SEPTEMBER 2008

tunnels & tunneling NORTH AMERICA

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CALIFORNIA: PIONEERING TUNNELLING PROJECT SUCCESSFULLY COMPLETED.

One of the most complex tunnel construction projects has been successfully completed in the San Bernardino mountains in Southern California. The Herrenknecht S-234 Single Shield TBM achieved successful breakthrough on August 20, 2008, just a few hundred meters from the San Andreas Fault. Its identical sister machine, the S-233, reached its target as early as the beginning of May. These two tunnel tubes were excavated to secure the drinking water supply for the Los Angeles metropolitan area for the future.

The excavation of the tunnels, measuring 6,840 and 6,059 meters in length was extremely difficult due to the strongly fractured, water-saturated rock. For this reason, the two machines (∅ 5.76m each) were equipped with active shield articulation cylinders, efficient drainage systems and a special probe drilling and injection technology to improve the construction ground ahead of the machine. The TBM sealing systems were also specially designed to resist the static water pressures of up to 10 bar. A difficult job worth the effort – showing that even the most challenging tunnelling projects can be realized safely with the necessary know-how and outstanding teamwork.

LAKE ARROWHEAD | USA

PROJECT DATA	CONTRACTOR
S-233, S-234 **2x Single Shield TBMs** Diameter: 5,760mm Driving Power: 2,000kW Tunnel lengths: 1x 6,840, 1x 6,059m Geology: granite, gneiss	Shea-Kenny JV

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Front cover
An Arup engineer inspects initial ground support for the 34th Street Station caverns.

S3II, a joint venture of Shea, Skanska and Shiavone, is currently blasting out the station, interlocking and other caverns required for the MTA's new 34th Street Station on the No 7 Line Extension, in West Manhattan, New York. S3II has engaged Arup to undertake the design of initial ground support.

The first "S3" JV (Skanska/Shiavone/Shea) is currently sinking the perimeter slurry (diaphragm) walls in the Upper East Side of Manhattan to create the launch box for a rock TBM to mine running tunnels for MTA's 2nd Avenue Subway.

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Stepping up to the plate

It is now obvious that we are headed for a skills shortage in the tunneling sector. Great news in the short-term for the engineer who feels they are ripe for a promotion – but bad news in the long-term for an industry that is seeing so little 'fresh blood' coming into its fold.

When I first joined *T&T*, nearly a decade ago, you could pretty much count the number of ongoing 'mega' projects on your hands. Even though the current boom had yet to take hold, and few of the current large-scale projects were more advanced than the preliminary design phase, it was already clear that there was a vast quantity of work on the horizon.

So one has to wonder, is it a result of industry disbelief, or just plain lack of planning, that we have continued to allow this skills gap to develop?

When looking at large-scale schemes, such as Portland's East Side CSO project (p20), where the benefits of starting up a project with a highly-experienced workforce have proved themselves so comprehensively, it has to be clear it is about time we invested some serious time and effort in recruiting, training, and keeping, a skilled workforce.

> Has it been disbelief, or just a plain lack of planning, that has allowed this skills shortage to develop?

It is therefore encouraging to see the UCA of SME stepping up to the plate by launching a number of initiatives to encourage students and training. Most recently, the UCA has established a permanent Education & Training Committee.

With a mission to increase the quality of training available to engineers and construction supervisors, it is hoped the Committee may oversee the creation of an institute or academy operated by SME volunteers. Another possible idea is to establish a 'certificate' program to recognize basic levels of competence.

The UCA is currently looking for volunteers to participate in the activities of the Education Committee and help to develop initiatives. I sincerely hope that many will step up to this request and look at possible ways they can contribute to the industry as a whole.

