heat transfer characteristics that forms a freezing length at depth. The portion of the zone freeze pipe extending from the top of the steel vessel to ground surface is comprised of high-density polyethylene (HDPE) brine delivery lines confined within a gasketed, watertight, polyvinyl chloride (PVC) sleeve. The HDPE lines are buffered from the PVC sleeve and the surrounding soils using air to form an insulated length with intrinsically low heat transfer characteristics. The insulated length of the zone freeze pipe served to minimize freezing of soils extending above the targeted freeze zone to the ground surface, thus reducing the required chiller capacity and maximizing system efficiency. This resulted in lower energy demand and also minimized the freeze system footprint within the narrow above-ground streets. It was estimated that the zone freeze pipe technology reduced the required chilling capacity and power requirements by at least half. Assembly of the insulated PVC portion of a zone freeze pipe installation is shown in Fig. 6.

FIG.6

Installation of the PVC portion of a zone freeze pipe.

Installation of the freeze system

The installation process for each freeze system posed its own unique set of challenges. When the freeze pipe grid was superimposed on existing conditions at each site, conflicts were apparent, requiring adjustments. The following is a summary of the conflicts at the ground surface for each cross-passage location.

- CP 21 — The location of the cross passage was partially located beneath a low traffic, two-lane roadway at the southeast corner of the University of Washington campus. The entire eastern half of the cross passage was located beneath a vegetated slope that could not be disturbed, requiring that all work had to be completed within an area that was less than half the size of the designed freeze pipe grid at depth. In addition, a 20-cm (8-in.) ductile iron water line and manhole structure were located within the work area.
- CP 29 — This cross passage was located beneath a narrow neighborhood side street. There were no buried utilities at this site, however overhead power was present on the north side of the road and local service lines crossed over the road and above the freeze pipe installations.
- CP 30 — This cross passage was located beneath a narrow side street. Large heritage trees were located on the north side of the road, with additional trees just to the south. The heritage trees had protected root zones that extended out into the work zone. Utilities consisted of overhead power on the south side of the road, two buried fiber ducts, a 5-cm (2-in.) gas line, a 31-cm (12-in.) cast iron water line and a 51-cm (20-in.) cast iron water line. Neither of the water lines were located within the work area.
- CP 31 — This cross passage was located below the northbound lane of a residential avenue. Accordingly, the work area was located within the northbound lane and extended slightly beyond the east curb line. The buried utilities extending through the work area consisted of a 104-cm (42-in.) diameter steel riveted water line, a 20-cm (8-in.) cast iron water line and a 5-cm (2-in.) gas line. A fire hydrant was removed prior to mobilizing to the site.
- CP 32 — The shallowest cross passage was located directly below a small residential road located near the intersection with a busier thoroughfare. Overhead power lines were present

to the south of the work area and buried utilities crossing the work area consisted of storm drain laterals, an 20-cm (8-in.) concrete sewer line, a 10-cm (4-in.) gas line and a small 5-cm (2-in.) water line lateral.

Where conflicts were identified, the location of the freeze pipes at ground surface were adjusted. In a few cases the adjustments were minor and the freeze pipes could still be installed vertically. However, in most cases the adjusted freeze pipe locations were significant enough that the pipes needed to be installed at an angle (or batter) to maintain the required spacing at depth. Freeze pipes that were installed at angles so that the freeze vessels passed through the original design grid point in plan at the mid-level elevation of the cross passage excavation. Due to the depth of the cross passages, installation angles were minor, typically ranging between 2 and 10 degrees from vertical. The battered freeze pipes typically resulted in slightly closer freeze pipe spacings at the top of the frozen soil column and a greater spacing at the bottom of the frozen soil column at depth. Thermal models were adjusted to include spatial variations of the freeze pipes with depth at each cross passage. Ultimately it was determined that the extent of the frozen ground was not significantly impacted by these spatial variations.

After layout of the freeze pipe grid was completed and conflicts were identified at each site, JCM returned to the site and installed 31-cm (12-in.) diameter PVC sleeves to mark freeze pipe installs that were located directly adjacent to utilities. In general, this process was safely completed with a vactor truck. The PVC sleeves extended to depths just below the utilities and served as a guide during the installation of the freeze pipes.

The second advantage provided by the PVC sleeves installed by JCM was to provide redundant insulation around the freeze pipes to reduce freezing around utilities. Freezing does not adversely affect most utilities including gas, fiber-optic, sewer, power and running water. However, during negotiations with the various utility agencies, there was an expressed concern about the impact of the freezing temperatures. Therefore, the additional insulation provided around the utilities was an added benefit of the PVC sleeves.

Freeze pipe installations from the ground surface were completed by Cascade Drilling. A steel casing was advanced using sonic drilling techniques to design depths. For each installation, a steel freeze vessel with HDPE brine supply/return lines attached was incrementally lowered into the cased hole while 6-m (20-ft) sections of PVC sleeve were stacked and joints waterproofed. After the freeze pipe was lowered to depth, the steel casing was retracted and the annular space around the freeze pipe was backfilled with grout to the ground surface.

The work zones required to install the freeze pipes blocked the narrow roadways at CP 21, 29, 30 and 32, however a single lane was maintained past the drilling zone at CP 31. Drilling was completed during hours dictated by the city and site cleanliness was maintained throughout the installation process. No complaints were received from the general public during the installations. After freeze installations were completed, roads remained closed at CP 29, 30, and 32. Pipes installed at CP 21 were recessed below the street level and covered with a steel sheet which allowed the road to remain open during freeze operations.

Tracking the locations of each freeze pipe at depth was critical, therefore the steel drill casing was surveyed prior to the installation of the freeze pipe. A downhole gyroscopic survey tool was used to determine the spatial locations of each installation between the tunnels for varying depths. If the space between two adjacent freeze pipes was excessive as determined by an updated thermal model utilizing as-built data, an additional freeze pipe was installed in the gap to maintain the necessary freeze coverage. A total of 14 additional freeze pipes were added for all five cross passages due to drilling inaccuracies. The downhole survey tool was also implemented mid-drilling process for pipes located immediately adjacent to the tunnels to verify that the hole alignment had not drifted towards the tunnel. All drill holes verified in this manner were found to be on target and were installed to depth.

Within the tunnels, JCM was responsible for installation of the haunch freeze pipes to better control schedule and space constraint impacts within the tunnels. JCM installed the short haunch pipes by pre-drilling through a pneumatic packer, removing the drill tooling, then driving the steel freeze pipes to depth. The location and alignment of the short haunch freeze pipes were surveyed by JCM using conventional optical surveying methods.

Freezedown and excavation

Freezedown. Start of freezedown and freezedown durations varied for each cross-passage location. Chilling units servicing the freeze pipes at ground surface were initially powered by generators. At some cross passage locations, chillers at the surface were eventually switched over to the local power grid. Chiller units at the ground surface had footprints of 2.4 m and 5 m (8 ft by 16 ft). One chiller unit was sufficient to freeze each cross passage, except at CP 31 where additional freezing capacity was needed to support the excavation for the deeper sump pit.

Chillers and generators operated full-time during freezedown, excavation and final lining construction phases of each cross passage. Accordingly, mitigation of mechanical noise for each freeze system was a requirement by the city. This was accomplished by using specially designed low-noise fan blades on each chiller unit, working with the power company to get a power drop at each site thereby eliminating the need for generators, and building a sound dampening structure around the generators and chillers. The sound dampening structures were constructed by JCM and consisted of plywood walls internally lined with sound dampening blankets and insulation. Each sound dampening structure was large enough to provide ample air circulation to the chillers, while remaining small enough to fit within the limited footprint at each site. These measures successfully dampened the mechanical noise to less than 63 decibels, the operational threshold allowed by the city.

In general, the frozen soil shoring was formed within the time frame calculated during the design process. Brine and ground temperatures were closely monitored during the freezedown process, using thermocouples installed at various depths around each site. Recorded ground temperature data was used to calibrate as-built thermal models. Measured brine temperatures were used as input to the thermal models and the soil and freeze pipe parameters were slightly adjusted so that the calculated temperatures closely matched the observed temperature trends. The calibrated thermal models were instrumental in estimating spatial extents of the ground freezing at varying depths, as well as extrapolating future development of the frozen soils.

Ground movement. One of the challenges on this project was monitoring and controlling the ground deformation associated with freezing the ground for extended periods of time. The expansion that occurs when pore water undergoes the phase change to ice does not typically cause significant volumetric expansion of a soil unit. However, when freezing is maintained for a long period of time, cryogenic suction will draw water toward the freezing front and can form lenses of pure ice. If conditions permit, such ice lenses can result in segregation heave and excessive deformations at the ground surface.

The zone freeze pipes were never designed to completely prevent freezing of soils extending above the freeze zone at depth. As a result, near surface soils eventually froze during prolonged freezing operations. As the near surface soils froze, some minor heaving at the ground surface was captured by optical monitoring points and extensometers. Observed ground movements were minor and slightly varied at each site. The observed movement was highly dependent on surface water runoff, available ground water, site soils, and instrumentation accuracies. Ground deformation was limited and controlled using a number of techniques which included:

- Managing surface water to limit surface runoff from entering the work area and collecting.
- Adjusting/raising the temperature of the brine. This was a delicate balance between being cold enough to maintain freezing at depth while simultaneously warming near surface soils to limit the development of ice lenses.
- Use of heat trace tape and blowing warm air into the upper portion of the zone freeze pipes.