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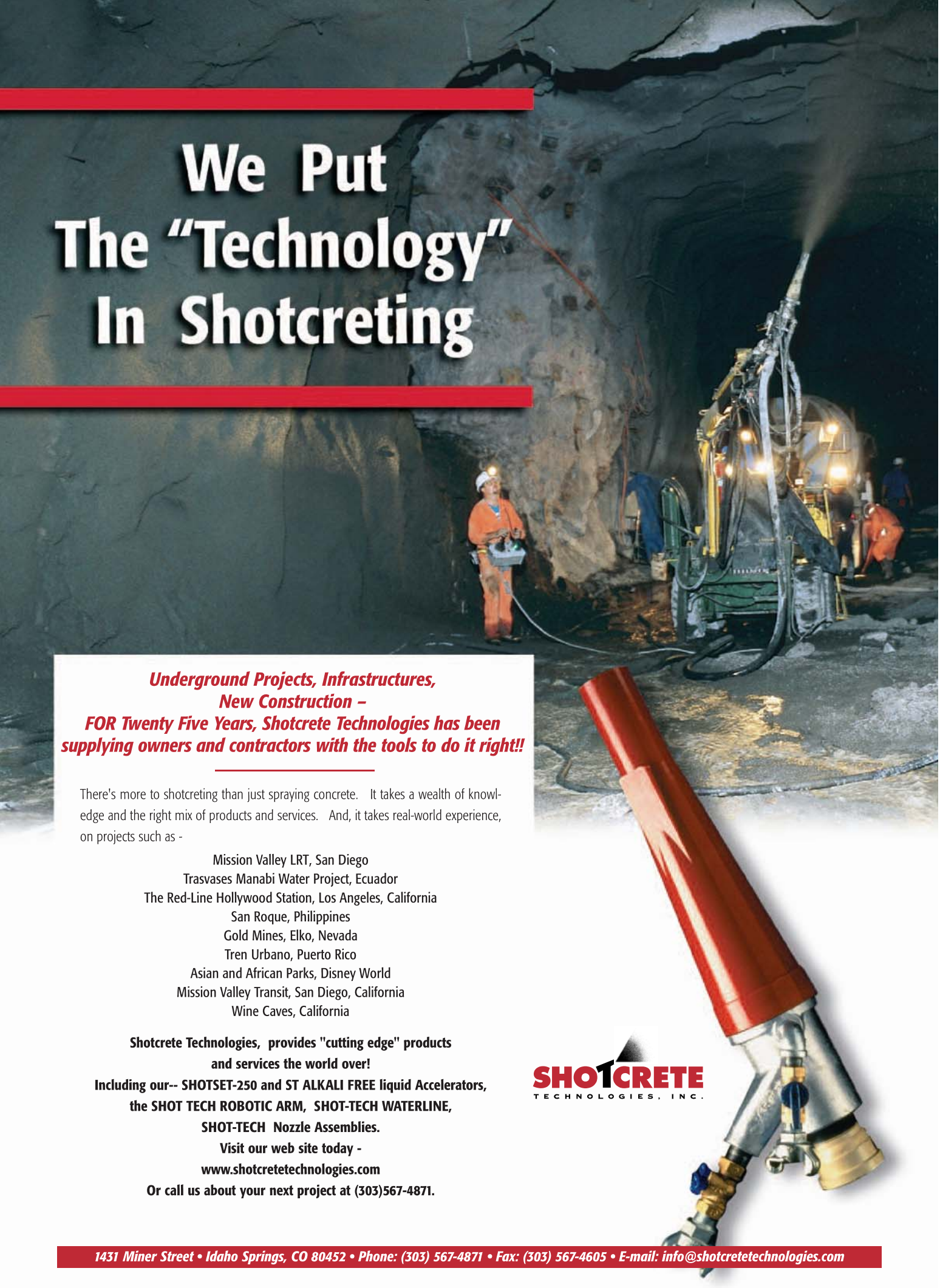

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Arrowhead triumph for JV

On August 20, the Herrenknecht TBM broke through to complete the 3.8-mile (6km) long Arrowhead West Tunnel as part of the Metropolitan Water District of Southern California's (MWD) Inland Feeder project.

The tunnel through the San Bernardino Mountains is the last of three to be completed for the 44-mile (71km) long scheme, which is a high-capacity, gravity fed water delivery system (*T&TNA,* Dec 2007, p15).

MWD Chairman, Timothy Brick, said: "For those of us who have followed this project since it first appeared on the drawing board 20 years ago, this is a thrilling moment."

He added it was, "a vital link in securing a more reliable, higher-quality water supply for Southern Californians".

Gene Koopman, Chair of MWD's Engineering and Capital Programs Committee described the feeder as "one of the most demanding construction projects" in the agency's 80-year history. Koopman described how the east and west Arrowhead tunnels were challenging due to the difficult geological conditions, close to several earthquake faults, together with the local risk of fires and flash floods inherent to the area. Indeed, in October 2003, a 100,000 acre wildfire engulfed the tunnel portal and destroyed some equipment. Two months later, on Christmas Day, a winter storm flooded the portal site and TBM, as well as washing away equipment.

The ground conditions have varied from granite, gneiss and marble. MWD Board papers state that very soft ground with shear zones caused the TBM to dive four inches below its alignment over a two week period, crews had to install a series of concrete steering pads in front of the TBM to serve as ramps to correct the machine's vertical alignment.

Above: **Final breakthrough**
Right: **Flooding of the portal site**

Work by the Shea/Kenny JV will now focus on a concrete and steel lining, followed by installation of a concrete water conveyance pipe. ■

Sound Transit gets going on Uni Link

In Seattle, some striking finishing works are being carried out to Sound Transit's Beacon Hill Tunnel Station, with the installation of an unusual blue color scheme.

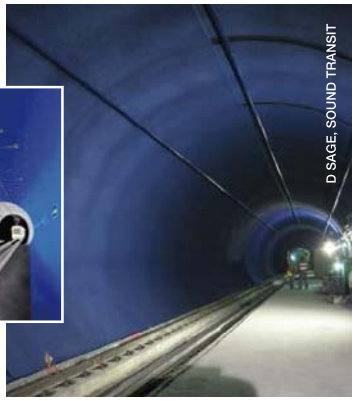
The décor will be augmented by Dan Corson sculptures, named 'Space Forms', which are to be suspended from the ceilings of the Northbound and Southbound platforms. Internally illuminated with LEDs, the sculptures are said to reflect imagery of microscopic plant and animal forms.

As the Beacon Hill project moves into its final phases, Sound Transit's 3.15-mile (5km) long University Link light rail extension continues to move towards construction. In September last year, the Sound Transit Board unanimously approved University Link's capital Baseline Cost Estimate of $1.61 billion and established a schedule that has the project completed in fall 2016.

On July 10, funding approval was received from the US Senate Appropriations Committee, $128.8 million, of which $100 million is for the University Link project. The bored tunnel components of the project will be separated into two contracts, U220 and U230.

Potential bid documents have since been issued for industry review. *T&TNA* was told by a Sound Transit spokesman: "It's a way to make the actual bidding as competitive and comprehensive as possible. On U220 we got more than 100 different comments on everything from the general conditions of the contract, to questions about various specifications. We heard from primes, major subs and one TBM manufacturer."

Running entirely underground, the extension will connect downtown Seattle with the University of Washington via Capitol Hill. The scheme is likely to utilize three TBMs. Two of which will start at the University site and simultaneously bore south to Capitol Hill. The third will start at the Capitol Hill station site and bore south to the end of the initial construction segment. That TBM will then be disassembled, returned to Capitol Hill and reassembled to bore a second tube south.



D SAGE, SOUND TRANSIT

As the design progressed, Sound Transit, with the Seattle Fire Department's concurrence, determined that the Montlake emergency ventilation facility originally proposed will not be required, as emergency ventilation functions can be fully met at the Capitol Hill and University stations.

U220, the tunnel contract from the University of Washington to Capitol Hill, is on the critical path of the scheme. Bidding and award is due to take place from mid-December this year through to mid-July 2009. With time allocated for various approvals, construction could begin by the end of 2009. ■

Muni moves ahead in San Francisco

In early August, the San Francisco Planning Commission approved the approximately $1.3 billion Central Subway project, which will extend the Municipal Railway (Muni Metro) into Chinatown.

Currently scheduled for a 2016 completion, the 1.7-mile (2.8km) long route will have four stops, one at street level and three underground. Reports say an additional 2000ft (610m) long stretch of tunnel will be constructed at North Beach to allow for future expansion.

The subway is the second phase of the Third Street Light Rail Project and has been described as "vital to connecting the city's civic, business and cultural centers with the diverse communities along the corridor," by the San Francisco Municipal Transportation Agency. ■

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Mexican boom gains momentum

Mexico City has recently embarked upon a massive infrastructure investment plan, which will see billions of dollars spent over the next five years on water and public transport projects. Shaft excavation works are due to commence this month for one of the largest of these projects, the $1.2 billion Emisor del Oriente tunnel.

This massive scheme, which will see six EPBMs bore a 38.5-mile (62km) long, 28.5ft (8.7m) o.d. wastewater tunnel and six new high-capacity wastewater treatment facilities, is being built by the National Water Commission (Conagua) with financing through the Mexican Federal District (FD) government, in order to halt the major water crisis in the city.

Over exploitation of aquifers (by an estimated 800%) to supply some 20 million inhabitants with fresh water, has lead to the slow 'collapse' of the Valley of Mexico, say officials, with some buildings having sunk by up to 33ft (10m) over the last century. With 40% of fresh water lost to leaks, and just 6% of wastewater recycled, drainage and water treatment is also a critical issue.

Due to the subsidence, the city's gravity-fed sewer, the 'Gran Canal', has lost its natural slope. Authorities are currently forced to drain the bulk of city's wastewater via the Emisor Central, a stormwater tunnel that was not designed to convey sewage – and as a result is now in desperate need of lining repair works.

TBM selection is currently ongoing, with an order having recently been placed with Herrenknecht for two EPBMs. A further four machine orders are yet to be placed.

The largest of the City's FD funded public transport projects is the 15 mile (24km) long Metro Line 12, which will be constructed entirely underground in two stages, with service to 22 stations. The line has been awarded to the ICA consortium, which comprises Empresas ICA, Cicsa and Alstom SA, and will connect the districts of Tlahuac and Mixcoac in the southern area of the city,

The consortium placed an order with Robbins in July for a 30ft (9.29m) diameter EPBM that is scheduled to begin boring a 3.7 mile (6km) long section of tunnel through clay and sand, in fall 2009, for Stage 2 of the project. The line is due to be fully completed by the end of 2011.

Alignment of Mexico City's Emisor del Oriente tunnel

Elsewhere in Mexico a number of drill and blast tunnels are underway, including: 56 tunnels (totaling 8.5-miles) for the Durango-Mazatlan highway project, a 1.2-mile (1.8km) long twin tube road tunnel under the "Cerro de la Silla" for the city of Monterrey, and a further 17 new highway tunnels in the state of Oaxaca. Numerous other tunnel projects will also shortly be published for bidding. ■

Topping up the work at Lake Mead

Arup, has been awarded the lead engineering role for the Lake Mead No 3 Intake scheme (T&TNA, March p5) that will maintain water system capacity even if the lake water levels decline an additional 100ft (30m) from current levels.