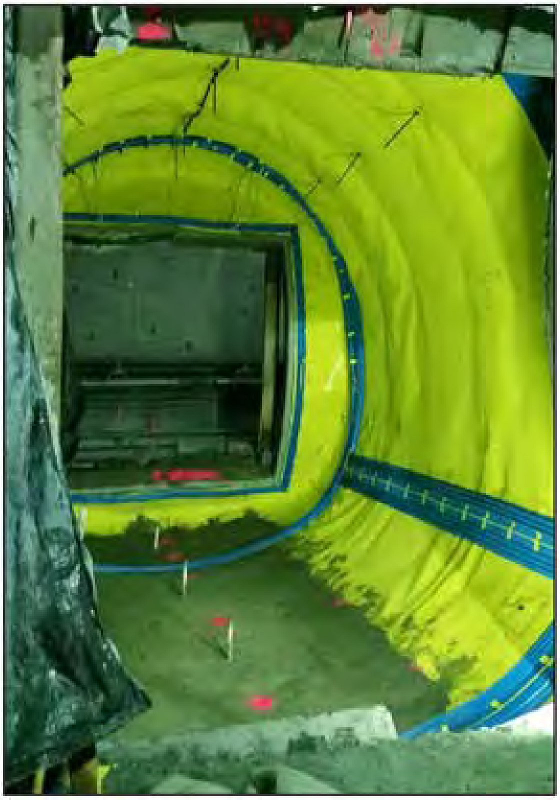
FIG.7

Cutting and capping the steel vessel within the excavation.

Where there were no utilities located within the freeze grid, ground movement was not controlled and any deformation was repaired as part of the site restoration.

FIG.8

A completed cross passage after waterproofing.



Where utilities were present, particularly the 107-cm (42-in.), riveted-steel water main at CP 31, movement was successfully maintained below thresholds defined in the project specifications. No damage to any utility was observed.

Deformations were also observed along the tunnel liners at depth. Some deformation of the tunnel was acceptable and remediation actions were limited to varying supplied brine temperatures. After taking such measures, observed deformations stopped and rebounded slightly after excavations began.

Excavation. Prior to excavating each cross passage, short probe holes were drilled through the tunnel liner to verify that ground water had been completely cut off, and the tunnel liner segments could be removed without ground water intrusion. Excavation was completed using SEM construction methods and a remotely operated roadheader. Ten cm (4 in.) of an initial shotcrete lining was placed over frozen soils exposed during SEM work. Conservatively, two of the 10 cm (4 in.) of initial shotcrete lining were intended to be sacrificial and provided an insulating barrier prior to application of the final shotcrete lining. This initial layer, paired with welded wire fabric, facilitated successful placement and strength gain of the dry shotcrete mix.

As the excavation progressed, rows of freeze pipes were deactivated and purged of brine ahead of the excavation work. This allowed the freeze pipes in the path of the excavation work to be cut and removed without releasing the calcium chloride brine into the excavation, which could thaw frozen soils, potentially impacting the integrity of the frozen soil shoring. Once the freeze vessels were cut and deactivated, soils along the base of the cross-passage excavations would no longer be actively frozen for the remainder of the project. This was anticipated during the design phase, and the outer rows of freeze pipes and the haunch pipes were strategically positioned to remain active and compensate for the additional heat introduced during the excavation and subsequent construction of the cross-passage.

During the excavation, the majority of the pipes installed from the surface were cut, recapped, pressure tested and then buried in the shotcrete. Two of these cut freeze pipes were brought back online immediately over the portals at each tunnel to help maintain the freeze along the crown of the excavation, directly adjacent to the concrete tunnel liners. In addition, several of the interior freeze pipes were replumbed with heavy duty rubber hoses that connected freeze vessel segments at the crown of the cross passages with freeze vessel segments extending beneath the excavation. The hoses were buried into the walls of the excavation and covered with shotcrete. This innovative approach was sufficient to keep the soil mass below the excavation actively frozen for the duration of the project.

After the excavation was completed, the freeze system remained in operation for approximately eight weeks during which time the waterproofing system was installed, reinforcing steel was placed and the permanent final concrete lining was cast in-place. During this time, the frozen soil system remained operational to maintain the robust and water-tight shoring.

Conclusion

Serious project challenges were successfully overcome with freezing from the ground surface providing safe, stable, and water-tight shoring for five Category 3 cross-passage excavations along tunnel alignments for the Sound Transit Northgate Link Extension project. Each of the above-ground freeze systems was successfully installed and operated within crowded and difficult urban environments with minimal impacts to the population. Zone freeze pipes were successfully employed to limit freezing impacts to near surface infrastructure, optimize chilling capacities and focus freeze efforts at depth to develop a robust frozen soil shoring system. Downhole survey techniques were established that can be implemented on future projects requiring drilling of freeze elements in close proximity to sensitive structures at significant depths. Methodologies to mitigate propagation of frozen soils and limit frozen-soil-induced heave deformations around existing infrastructure were successfully employed. ■

Advances in tunneling technology is theme of seventh Cutting Edge conference

Repairing and replacing the nation's aging and crumbling infrastructure has become a major issue with the American public. It is no secret that the upkeep of roads, tunnels, bridges, and water and waste water facilities has been neglected for decades. Cities, states and towns across the United States are now grappling with these issues, ones that will take decades and billions of dollars to fix.

Because of this infrastructure issue, the North American tunneling industry is flourishing. Cities across the country are looking to go underground to alleviate traffic issues, transporting water and waste water to more people in more efficient ways.

Tunnels used by the New York City subway and train systems are among the many in the United States that desperately need to be repaired and updated. The need to invest in infrastructure was discussed at the seventh annual Cutting Edge conference.

In October, the seventh annual Cutting Edge conference was held in Atlanta, GA. Put on by the Underground Construction Association of SME and Britain's *Tunnelling Journal*, about 175 tunneling and underground construction professionals from around the world attended. Attendees included owners, designers and contractors. An accompanying exhibit included 28 companies.

The theme of the two-day conference was Advances in Tunneling Technology. Speakers examined the latest advances in tunneling technology, its methodology and how these advances can be harnessed to assist upcoming major tunneling projects. The conference featured a tailored, high-end, single-track program of subject-specific presentations that focused on innovation and practical experience. Two in-depth panel discussions at the end of each day were also included.

Patricia Mulroy was a keynote speaker on Monday. She is senior fellow for climate adaptation and environmental policy at The Brookings Institution. Like many others, Mulroy believes the U.S. infrastructure in in a state of disrepair. But, she said, no one wants to talk about it. "We need to have a conversation about infrastructure. We cannot be afraid to talk about building it and the cost." For this to happen, though, the nation needs leadership.

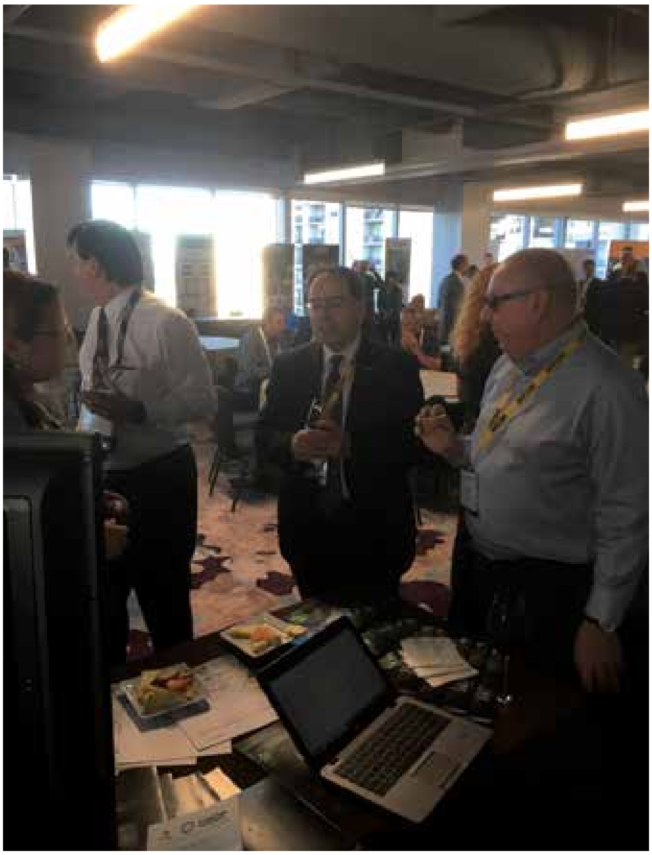
Mulroy said that climate change — she is a believer — will have a significant effect on water storage in the United States if governments don't act now. She said the issue of water storage and climate change has become politicized and no one wants to tackle the problem. "We have regulatory paralysis," she said. When trying to permit a water project, there many groups that interject themselves into the process, mostly through the courts, and the permitting process gets dragged out.

The administrative and regulatory system needs to be fixed, Mulroy said. Building a 21st-century water system is going to be a daunting task, she said, but it must be done. Nothing, she said, affects water storage like climate change. So, in order for the nation to keep up with its water needs and ensure there is enough for future generations, governments must act now.

A panel discussion on Monday, scheduled for an hour-and-

by Steve Kral, Editor

About 175 people attended the Cutting Edge conference in Atlanta, GA, in October.



a-half but could have easily gone on for two, addressed the subject of alternative procurement models for the tunneling and underground construction industry. Randy Essex, of Mott MacDonald, chaired the session. He began things with a few questions for the panelists and the audience: How do we allow owners to maintain control and still encourage innovation from contractors? And, what goal do we seek when we talk about alternative procurement models?

"Contractors do not know what they are getting into until they get into it," said Mike Roach, of Traylor Bros. and current UCA of SME executive committee chair. "The definition of design-build means something different to different people, particularly contractors and designers. Not understanding or completely knowing what is in a contract makes it difficult for those involved in a project. More certainty in a contract would allow contractors and designers to be more innovative," he said.

Greg Colzani, of Jacobs, said collaboration is the key word in any contract. He said that owners want earlier project involvement from contractors. But what is in it for the contractor? Are there hidden risks for the contractor? And, is there equal benefit for the owners and contractors?

Technical sessions

The single-track conference features several technical presentations from authors from around the world. Monday morning started with the session The Challenges of Subaqueous Tunneling. This session looked at the challenges of subaqueous tunneling and the approaches that are being developed to deliver these complex projects. Projects discussed included the Chesapeake Bay Bridge and Tunnel Districts Parallel Thimble Shoal Tunnel, VDOT's I-64 Hampton Roads Bridge-Tunnel Expansion and Toronto's Ashbridges Bay Treatment Plant Outfall.

Next up was the Advances in Contract Delivery session. This session focused on alternative forms of contract delivery, such as Construction Manager at Risk, progressive design-build and early contractor involvement. Key industry figures and project owners also discussed issues surrounding financing and the sharing of risk.