Arup is currently serving as design engineer for Vegas Tunnel Constructors (VTC), a JV between Impregilo and its US subsidiary, SA Healy, with support from Brierly Associates LLC. Don Phillips, VTC's Design Manager and Project Director for Arup said: "This is a significant and technically advanced assignment for Arup, we are thrilled to be involved."

The work was awarded by the Southern Nevada Water Authority (SNWA), the agency that manages the region's water resources. SNWA Director of Engineering, Marc Jensen, stressed the importance of the scheme saying: "Successful completion of the project is vital to the reliability of the water supply for Las Vegas."

As *T&TNA* goes to press, it is also thought that bids could be imminently advertised the Clean Water Coalition's (CWC) Systems Conveyance and Operations Program (SCOP), which includes a 7.5-mile (12km) tunnel through River Mountain to discharge treated wastewater into Lake Mead. The CWC comprises Clark County Water Reclamation District, the City of Las Vegas and the City of Henderson, all of whom are responsible for wastewater treatment in the Las Vegas valley.

An Environmental Impact Assessment was completed this Spring and *T&TNA* has obtained documents indicating an approval could be granted by the end of August. If this timetable is met, calls for bids may be advertised in September, with bids due by the end of the year. The tunnel, which has been designed by Black & Veatch and has a construction estimate of the order of $200 million, could be awarded as soon as early February next year. ■

East Side update

A Robbins TBM has reached Grand Central Station as part of New York's Long Island Rail Road (LIRR) East Side Access project. The double shield 6.7m diameter main beam TBM was rebuilt by SELI and launched by the Dragados / Judlau JV in October last year, three months before the launch of another 6.7m diameter Robbins main beam TBM that is excavating a parallel tunnel. Both TBMs are said to be performing "satisfactorily considering the tough conditions, averaging 9.8m per day [double shield machine] and 11.1m per day [main beam machine]".

The Metropolitan Transportation Authority (MTA), says that now the machine has reached its initial destination, work will begin on excavation of a cavern underneath Park Avenue, between 49th and 51st Streets, which will connect the new tunnel with parallel tunnels, enabling the future LIRR access to all eight tracks in the new station under Grand Central.

The Dragados / Judlau JV was awarded the $428M contract for the Manhattan Tunnels scope of East Side Access in July 2006. The tunnel alignment is entirely through Manhattan schist, at a depth of 140ft below the surface. The TBMs will be used to drive multiple headings beneath Grand Central Station as well as the approach tunnels. Once tunnel excavation work is complete, a cast in-situ lining will be installed, together with M&E installations. The line is expected to be operational by 2013 and will provide for 160,000 commuters daily between Manhattan and Queens.

The entire project consists of 13.7km of twin tunnels and is expected to cost $7.2 billion. One of the challenges ahead is to secure the additional funding required. Reports say the federal government has agreed to provide $2.7 billion, with $1.7 billion allocated through the MTA's capital spending programs, but that leaves $2.8 billion that must be sought by way of a new capital program that will be submitted for approval next year. ■

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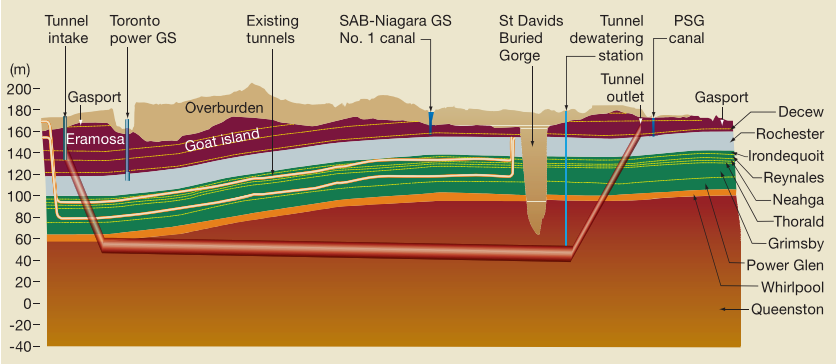


Niagara tests team and TBM

T&TNA first visited Canada's new Niagara Tunnel in late 2006, just after launch of the project's 14.4m diameter Robbins TBM by main contractor Strabag. Since then, the site team has encountered very difficult ground conditions and the threat of significant schedule completion penalties

The C$623M design-build fixed price contract for the 10.4km (6.5-mile) long Niagara Tunnel, in Niagara Falls, Canada, will divert a further 500m^3/s to the Sir Adam Beck hydroelectric generating facility, downstream of the iconic waterfalls.