The Advances in Materials, Equipment and Linings session looked at recent advances and novel applications of tunneling materials, equipment and linings. These included innovation in precast segment connections and corrosion protection for linings, and advancements in grouting techniques and TBM grouting systems.

The UCA of SME Young Members Committee prepared a session called New Ideas and Faces. Speakers in this session provided insight into innovative uses of underground space, emerging tunneling trends and technology, new techniques for renovation, uses of underground space and new developments in digital technology and three-dimensional imaging.

The Advancements in Excavation Technology examined the challenges of going faster and rapid excavation techniques. The session included presentations from The Robbins Co. and Herrenknecht and discussed approaches and innovations that are being developed to deliver complex projects safely and efficiently. ■

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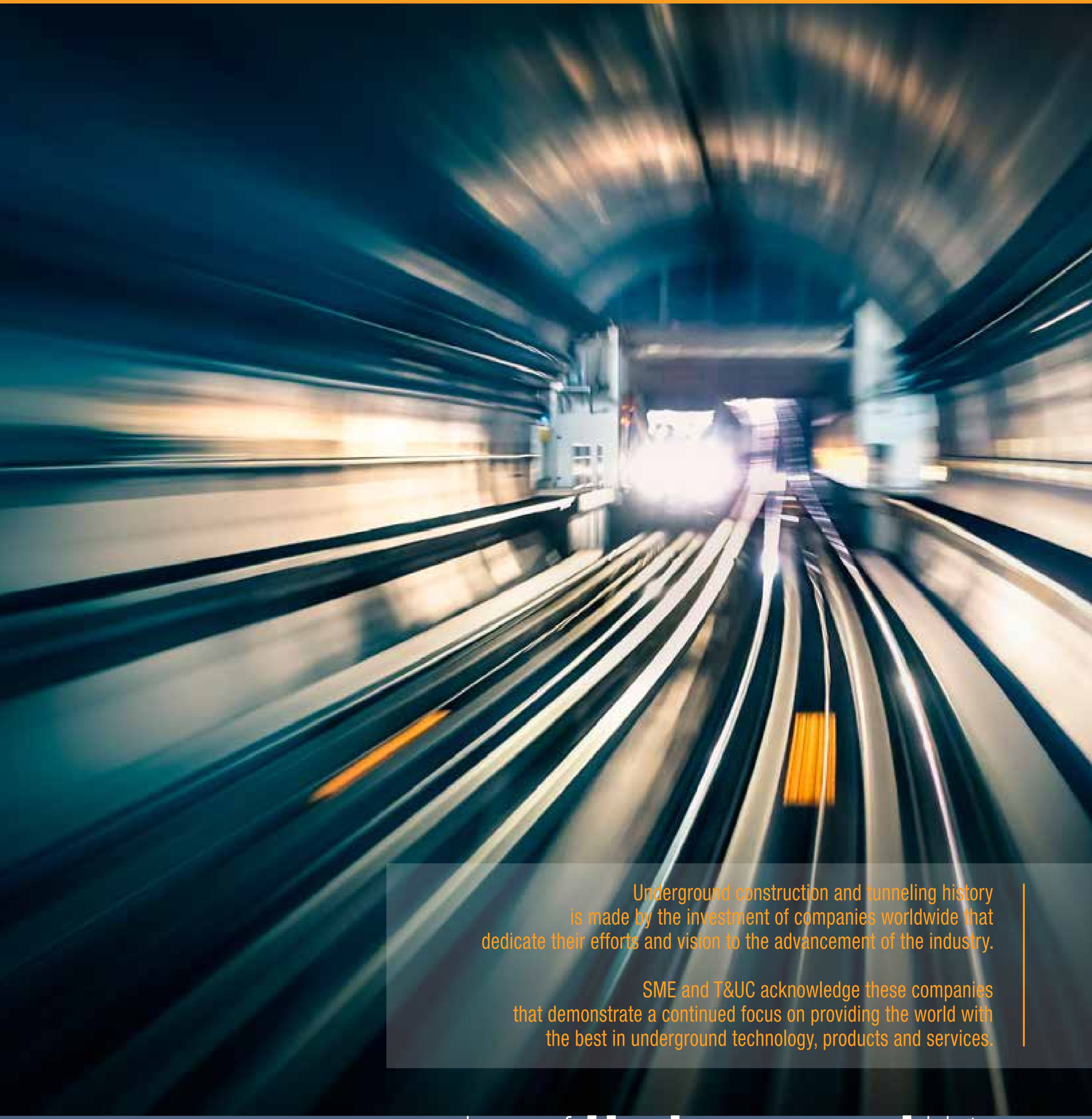

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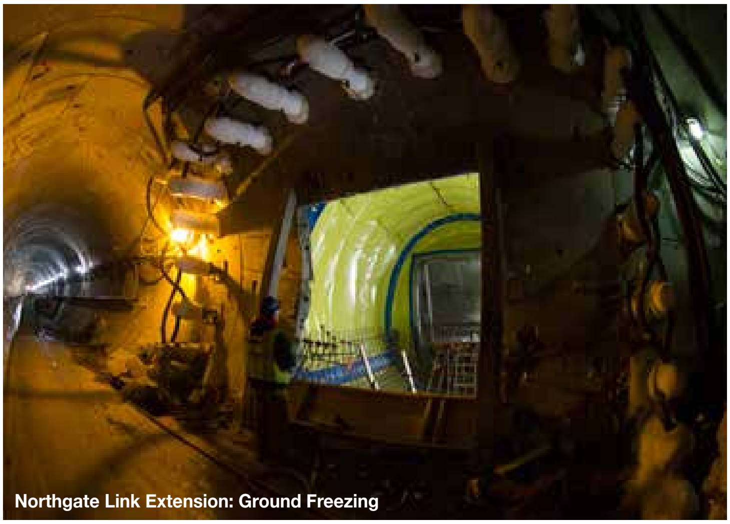

Northgate Link Extension: Ground Freezing

Northgate Link Extension: Ground Freezing
When soil conditions at the locations of six of the 23 cross passages planned for an extension to Seattle's twin bore light rail system proved to be more permeable than anticipated, several deterrents to the planned dewatering program emerged. The large volume of water to be pumped and properly disposed of would be costly and could overload the sewer system. Flowing ground discovered during advance probing would make adequate wellpoint operation within the tunnel itself very difficult. And surface access for vertical drilling was severely limited. Moretrench designed and installed horizontal ground freezing systems in lieu of the original dewatering design. Ground freezing also offered the advantage of groundwater control and support of excavation in one operation.

Westside Subway Extension, CA: Dewatering

Westside Subway Extension, CA: Dewatering
When completed, the Westside Subway Expansion will extend the Los Angeles County Metropolitan Transportation's subway system nine miles to the west. The first phase of the project will run from the current terminus at Wilshire/Western to La Cienega Boulevard and includes three underground stations. The 985-ft long by 70-ft wide La Brea station, which is the launch point for the westbound and eastbound tunnel boring machines, presented particular excavation challenges that were resolved by Moretrench with a two-stage dewatering system design. A perimeter deep well system was installed to facilitate excavation to just above subgrade at a depth 85 feet. Once the excavation reached that interim level, wellpoints were installed within the excavation to dewater to the top of rock for excavation to final depth.

Anacostia River Tunnel: Compensation Grouting

Anacostia River Tunnel: Compensation Grouting
Construction of the Anacostia River Tunnel in Washington DC required the tunnel boring machine to pass beneath several utilities that were sensitive to movement as well as critical to the regional infrastructure. Moretrench designed and implemented a compensation grouting program to reduce the risk of utility settlement during tunneling. Challenges included limited access, complex subsurface conditions, and very sensitive utilities. Compensation grouting parameters were established through an effective trial program and the grouting was then implemented in conjunction with an extensive monitoring program. Settlement of the utilities during tunneling was successfully prevented.

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LACMTA Regional Connector Subway
Los Angeles, CA

The LACMTA Regional Connector consisted of two 21-foot-diameter subway tunnels. Compensation grouting was required to minimize settlements induced by soft ground tunneling. Due to the remote drilling location, directional drilling was used to install the injection sleeve port grout pipes. Compensation grouting was then successful in controlling structure movements. GEO-Instruments, a Keller Company, provided instrumentation and real-time data visualization for a critical segment of the project. Structures along the tunnel route were instrumented with precise wireless tiltmeters and hydrostatic level. In addition, two long shape arrays were installed in 450-foot-long boreholes that followed the curve of the tunnel alignment. The grouting program, together with instrumentation, was a great success and provided data that allowed a record pace for the second tunnel boring machine (TBM) drive.

LACMTA Regional Connector Subway

Blue Plains Nitrification Tunnel
Washington, D.C.

To construct a tunnel at the Blue Plains Advanced Wastewater Treatment Plant, a shaft needed to be installed to allow a microtunnel boring machine access to perform its work. Since there were two distinct soil layers at the site, HBI constructed a very unique shaft using two types of excavation support. In the top approximately 35 feet of soil, a jet grouted soilcrete wall with walers was constructed and in the next 30 feet, soil nails and shotcrete completed the support system.

Faraday Launching Tunnel Shaft
Carlsbad, CA

The Carlsbad Desalination Plant was excavating a 55-foot-deep, 18-foot-diameter secant pile supported shaft installed by another contractor when soil and water leakage occurred due to insufficient pile overlap. The leakage resulted in a sinkhole opening near the perimeter of the shaft. HBI performed compaction grouting to stabilize the sinkhole. Once the area was stabilized, HBI used jet grouting to restore the continuity of the shaft and seal the perimeter of the excavation, stopping the soil and water seepage. Compact equipment was used to safely navigate the congested project site.

Faraday Launching Tunnel Shaft

Thornton Tunnel Grouting
Thornton, IL

The Thornton Composite Reservoir project included a 30-foot-diameter connecting tunnel and a 20-foot-diameter connecting tunnel. Grouting was required to create cut-off rings to reduce groundwater movement along the exterior of the tunnels and to tie into the double row grout curtain around the reservoir. HBI was contracted to reduce the permeability of the bedrock to an approximate value of 1 Lugeon by drilling and grouting from inside the tunnels (tunnel grouting) in a 360-degree ring-pattern, drilling holes with strict alignment requirements and injecting a suite of balanced and stable grouts in multiple stages overhead. HBI used upstage and downstage techniques to complete the ring drilling and grouting operation.

Thornton Quarry

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Geotechnical Construction
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Herrenknecht tunnel borers continue success story in L.A.

Los Angeles is a vibrant center of international film art and innovation – not just on the surface. The area below ground is the scene of state-of-the-art engineering achievements. German high-tech machines from Herrenknecht are creating underground arteries for the American city. Tunnel boring machine (TBM) »Harriet« successfully completed her drive for the Crenshaw/LAX Transit Project in April 2017. »Angeli« just finished digging the first of two tunnels for the Regional Connector Transit Corridor on July 18th. From spring 2018 onward the tunnel boring stars will have additional company: for each of the "Purple Line Extension Sections 1 + 2", two more Herrenknecht TBMs will be working their way through the difficult ground. All three projects are part of the strategic subway extension in L.A. to relieve the traffic above ground.

Los Angeles, the city of angels, suffocates in traffic during rush hour. For this reason the Los Angeles Metropolitan Transportation Authority (Metro) is pushing ahead at full speed with the expansion of local transport links. In the coming years, the existing metro rail network will be expanded in a number of different places. The latest example is the Crenshaw/LAX Transit Corridor. The nearly 14 kilometer long new light rail route will improve the connection between the urban centers of Crenshaw and Inglewood as well as the region around Los Angeles International Airport (LAX). LAX passenger numbers alone show the high demand for public transport capacity: in 2016, more than 80 million passengers were processed – and the trend is rising.

Between May 2016 and April 2017 the Earth Pressure Balance Shield (EPB) »Harriet« worked its way forward underground for a section of the Crenshaw/LAX Transit Corridor. The Herrenknecht TBM (Ø 6.51m) first excavated a 1.6 kilometer long tunnel between the future stations of Expo/Crenshaw and Leimert Park. It was then disassembled and transported back to the launch shaft for the second, parallel section. In April 2017 »Harriet« completed her mission below Los Angeles with the second breakthrough in the target shaft at the Leimert Park station. With a 24 hour best performance of 43 meters a new record in mechanized tunnelling with a subway sized EPB Shield was set for the city of Los Angeles – four more times 40 or more meters were created within one day. Thanks to weekly best performances of 170 meters the Crenshaw/LAX Transit Corridor is expected to go on line on schedule in 2019.

Meanwhile, in February 2017 the Earth Pressure Balance Shield »Angeli« got under way. The TBM is boring a section of the Regional Connector Transit Corridor. It will link the existing Gold, Blue and Expo Metro Lines to new and faster direct connections. From 2020 this will allow locals and visitors to travel north-south from Azusa to Long Beach and east-west from East Los Angeles to Santa Monica without having to change. »Angeli« has just finished the first of two 1.7 kilometer long tunnelling routes. On July 18th she reappeared in the target shaft at 4th Street.

High-tech machine »Harriet« built two tunnels and covered 1,600 meters for each of them.

The machine S-952 »Angeli« for the construction of the Regional Connector Transit Corridor.

Next she will dig a parallel tunnel with the final breakthrough scheduled for the end of the year.

One of the greatest challenges in mechanized tunnelling under L.A. are the possible gas deposits. In order to master these safely, the contracting joint ventures have opted for special technology from Herrenknecht. The electrical components in »Harriet« and »Angeli« are explosion-protected so that safe tunnelling can be realized at all times. This measure has previously proved its worth worldwide in various reference projects. Despite the complex geological conditions and the inner city drive beneath densely populated areas, thanks to the active communication of Metro the two Earth Pressure Balance Shields have already gained a certain cult status with the population of L.A. The much-read Twitter account of »Harriet« was closed after its breakthrough, »Angeli« continues to communicate with the interested population (account: Angeli@regionaltbm).

To name the machines, Metro ran a competition for school children. From the many suggestions, the majority of the more than 50,000 online voters chose »Harriet«, thereby honoring anti-slavery activist Harriet Tubman. »Angeli« also comes from the pen of a school child. The term comes from Latin and means "angel".

In the meantime, designers and engineers at the Herrenknecht headquarters in Schwanau are already working on the next order for Los Angeles. The existing Purple Line is also planned to grow by 14.5 kilometers and seven stations. To this end, in both the spring of 2018 and the spring of 2019 two additional Herrenknecht Earth Pressure Balance Shields each are to be launched in the USA. In just a few years the four machines will produce over 11 kilometers of high quality tunnel tubes. A decade ago, under similar conditions two EPB Shields from Herrenknecht had already built a total of 4 kilometers of tunnel for the expansion of the Gold Line. Herrenknecht technology in Los Angeles is thus already a real success story. To be continued.

www.herrenknecht.com

A total of six Herrenknecht tunnel boring machines are realizing state-of-the-art metro tunnels for the Los Angeles metro rail extension

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 types of machines.

The first Crossover to ever be used in the U.S. finished boring the Ohio Canal Interceptor Tunnel (OCIT) in Akron, Ohio August 29, 2018. The 9.26 m (30.4 ft) Crossover (XRE) TBM was designed for the project's geology, which transitioned from soil to partial face shale to full face shale rock. The Crossover XRE included features of both EPB and Hard Rock Single Shield TBM types, with a versatile cutterhead that could be configured for hard rock or soft ground conditions. While in soft ground and mixed face conditions the machine operated in closed mode, but once it hit solid rock crews switched excavation to open mode. Advance rates once in full-face shale rock reached a high of 34 m (111 ft) in one day. Muck removal was achieved using a Robbins continuous conveyor, and conveyor availability remained high throughout the project.

Thinking Outside the Tunnel

Robbins recognizes the importance of having the right machine for each unique project. The most recent example of this can be seen at the Hiroshima Expressway Line 5 Project, where a slurry machine made its first cut into hard rock September 18, 2018. The mega-sized Robbins Slurry machine, measuring 13.7 m (44.8 ft) in diameter, was built using Onsite First Time Assembly (OFTA). The massive machine is the country's first foreign-made large diameter Slurry TBM to excavate hard rock in Japan.

The Slurry machine was powerfully built in anticipation of potentially abrasive rock conditions and water pressures up to 13 bars. In preparation for the conditions, the machine was designed for 20-bar water pressure. The cutterhead was fitted with 20-inch and 17-inch diameter pressure compensating cutters, which utilize a patented design to effectively operate under high pressure. The 2,400 metric ton (2,650 US ton) machine will bore 1.4 km (0.9 mi) of the 1.8 km (1.1 mi) long tunnel that, once completed, will better connect areas of downtown Hiroshima with the city's airport.

The Robbins Company
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DSI UNDERGROUND

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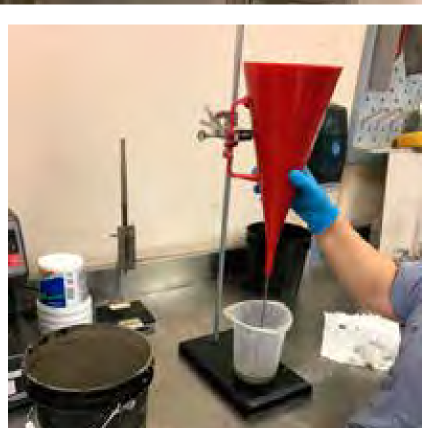
MAPEI Corporation

MAPEI, a global leader in supplying adhesives, grouts and chemical products to the construction industry, provides a combination of products and a skilled, experienced Underground Technology Team to assist contractors on projects involving tunnels, mining, and other underground construction. Recently, UTT representatives assisted on the Anacostia River Tunnel (ART) Project. The ART is the second in a series of four tunnels that comprise the DC Water's Clean Rivers Project, which is intended to reduce the ongoing pollution of the Potomac and Anacostia rivers.

MAPEI products from the Underground Technology Team (UTT) were used to help the tunnel boring machine "Nannie" dig a tunnel 2.37 miles (3,81 km) in length that extends from Robert F. Kennedy Stadium in northeast D.C. to Poplar Point in southeast D.C. These solutions included soil conditioners as well as products utilized for the two component grout.

As the TBM Nannie bored through the earth, it utilized a two-component grout to fill the annulus space between the concrete segmental liner and the ground. The grout needed to be pumped for long distances and exhibit good stability. Therefore, the project utilized Mapebent CBS 5, a sodium bentonite, to keep the grout from segregating as well as Mapequick CBS System 1, which allowed the grout to be pumped for long distances while retarding the setting time. Once the grout reached the point of placement, it required a quick set. To accomplish this, the sodium silicate Mapequick CBS System 2 was used to produce the rapid set required, typically in 5 to 10 seconds, to support the segmental lining.



The ground that is being mined is often treated as it is being excavated in order to facilitate the extraction and removal of the spoils (soil, dirt and rubble). For the ART project, MAPEI provided Polyfoamer FP/CC, which is foamed before being injected into the ground. It works to reduce the stickiness of the clay that the tunnel boring machine passed through and to provide body to the coarse sands and silts.