Under existing agreements, 6000m^3/s of run of the river flow is available for power generation, which is shared between Canada and the United States. Current diversion capacity for power generation in Canada stands at 1800m^3/s, meanng available flow currently exceeds diversion capacity 65% of the time.

Ernst Gschnitzer, project manager for Design-Build contractor Strabag, told *T&TNA* that once the new tunnel is commissioned flow will exceed generation capacity just 15% of the time. He added it would not be economical to try and attain 100%. Although the scheme will also see upgrades to the Sir Adam Beck facility, there will not be any new turbines installed, just increased flow, which will provide enough clean power to supply 160,000 households.

An international pre-qualification call in August 2004 elicited seven responses. The subsequent tender period ran from December 2004 through May 2005, with three design-build proposals received on May 13, 2005, by client Ontario Power Generation (OPG) and its representatives Hatch Mott MacDonald (HMM) with Hatch Acres (HA). The technical and commercial evaluation criteria included: safety/environment, personnel, methodology, cost/schedule and risk allocation.

A geotechnical baseline report (GBR) produced by HMM for the project went through three revisions as part of the tender process, loosely referred as GBR (A), issued with the tender; GBR (B), which included questions and answers from contractors; and GBR (C), the collated result of the interactive procurement process and contract formation.

Strabag was awarded the contract on August 18, 2005, with an open gripper TBM that was to be built (see *T&TI*, p29), not just assembled, on-site and a cast in-situ lining to be formed concurrent with TBM excavation, in a move that surprised some in the industry. Given the owners criteria, many had expected a shielded TBM and gasketed segmental lining to be the methodology chosen. On the contrary, Gschnitzer says such an approach could not guarantee the owners requirements, which include a 90-year design life, no planned maintenance, and approximately 14 bar of operating hydraulic pressure. It was these requirements that triggered the two-pass lining approach, says Gschnitzer.

When Strabag considered the documents it realized the annular gap had to be perfect to guarantee liner integrity. It was felt this could only be achieved with a two-pass system that incorporates a shotcrete primary lining, waterproof membrane and cast in-situ lining.

Contact grouting is used for voids, with pressure grouting undertaken between the primary liner and the membrane to pre-stress the secondary lining in order to contain the 14 bar operating water pressure without the need for steel reinforcement - and the long-term corrosion risk this could present.

The Owners Mandatory Requirements (OMR) define quality and performance standards and HMM and HA have a full-time role monitoring and auditing the quality of the contractors' work. Strabag has partnered with several main subcontractors for the design and construction of the works, including: Dufferin Construction, ILF, Morrison Hershfield and Jegel. These arrangements have spawned further subcontractor agreements, for example, the outlet and intake works surface drilling was carried out by Canadian driller Castonguay as a subcontractor to Dufferin, the cofferdam at the intake was done by Bermingham Construction, grouting by Geo-Foundations and in-water works by McNally.

Key stakeholders include the Ministry of Environment (MOE), the Ministry of Natural Resources (MNR), the Department of Fisheries and Oceans (DFO), and Niagara Peninsula Conservation

Top left: **Fig 1 - Geology along the alignment;** Top right: **Rowa's L2 ground support area with Meyco robojets;** Above right: **The crown monorail;** Left: **One of two boom mounted man-baskets in the L1 area**

Authority (NPCA). These regulators issue permits and approvals, as well as monitor compliance with Environmental Assessment Approvals. The host municipalities of Niagara Region, Niagara Falls and Niagara-on-the-Lake provide municipal services, issue municipal permits and manage tourism impacts.

Discussing the approvals and permits, Gschnitzer says there was "lots of paperwork, but it didn't hold us up," which he attributes to the politically popular nature of the project. "Thanks to the open information policy of OPG the host communities had a very good response [to the project]."

Geology and equipment

The planned alignment sees the tunnel descend 1500m at -7.82% from the outlet through the upper sedimentary layers to the Queenston Shale at a depth below surface of 140m. From there, the tunnel follows a relatively horizontal plane for 7400m on a 1000m radius. Towards the intake, the tunnel follows an incline gradient of +7.28% for the final 1500m.

Geology is varied (see figure 1) and includes limestone, dolostone, sandstone, shale and mudstone. The rock strength for most of the drive is in the region of 100-180MPa, although rock strengths as low as 15MPa will be encountered. The rock is non-abrasive with the exception of the sandstone. Roughly 80% of the alignment runs through the Queenston Shale, which is described as prone to swelling and very affected by water and gas for degradation.

The previous two tunnels followed a different, shallower alignment and did not run through the Queenston Shale. This was dictated by the avoidance of both the Shale and the buried St David's Gorge. *T&TNA* was told that 12,000 years ago, the Niagara River ran through the gorge, but roughly 10,000 years ago changed to the current route. The falls eroded and retreated at a rate of approximately 1m per year to where they are presently, with retreat now much reduced due to counter measures and the diversion of flows for power generation. During this time St David's Gorge became filled with overburden and the previously driven tunnels avoided it due to concerns about water filled sediment. Gschnitzer says the current tunnel could have traversed the gorge, but environmental concerns relating to groundwater contamination has resulted in the TBM driving below it, through the Shale. In hindsight, this is proving more difficult than expected.