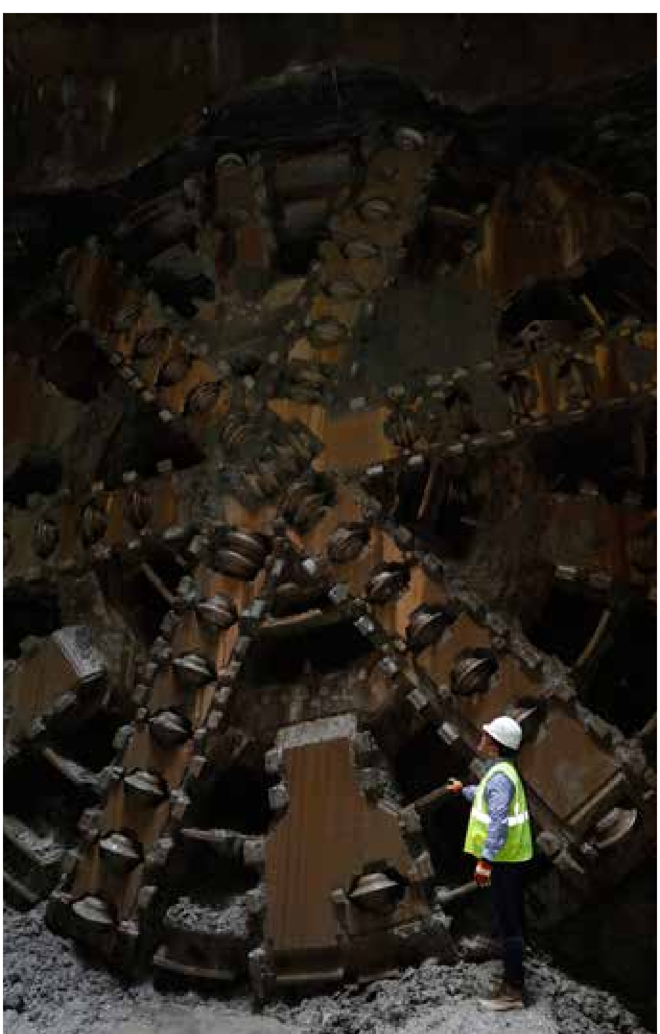
More importantly, MAPEI UTT utilized their laboratories to develop and optimize the two component mix design and the soil conditioning parameters prior to the commencement of the project. In addition, members of MAPEI UTT were on hand during production to consult with the project engineers and workers and to ensure that the dosage of the MAPEI products was optimal for the ART project. Nannie passed under many pieces of critical infrastructure and MAPEI products were part of the project all the way.

In addition to the ART project described here, global MAPEI UTT personnel work on large tunneling projects worldwide. These projects include the Thomson-East Coast (Contract T208) in Singapore, the Ejpovice Tunnel in the Czech Republic, the Cucchero Tunnel in Italy, the Gotthard Base Tunnel in Switzerland, and a number of tunneling projects elsewhere around the globe. Details on these projects can be found on the MAPEI web site at **www.mapei.com.**

BASF

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

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



Sprayed concrete, bolting, injection and water management systems are also widely considered, selected and used for ground support and enhancement in tunneling. BASF offers customers innovative product solutions and experienced technical resources to tailor cost-effective solutions to specific project needs. These solutions dramatically improve working environments, production and safely.

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

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

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

Dragados TBM Bertha
Photo credit-Catherine Bassetti Photography

Open Tunnel
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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
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- 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

Putzmeister America, Inc.

Putzmeister has been a global leader in the world of construction and mining since 1958. The company develops, produces, sells and serves customers with high quality and high reliability machines for pumping, distributing and placing concrete, mortar and high-density solids, and for preparing, temporarily storing, processing and transporting these materials. Putzmeister strives to serve customers by delivering the number one customer experience in the industry and this continues to be the mission for the future.

Putzmeister consistently provides innovative technologies that are constantly updated as per the latest research and development, and market requirements. Customizing equipment to the exact needs of customers and providing effective, long-term and simple solutions to complex problems through Putzmeister's hardy and versatile machines. Putzmeister ably and actively partners with clients on projects to help them deliver on their promises. Skilled, committed and motivated teams ensure Putzmeister clients get value for their money at all times and at every location.

World-class products and services set the standards for quality through continuous and significant investment in research and development. To guarantee customers are getting the number one customer experience, Putzmeister provides 24/7 advice and support ranging from the right choice of machines to be used for a construction project to engineering solutions. Putzmeister carries thousands of parts on hand to allow for quicker processing and handling.

Putzmeister machines are used for a range of applications including civil engineering, mining, tunneling, precast factories, large-scale industrial projects and power stations. Putzmeiser combines top-end German engineering, technology, expertise and high manufacturing standards with locally relevant requirements to provide a comprehensive solutions package.

The know-how of Putzmeister is shown in the handling of different material like concrete or mortar and in the conveying of a variety of solids like sewage sludge, coal sludge or mining tailings. On job sites and in industrial facilities worldwide, Putzmeister technology confirms that all machines and installations are working perfectly. Putzmeister's first class products are setting the standard in the industry, especially in terms of sustained and profitable growth for customers. With different pumps and conveying systems, Putzmeister always offers the right machine for every application.

For more information, please visit:
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How Can a High-Speed Wi-Fi-Enabled Tunneling Network Operate Without Specialized Staff?

In the past, it would be impossible to install a high-speed network with Wi-Fi and Ethernet communications in a tunneling project without specialized installation and maintenance personnel. N-Connex now makes it possible – and simple. This award-winning, modular plug-and-play network is easy to install, expand and maintain. The cables and extenders come pre-terminated, eliminating the need for on-site splice repairs. And the modular components allow you to customize your network based on environmental conditions and communications requirements.

N-Connex is the most comprehensive and flexible gigabit Wi-Fi network – with the lowest cost per mile – on the market today. Used by forward-thinking mining and tunneling companies around the globe, N-Connex offers a basic network to which multiple solutions can be added. N-Connex's unique design allows third-party electronics and hardware integration, providing a one-stop shop for add-on solutions and eliminating the need for sourcing components.

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Why have Wi-Fi in your tunnel? The first reason is communications. Voice and data comms enable private calls, PTT broadcast, IP intercoms, phones, tablets, laptops, wireless adapters, input/output devices, tracing tags, radios and more. Reception over Wi-Fi is crystal clear and calm with multiple channels over which you can talk individually or as a group. Additionally, being able to transfer data and get updates provides you with the ability to make changes mid-shift to enhance efficiency and productivity.

Second, the N-Connex tracking solution offers a reliable, detailed and flexible approach to locating personnel, vehicles and assets throughout a project. Tracking also interfaces with a suite of emergency features such as N-Connex's alarm module and advanced evacuation technology. These features alert and help provide the exact location of all personnel in the event of an emergency. Increasing personnel health and safety are primary goals of the N-Connex system.

In addition to tracking, N-Connex offers telemetry data in real-time on vehicles, providing you the ability to remotely monitor the health of your machines, including TBMs, and make adjustments or pre-empt failures. Less down-time means more production.

Most anything you can imagine

N-Connex's suite of solutions is incredibly diverse, typically providing the operator with additional levels of functionality well beyond their initial use cases. In addition to communications, tracking and safety features, it offers a multi-level map interface and zone management, as well as video, real-time condition and environmental monitoring. All of this functionality is packaged in a ruggedized enclosure, specifically designed to withstand harsh environments.

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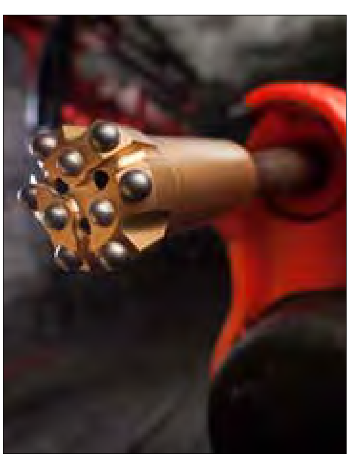
Sandvik in Tunneling

Sandvik tunneling expertise covers a variety of methods: Drill and blast, mechanical cutting and breaking. The equipment range includes tunneling jumbos, roadheaders and cutting units, bolters and bolts, drilling and cutting tools, hydraulic breakers, loading and hauling equipment, mobile crushers, and financing, parts and consumables, training, technical support, and repair and rebuild service.

The Sandvik DTi series of intelligent tunneling jumbos are fast, accurate and user-friendly. The series is available in four models for excavation of 12–211 m³ cross sections, including face drilling, bolt hole drilling and mechanized long-hole drilling.

Sandvik rock tools offer straight holes, high penetration rate and low costs per meter. As the only supplier with in-house resources for cemented carbide production and R&D as well as drill steel production and R&D, Sandvik can control the whole supply chain from raw material to finished products.

Sandvik roadheaders are extremely powerful, robust rock cutting machines that let you focus on the essential: breaking on through to the other side. These roadheaders are designed to excavate roadways, tunnels and underground chambers without using explosives that can cause harmful vibrations. This is highly valued for both environmental and safety reasons, making roadheaders extremely suitable for underground construction in urban areas.



Research & Development

In order to ensure the best solutions, Sandvik has specialized R&D centers for different fields of rock excavation. Sandvik also works in close cooperation with universities, research institutes and specialist associations everywhere in the world. As results of these R&D projects, Sandvik now offers an energy saving cutting system for roadheaders, a new roadheader type equipped with state-of-the-art profile control and automatic sequence control systems, as well as the DTi jumbos with iSURE® process optimization tool software – just to name a few.

Sandvik Cutting Technology Center runs its own in-house cutting test laboratory, addressing particular customer requirements and offers the latest solutions in mechanical cutting for all kinds of soil and rock. In addition, Sandvik has specialized R&D centers for Drilling Control, Rock Drill and Drilling Tools technologies. Sandvik is also the only manufacturer in the industry owning a unique test mine for practical testing in real life conditions.

Cleaner and safer tunneling

Sandvik focuses on continuously developing novel tunneling methods, making equipment safer, more efficient and more productive, giving results of the highest quality. As a key core value, Sandvik engineers are committed to safety, constantly developing solutions to offer a protective working environment, with efficient ergonomics. All Sandvik production operations are ISO14001 and ISO9001 certified.

Intelligent Solutions

Sandvik iSure® tunneling excavation management tool is designed for the people on site. Revolutionary in its approach - iSure® uses the most critical spot, the blast plane, as basis for the whole planning process. As a result, hole locations and blasting, are optimized. This translates into excellent accuracy, fast process and large-scale savings.

Find out more about Sandvik Tunneling offering on www.understandingunderground.com

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Epiroc is a leading productivity partner for the mining, infrastructure and natural resources industries. Epiroc develops and produces innovative drill rigs, rock excavation and construction equipment, and provides world-class service and consumables.

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We offer drill rigs for blasthole drilling, production drill rigs for long-hole drilling, one of the industry's largest offerings of tophammer drilling tools, and down-the-hole drilling tools. All are designed for long life and maximum uptime.

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Epiroc offers tools and equipment for conventional raiseboring, boxhole boring and down reaming. These products are designed to reduce fatigue and maximize uptime, with features that enhance operator safety.

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We supply a complete ventilation solution for tunneling and underground operations, including system design and installation of fan stations and ducting.

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ACT's plant solutions deliver superior quality concrete with the ideal combination of proven components engineered by the world's most respected names in the business - Wiggert & Co. and Würschum GmbH.

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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.

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

Surecrete Inc.

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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

You Can Count on Case

Case Foundation Company has extensive knowledge involved in the tunneling and underground construction industry. This experience extends to various tunneling and underground applications such as:

- Traffic Tunnels
- CSO Tunnels
- Subway Tunnels
- Outfall Tunnels
- Airport Tunnels

Typical applications have been the installation of support of excavation systems for large diameter access shafts, retrieval shafts or vent shafts for both temporary and final design applications. It is typically accomplished using secant piles, auger cast piles or a combination of both. Similar procedures have also been employed on cut and cover tunnels.

We also have installed shafts up to 15 feet in diameter in both soil and rock using full face drilling tools for access shafts for micro tunneling projects and vent shafts for various tunnel applications.

Case Foundation Company
1325 West Lake Street
Roselle, IL 60172
800-999-4087
www.casefoundation.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

Colorado School of Mines

underground.mines.edu

The Center for Underground Construction and Tunneling at Colorado School of Mines, aka Underground at Mines, is a community comprised of collaborative, interdisciplinary faculty and students with a collective interest in education and research, within underground science and engineering. With a mission of advancing knowledge and developing leaders, many experts, researchers and students are united across disciplines: civil engineering, geology and geological engineering, mining engineering and mechanical engineering, as well as geophysics and computer science.

Mines is a public university focused on science and engineering, dedicated to educating and inspiring students, advancing knowledge and innovating to address the great challenges societies face today—particularly those related to the Earth, energy and the environment. Founded in 1874 with specialties in mining and metallurgy, Mines' scope and mission has expanded to meet the needs of industry and society, producing distinctive graduates and revolutionary innovations, and becoming a world leader in advancing sustainable use of the Earth's resources.

Mines has a long-standing tradition of hosting world-class short courses on our beautiful campus in scenic Golden, Colorado. Short courses combine classroom instruction with hands-on labs and demonstrations, creating unique opportunities to learn, network and earn CEUs. Short courses also present a unique opportunity to learn from the most experienced and innovative talent in the tunneling industry for both seasoned professionals and those new to the field.

Underground at Mines short courses are designed for industry professionals. With new discoveries consistently leading to exciting breakthroughs, ours is an industry with an almost unparalleled opportunity for innovation. While this is technically a "short course," it's one that's been thoughtfully designed to cover a broad range of the most relevant industry topics in as short a time as possible. In this way, Underground at Mines can be sure to offer you an efficient learning experience developed to help you get where you want to go — faster.

GROUTING AND GROUND IMPROVEMENT COURSE

MAY 13-16, 2019
GOLDEN, COLORADO

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

Our short course presents a unique opportunity to learn from the most experienced and innovative talent in the tunneling industry. This is a 3.5 day course that covers engineering, equipment, materials and methods for grouting and ground modification used in civil and geotechnical engineering, underground construction, tunneling and mining.

Don't miss this opportunity for professional development and high-level networking — all while earning 2.4 CEUs!

Hands-on labs and workshops will give you the real-world experience you need to elevate your skillset and take your place at the cutting edge of the field. Learn more at **underground.mines.edu**.

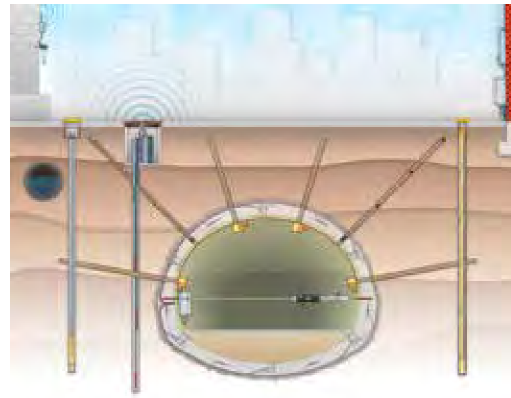
Geokon, Incorporated

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

With over 100 associates, GEOKON incorporates state-of-the-art manufacturing processes and equipment to produce the highest quality and performing products on the market. Geotechnical, mechanical, electrical and software engineering teams collaborate to develop the highly innovative, accurate and reliable instrumentation. As a result, GEOKON has been awarded ISO 9001:2008 registration from both ANSI•ANAB, USA and UKAS of Great Britain. GEOKON's calibration program complies with the ANSI/NCSL Z540-1 Calibration Laboratory and Measuring and Test Equipment General Requirements and all products have achieved Russian GOST certification for safety.

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

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



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

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

Geokon, Inc.
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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

Drill Tech Drilling & Shoring, Inc.

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

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

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

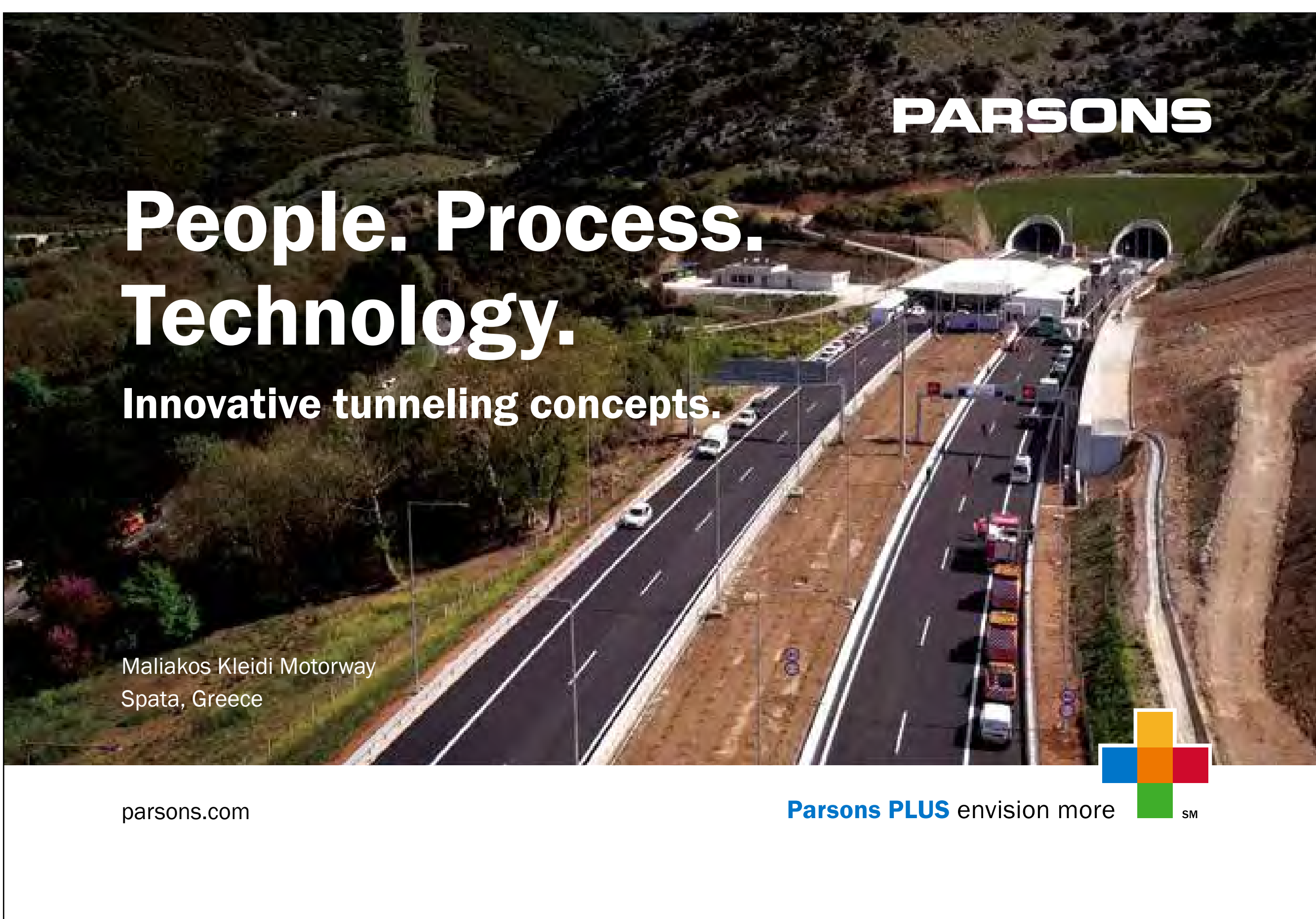
For more information, please visit www.drilltechdrilling.com, email us at dtds@drilltechdrilling.com or call at 925.978.2060
Drill Tech Drilling & Shoring, Inc.
2200 Wymore Way
Antioch, CA 94509

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.



Mining Equipment Ltd.

Mining Equipment Rolling Stock for Columbus, Ohio

"Rolling for more than 35 years"

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

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

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

Mining Equipment 10 Ton Locomotives for Columbus, Ohio

Normet

Our mission: Leading transformation into digitalised and sustainable underground mining and tunnelling.