The 10,398m long tunnel is being driven by Big Becky, a 14.44m o.d. full face Robbins open gripper TBM, the largest of its kind to date. The tunnel's internal diameter varies between 12.28m and 12.78m, depending on the predominant support class. The smaller diameter reflects the less frequently expected scenario where steel ribs are required with up to 200mm of 25MPa shotcrete and mesh. The other primary support classes vary from mesh with 50mm of 25MPa shotcrete, to mesh with 6m long rockbolts, 25MPa shotcrete 150mm thick and UNP 140 steel channels.

The final lining will feature a waterproof membrane, a cast in-situ concrete invert and arch, contact grouting and interface grouting to pre-stress the liner. The waterproof membrane was described as "essential to the design life and quality" of the tunnel lining and it means the "tunnel is not interfering with the groundwater conditions of the surrounding rock".

As the lining work is due to be carried out concurrent with TBM excavation, one of the challenges faced by the site team is the running of services and logistics through the various work platforms. In addition, the tunnel has encountered severe overbreak issues (see below), which has necessitated a further traveling work stage behind the invert work stage to restore the profile prior to installing the membrane and final lining.

Above: View towards the face from the L2 area, showing overbreak

Of all the equipment on the project, the flagship is the 14.44m diameter Robbins TBM, dressed with 85 x 20" cutters. At the time of *T&TNA*'s last site visit, Robbins Company President, Lok Home, claimed the 20" cutters would have a better wear life due to the 35-40% volume increase over 19" cutter. Now, with 2742m driven, Gschnitzer says: "The 20" cutters are performing very well in fact. Cutter life is significantly higher due to higher cutter ring profile."

Contrary to concerns voiced by Robbins about cutterhead vibrations and uniform application of the cutters to the face, Gschnitzer says there have been no issues. Early in the drive, the TBM did encounter problems with fines clogging the muck buckets, so a foam spraying system was retro-installed to alleviate the issue.

The 2000t TBM has a cutterhead speed of 0-5 rpm and in low speed (0-2.4 rpm) configuration can deliver 18,800kNm of torque. At maximum speed, delivered torque is 9,025kNm. Maximum thrust is 27,900kN, with a maximum gripper force of 71,500kN. The stroke is 1.82m.

The area directly behind the cutterhead, 5m behind the face, is designated as "L1", the primary rock support area. This area contains a ring beam erector that can hydraulically expand steel sections against the rock profile. The "donkey" is a dual-function handling cart on the top section of the main beam. This allows horizontal transport of steel sections and mesh forwards and also vertically to the crown for installation.

Two Atlas Copco 1532 rock drills on 6m slides are installed on a rotary positioner, which allows independent operation of each drill. An additional drill is used for probing. The design is such that bolts can be installed during boring operations to improve the work cycle. Two boom-mounted manbaskets are also located in the L1 area to facilitate scaling and ground support installations. A crown monorail serves for most material handling needs. Site staff told *T&TNA* that the original design had been considerably altered to make it more flexible in coping with the areas of high overbreak.

Left: View of the 800t backup trailing behind the TBM

Robert Goliasch, Strabag's Equipment Manager, gave an overview of the components that will be used to line the tunnel. The 800t trailing backup behind the TBM, designed and provided by Rowa Tunneling Logistics, includes the L2 ground support area, together with workshops, power support installations and other ancillary equipment. Two additional Atlas Copco 1532 rock drills are mounted on 6m slides, again on a rotary positioner. Here are also two Meyco Suprema shotcrete robots to provide 360° coverage and 8m of lateral travel. The shotcrete pumps feeding the nozzles can deliver 20m^3/hr per pump. Shotcrete is delivered in 12m^3 capacity mixer trucks.

Muck haulage is by H+E continuous conveyor to the transfer at the portal, then by overland conveyor to the storage area, where the plan is for some of the muck to be blended and used for manufacturing bricks.

Due to be launched in October this year, and trailing behind the TBM by 3000m, is the 800t invert lining work station provided by Bystag with BMTI, which is part of the Strabag group. An 87m long bridge section ramped at both ends will allow the rubber tired TBM supply vehicles to travel uninterrupted in a single lane as the invert is cast. The crown and sidewall bracings on the invert formwork, to prevent heave, have been designed so as not to interfere with the 2.6m diameter ventilation duct or the sidewall mounted conveyor and services. The invert will be cast using two 12.5m long forms that can be leap-frogged to give 25m of invert lining advance per day.

Goliasch says the 100t restoration carrier to make good the profile prior to arch lining will follow the invert lining by 1500m. It is planned to get underway in April or May next year. A final meeting is due to take place in

September to decide on options, which have been narrowed to either custom equipment or standard mobile gear mounted on big platforms. It will likely use shotcrete to restore the profile.