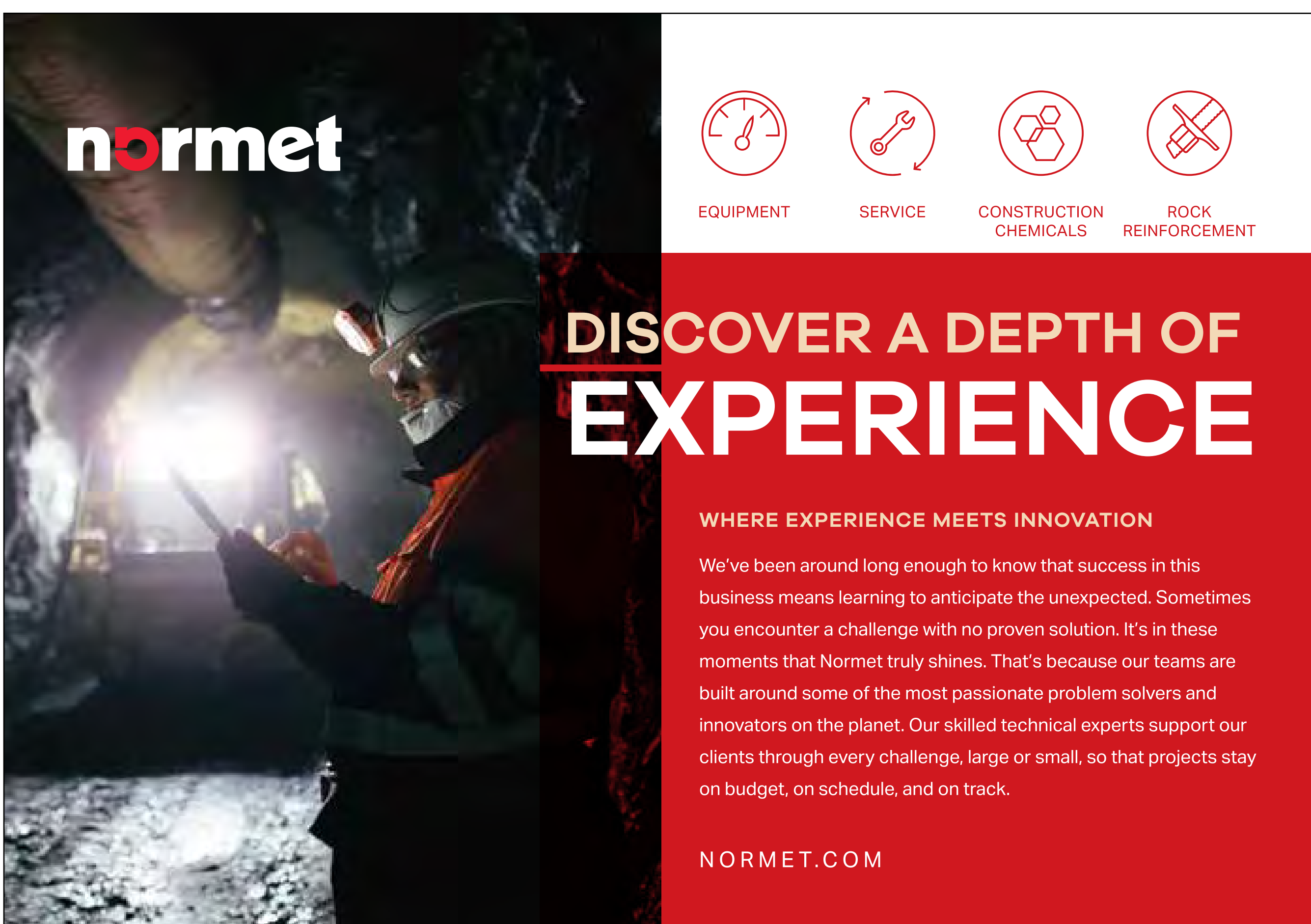
Normet is a fast growing and innovative technology company. We help our customers to build the safest places underground – highlighted in our vision: We help our mining and tunnelling partners to continuously improve their processes, increase the safety and productivity of their underground activities, and improve the sustainability of their operations.

Normet encourages a strong collaboration with its customers. We have amassed process expertise over thousands of mines and tunnel projects all over (and under) the globe. The broad perspective means experience and expertise about what should and should not be done to achieve the optimum results. Normet improves underground mining and tunnelling processes with knowledge and technology translating process expertise into actions and financial results.

Normet has a broad underground offering:

- Equipment for concrete spraying and transport, explosives charging, scaling, lifting, installation works, and logistics.
- Construction chemicals for sprayed concrete, admixtures for all types concrete, injection systems for rock improvement, reinforcement systems for high deformation conditions, spray applied waterproofing systems and needed chemicals for Tunnel Boring Machine (TBM) technology covering hard rock, Earth Pressure Balance (EPB), open face and slurry type machines.
- High quality and innovative rock reinforcement products that reduce the risk and consequences of accidents and facilitate high productivity in challenging rock conditions.
- Services for underground mining and tunnelling, including for example spare parts, rental equipment, equipment refurbishment, performance and field services.

For further information, please visit us at: normet.com



SoilFreeze, Inc.

SoilFreeze, Inc. is the largest U.S. contractor specializing in ground freezing for the construction industry. For nearly two decades, SoilFreeze, Inc. has successfully completed scores of complex and technically challenging excavation support projects throughout the U.S.

For further information, please visit us at: soilfreeze.com


TBM SB North Shaft


Newark Shaft

SoilFreeze

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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

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 metal processing, nuclear and other specialty applications.

The new Brokk 170, Brokk 200, Brokk 300 and the diesel Brokk 520D incorporate the revolutionary new SmartConcept™ system.

Brokk will launch four new machines at World of Concrete 2019. The new Brokk 170, Brokk 200, Brokk 300 and the diesel Brokk 520D incorporate the revolutionary new SmartConcept™ system, which ensures improved performance and uptime. SmartConcept consists of three features: SmartPower™, SmartDesign™ and SmartRemote™. SmartPower senses when the power supply is poor or faulty then compensates before damage to components occurs. This allows contractors to use the machine with generators or unreliable power sources. SmartDesign extends machine life and provides unprecedented ease of maintenance due to 70 percent fewer cables, hardened components, LED headlights and easily accessible grease points and hydraulic hoses. An ergonomic remote control, the SmartRemote, incorporates adjustable straps, intuitive controls and professional-grade radio technology with a 984-foot working range. Along with the launch of the new line, Brokk also introduced new attachments, including BHB hydraulic breakers and three Darda concrete crushers.

Brokk introduces four new next generation demolition robots.

The four new demolition robots from Brokk reflect the company's constant focus on innovation, improved performance and increased uptime. The new machines combine state-of-the-art technology, significant improvements in power-to-weight ratios and rugged reliability.

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.

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

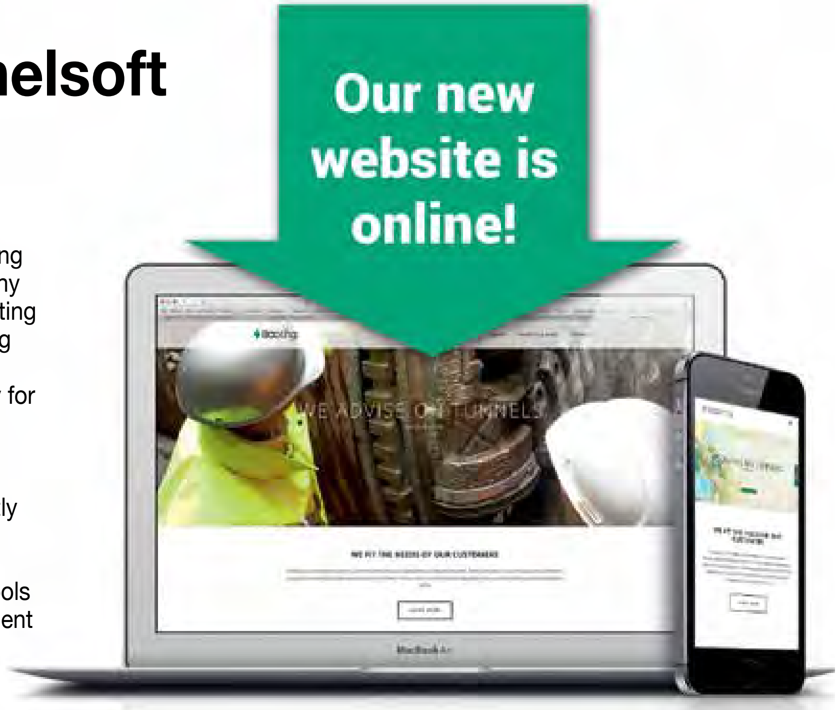
The Safety and Hazard Awareness for Tunnels (SHAFT) program seeks to provide comprehensive safety training for both new and experienced tunnel professionals.

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, loci, 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

BabEng and Tunnelsoft



For 25 years BabEng (formerly known as BABENDERERDE ENGINEERS) operates in the tunneling sector as an engineering and consulting company. With our team we share the philosophy of mutual respect and the challenge of contributing to the continued success of our company during all phases – from feasibility study to design and from construction to contract closure especially for projects involving TBMs.

Thanks to our hands-on experience, our division Tunnelsoft has developed and constantly refines our software TPC (Tunneling 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.

Our network of offices in Germany and America allows us to respond quickly and effective across the globe. Please visit our new website to learn more!

www.babeng.com I www.tunnelsoft.com or write to contact@babeng.com I tpc@tunnelsoft.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.

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.

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.