Trailing the restoration carrier by 1500m is the membrane installation platform and the arch shutter. This weighs in at a hefty 1800t, which Goliasch explains is due to the heavyweight steel required in the design to resist the concrete loads. Tubes for pressure grouting, together with ports, will be installed at the same time. A further 2000m behind this will be the 60t contact grouting station, with the 60t pressure grouting set-up 1500m behind that.

Overbreak and ground

This unionized job site features an entirely Canadian workforce on two production shifts of 10 hours each, plus one maintenance shift working on a 24/7 cycle. The workforce totals 180 plus subcontractors.

With the TBM launched at the end of 2006, advance rates of 18m/day were being achieved by April 2007. This was not to last however, and at chainage 839m large blocks collapsed from the crown and the works were suspended for six weeks to determine the best way forward. It was decided the safest and most reliable way to proceed was to excavate under a spiling umbrella and the tunneling works restarted in such a fashion.

Spiles 9m long were used, so with a 5m cutterhead spiling was 4m ahead of the face, with a 4.5m overlap carried forwards. The advance rate dropped to 3m/day and on August 9 2007, at Ch900m, the decision was made to stop spiling. Overbreak in the region of 2.5m in the crown was encountered.

Since then, overbreak in the crown of up to 3.5m has been experienced and continuous overbreak of 1.5m is common, with crews averaging 8m/day in such conditions. To put into perspective the effect this has on volumes and the need for the restoration carrier, 3m of saddle overbreak equates to 20-25m^3 of volume per metre or tunnel.

Site has opted to use 4m long Super Swellex rockbolts, rated at 240kN as the best way to achieve active support close to the face. It has been necessary to shotcrete directly behind the cutterhead in the L1 area, where a wet mix is applied by hand.

During *T&TNA*'s recent visit, the face was at 2742m and significant overbreak was still being encountered. Despite this, crews were maintaining the 8m/day advance. The site team should also be commended as despite such conditions, the lost time injury frequency rate for the project is just 1.06, compared to a rate for the industry of 2.9.

When the tunnel was being driven down to the Queenston Shale horizon, one problem was the magnitude of overbreak that occurred when traversing the interface between the sandstone and the mudstone.

Although the site team was not able to discuss these matters in depth, due to the ongoing negotiations between contractor and owner/owner's representatives, a realignment option is still being considered (*T&TNA*, May 2008, p8) that could mitigate the delays associated with the advance rates. This could see the tunnel shortened by the order of 200m and realigned so that the crossing of the sandstone/mudstone interface when driving towards the intake is traversed as favorably as possible.

Looking forwards

Following a positive start, it seems ground conditions have held some surprises for the site team, but personnel and equipment have demonstrated their flexibility and achieved commendable advances under difficult conditions.

However, with onerous liquidated damages facing the contractor, and the completion date slipping from 2010 to 2011, it will be interesting to see contractually how the proposed changes are handled with respect to cost and schedule - particularly as Hatch Mott MacDonald's web site claims one of the project highlights is: "...a negotiated Geotechnical Baseline Report (GBR) used to equitably share underground risks on the project." ■

Intake works

Prior to *T&TNA*'s recent visit, the first full round had just been fired in the grouting tunnel driven from the intake. Sometimes overshadowed by the presence of Big Becky, this work is impressive in its own right. Located at the gates of the International Control Works structure, which regulates flows over the falls, in-water blasting was used and a new precast concrete shorewall constructed, together with demolition and reconstruction of a precast concrete accelerating wall one pier further out into the river.

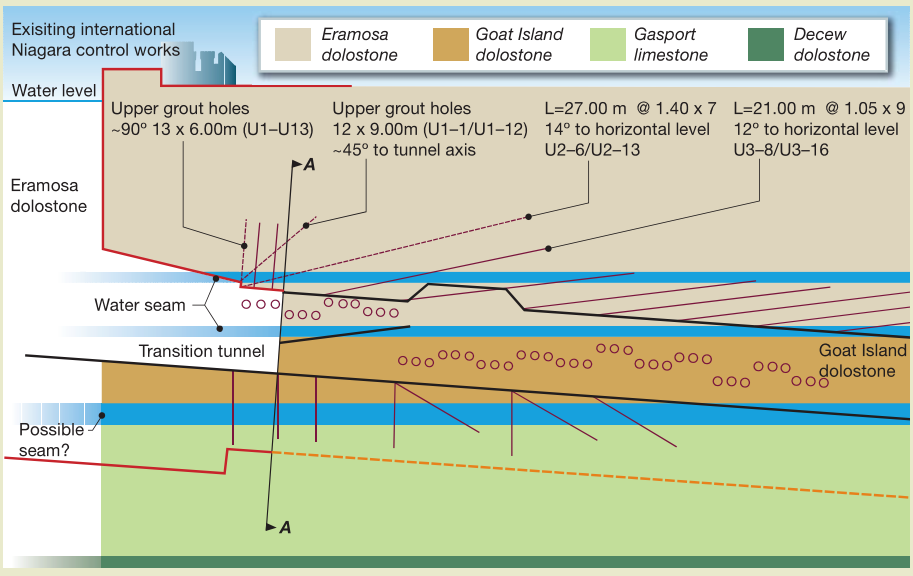
A sheet pile cell cofferdam was constructed out in the river and dewatered in summer 2007. Blasting and rock excavation of the portal then got underway, together with grouting works to seal the two main sources of flows; leaks through the cofferdam and through horizontal layering in the riverbed. The impressive portal profile was achieved by controlled blasting, with scaling/profiling by excavator mounted roadheader.