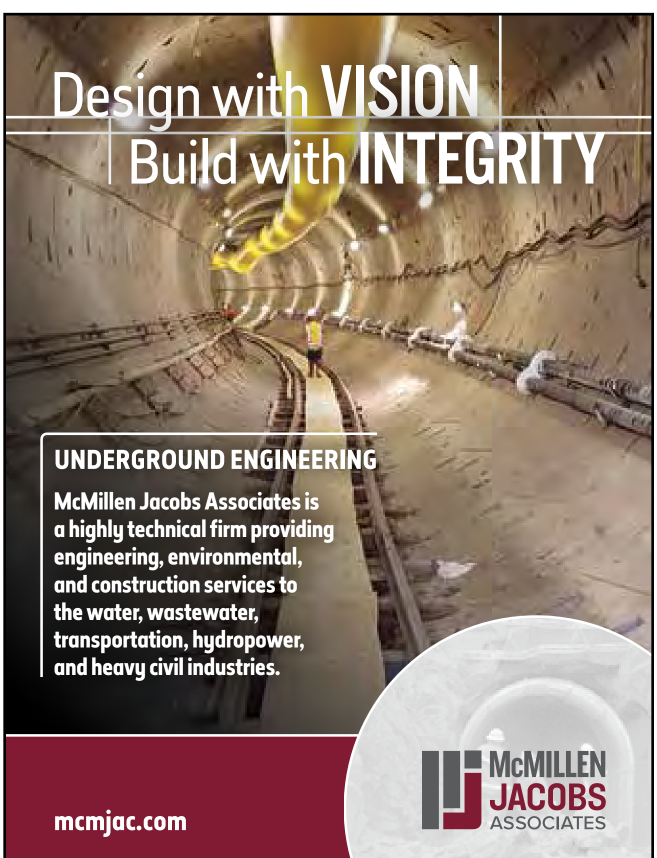
Bradshaw Construction Corporation
175 West Liberty Road
Eldersburg, MD 21784 USA
Telephone: +1-410-970-8300
Fax: +1-410-970-8340
www.bradshawcc.com

Rock Splitting Technologies

The N50 Power Splitter uses a feather and wedge system. Hanging from an excavator, the N50 uses the existing excavator hydraulics to push the wedge between the feathers exerting a force in excess of 2,700 tons! The Rock Splitter's wedge requires a pre-drilled 4" hole that is 4.3 feet to 5 feet deep. The wedge travels 700mm or 2.3 feet into the hole. The breaking of rock or concrete will happen immediately. RST also distributes the K25 hand held splitter.

- Splitter uses 21 MPa working pressure, which can be supplied by most excavators, creating a splitting pressure in excess of 2,700 tons.
- Equipped with relief valves to help prevent too much pressure and damaging the splitter.
- Equipped with pressure gauge for easy maintenance.
- Easy to replace wedge and counter-wedges.
- Attaches to Excavators and can be hung from a crane for shaft work.
- No vibration, quiet and simple to use!

Rock Splitting Technologies, Inc.
2393 Canton Hwy, Suite 400
Cumming, GA 30040
Office: (770) 886-4711
Sales@RockSplittingTech.com
www.RockSplittingTech.com



McMillen Jacobs Associates

McMillen Jacobs Associates provides technical engineering design and construction expertise in the conveyance (water, wastewater, stormwater), dispute resolution, energy and power, transportation, transit, 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

ABC Industries, Inc.

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

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

RIGIDUCT®

Filament-Wound Fiberglass Tubing

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

Dā-mite

Rock Splitting Mortar

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

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

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

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

Daigh Company, Inc.
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

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Soft Ground & Rock Tunnels & Shafts • Ground Freezing
Underpinning • Excavation Support • Tunnel Rehabilitation
Microtunneling & HDD • Instrumentation & Monitoring
Construction Evaluation • Utilidors • Tunnel & Shaft Design

CSX Virginia Avenue Tunnel
Washington, DC

MRCE
built on firm foundations

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MRCE.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 tunneling projects include the new entrance and underpass for WMATA's NIH Medical Center station in Bethesda, CSX Virginia Avenue Tunnel, VDOT Midtown Tunnel, DC Water's Blue Plains and First Street Tunnels, Toronto Subway Yonge-Eglinton Station, and New York City's LIRR East Side Access, NYCT 2nd Avenue Subway, and the DEP's Catskills and Delaware Aqueduct Rondout-West Branch Tunnel and Brooklyn to Staten Island Harbor Siphon Tunnel.

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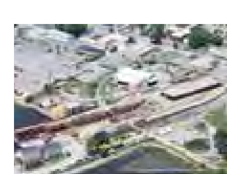
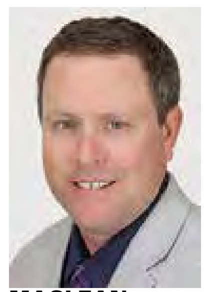


PERSONAL NEWS


WILSON

The McMillen Jacobs Associates Board of Directors has elected **SARAH WILSON** as board chair. Wilson is a vice president at McMillen Jacobs Associates, where she has worked in tunnel design and construction management for more than 19 years. Wilson's leadership experience and technical expertise stem from final design roles on transit, dam and water conveyance facilities, and construction management experience on numerous underground contracts in both soft ground and rock. She is a past president of the American Rock Mechanics Association.


MACLEAN

DANIEL R. MACLEAN, P. Eng. has been elected a Deep Foundations Institute's (DFI) Trustee. MacLean is the business development manager at Keller Foundations Ltd. in the company's office in Acton, ON, Canada. MacLean has more than 17 years of deep foundations experience, primarily focused around micropiles and anchors. He has been a member of DFI for almost 15 years and served a two-year term as co-chair of the DFI/Association of Foundation Drilling's Micropile Committee.


OWEN

ANDREW OWEN has joined McMillen Jacobs as a principal in its Melbourne, Australia office and also serves as the office manager. He has more than 34 years of experience specializing in commercial and operational project planning, construction estimating, performance management and cost analysis. Owen has managed multidisciplinary teams and mobilized resources on overseas assignments including public-private partnership projects. He was a key player in the design management for North West Rail Link, KVMRT projects and Doha Metro Tenders for Red and Green Lines. ■

PRODUCTS

Blastcrete's refractory paddle mixer delivers speed and reliability

Blastcrete Equipment, manufacturer of shotcrete and gunite mixers and pumps, offers a refractory paddle mixer that delivers fast mix times while working with mixtures that include aggregates up to 13 mm (0.5 in.) thick. The hydraulic machine mixes as much as 227 kg (500 lbs) of refractory castable in 1.5 to 2 minutes and performs well in form-and-pour jobs and other applications involving precast shapes, mortars and grouts.

The refractory paddle mixer's oversized, heavy-duty, chain-and-sprocket drive system provides years of reliable use under harsh conditions. It also features a pair of easily accessible levers to control the hydraulic dump and operate the system in both forward and reverse.

Users can pair the 862-kg (1,900-lb) machine with a variety of electric power options for safe indoor use and to meet global needs. Customers have their choice of three electric motors; a 7.5-kW (10-hp) electric motor with starter disconnect, a 240- or a 480-volt, 60-hertz motor or a 380-volt, 50-hertz motor. Customers also can choose to power the paddle mixer with a 14-horsepower Kohler gas engine.

The 1.2-m (4-ft) wide refractory paddle mixer's trailer features a single axle for easy towing, or it can be skid-mounted.

"The market lacked a small, heavy-duty refractory mixer," said Tripp Farrell, president of Blastcrete Equipment. "We intentionally designed and built this paddle mixer to fill this void in the market. We want our customers to have the tools they need to be as successful as they can be." ■

www.blastcrete.com

The refractory paddle mixer combines as much as 227 kg (500 lbs) of refractory castable, mortar or grout in less than two minutes.

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	2019	Design study
2nd Ave. Phase 2	NYC-MTA	New York	NY	Subway	16,000	20	2019	Under design
2nd Ave. Phase 3-4	NYC-MTA	New York	NY	Subway	89,600	20	2020-25	Under study
Kensico-Eastview Connection Tunnel	NYC-DEP	New York	NY	Water	10,500	27	2020	Under study
Flushing Bay CSO	NYC_DEP	New York	NY	CSO	13,200	20	2026	Under study
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Rail	25,000	30	2022	Under study
Redundancy Tunnel Program - Northern	Boston MRWA	Boston	MA	CSO	23,760	10	2022	Under study
Redundancy Tunnel Program - Southern	Boston MRWA	Boston	MA	CSO	50,160	10	2022	Under study
Narragansett Bay CSO Phase III - Pawtucket Tunnel Conveyance Tunnel	Narragansett Bay Commission	Providence	RI	CSO	 13,000 8,800	 28 10	 2020 2024	 Under design Under design
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	Rail	40,000	32	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	Shortlist announced
Alex Renew Long-Term Control Plan	City of Alexandria	Alexandria	VA	CSO	10,500	20	2021	Under study
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	24,000	18	2022	Under design
Olentangy Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2019	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
Westerly Main Storage Tunnel	NEORSD	Cleveland	OH	CSO	12,300	24	2020	JayDee/ Obayashi awarded
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
I-75 modernization project	Michigan DOT	Detroit	MI	CSO	22,000	14	2018	Oakland Corridor awarded
Enbridge Line 5 Tunnel	Enbridge	Traverse City	MI	Oil	23,760	12	2020	Under study
I-70 Floyd Hill Highway Tunnel	Colorado Dept. of Transportation	Denver	CO	Highway	15,840	60x25	2022	Under design

FORECAST T&UC

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
W-6: Highway 90 to SW Military Drive	San Antonio Water Systems	San Antanio	TX	Sewer	28,000	10	2020	Under design
D2 Subway - 2nd Light Rail Alignment	Dallas Area Rapid Transit	Dallas	TX	Highway	3,000	22	2020	Under design
Ship Canal Water Quality Project	Seattle Public Utilities	Seattle	WA	CSO	14,250	19	2018	Under design
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	Transit	10,500	18	2022	Under design
L.A. Metro Westside Phase 2 Phase 3	Los Angeles MTA	Los Angeles	CA	Subway	 26,500 26,500	 20 20	 2016 2018	Tutor Perini/O&G JV awarded Frontier-Kemper/ Tutor/Perini awarded
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	Frontier-Kemper awarded
JWPCP Effluent Outfall Tunnel project	Sanitation Districts of LA	Los Angeles	CA	Sewer	37,000	18	2015	Dragados USA low bidder
Freeway 710 Tunnel	CALTRANS	Long Beach	CA	Highway	26,400	38	2016	Under design
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	Single tunnel option approved
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	JayDee/Michels/ C&M McNally awarded
Ashbridges Bay Outfall Tunnel	Metrolinx	City of Toronto	ON	CSO	11,500	23	2018	Southland/Astaldi JV Awarded
Keswick Effluent Outfall	City of Toronto	Toronto	ON	CSO	11,600	23	2018	Under design
Yonge St. Extension	Toronto Transit	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	SNC/Dragados/ Aecon JV Awarded
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	Proposals submitted
Annacis Island Outfall	City of Vancouver	Vancouver	BC	Water	8,000	10	2017	Bid date 9/13/2018
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

AD INDEX

ADVERTISING INFORMATION

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