The 400m long, 8m wide x 7.3m high tunnel is to precondition and seal the ground in preparation for the TBM and to facilitate the demobilization of the TBM once the main tunnel drive is complete. Extensive grouting will be carried out as the tunnel advances, to prepare the ground for the TBM drive through the grout tunnel alignment - with the TBM crown just inside the crown of the grout tunnel - without problematic inflows.

The initial access was driven at -25%, but the majority of the tunnel is driven at -7.5% using a two-boom Atlas Copco jumbo. Driven as a top heading, 90 x 3" diameter charge holes are used, with 4 relief holes. The holes are charged with Unimax 40x400 and Dyno Split 22 for the perimeter. Initiation is by means of Nonel LP detonators. As the initial rounds are below the control gates, round length is limited to 1.2m for the first 60m. Since vibrations are currently far below the specified limits, the plan is to increase rounds up to 3m so long as vibration compliance is maintained.

Ground support is by means of 3m long Super Swellex bolts, mesh and shotcrete in the crown.

The TBM will drive through the tunnel, then pull back to the area where the crown has been slashed (see below) to enable lifting points to be used for disassembly. Finishing works at the intake will include a control gate and catchpit.



Thumbs up for NAT

The 2008 North American Tunneling Conference, held in San Francisco this June, was a resounding success. As the second NAT event to be managed by the Underground Construction Association (UCA) of the Society for Mining, Metallurgy & Exploration (SME), the conference benefited greatly from the Society's experience, as well as the dedication of the event's organising committees, resulting in grander and more sociable atmosphere than seen at previous NAT conferences.

Some 718 tunneling professionals from around the world attended the three days of technical sessions, with over 100 papers presented across numerous topics. The sessions were opened with keynote lectures from Maria Ayerdi, of Transbay Joint Powers Authority, who presented plans for San Francisco's stunning new Transit Centre, and Bijan Sartipi, of Caltrans, who discussed a number of ongoing projects, including the Devil's Slide tunnel – which was a sell-out as the conference field trip.

Manning the booth at NAT 2008

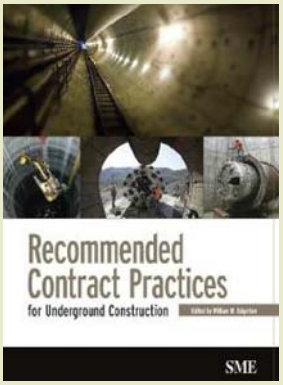
Amongst other highlights were the well-attended short courses "DRB Process Update", "Soft Ground Tunneling" and "Underground Blasting" and also the accompanying exhibition, which saw 79 company booths providing a wide range of interest for attendees.

"NAT 2008 turned out to be one of our best conferences ever. It is a real tribute to the professionalism of the underground industry with literally hundreds of volunteers, sold out sponsorships, and management by SME, we could not have asked for more," said conference Chair, Greg Raines.

At the NAT congress the UCA of SME also launched its new publication "Recommended Contract Practices for Underground Construction". The culmination of four years of effort toward defining best practices, the book aims to improve the administration of contracts for underground projects.

"The manual was undertaken in response to the increase in the extent of our use of underground space, which has been mirrored by a noticeable lack of development in contracting practices," says Bill Edgerton of Jacobs Associates, who chaired the steering committee responsible for developing the new manual.

The book makes recommendations in eleven separate areas: Relationships of the Parties, Project Planning, Subsurface Conditions, Risk Management, Design and Construction Management, Cost Estimating, Schedules, Pricing and Payment, Contracts, Changes, and Dispute Resolution. Each chapter gives a comprehensive overview of one of these topics, then discusses its impact on contracting and presents the perspectives of owners, design engineers, contractors, and/or other stakeholders.



The authors of the book are all acknowledged authorities in underground construction. The recommendations made reflect their experience as well as industry consensus on best practice.

Copies of the book are available from SME, visit the web site for further details.

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NOTICE BOARD

New border tunnel for Windsor? The railway issues committee for the city of Windsor, Ontario, has recently presented the results of its study for a proposed Can$313 million project, which aims to eliminate two-thirds of the city's railway tracks and could assist in easing Detroit/Windsor border crossing congestion.

Speaking to local press at the end of August, committee chair Coun. Fulvio Valentinis, said the preferred technical solution for the multi-phased project sees Windsor's existing Canadian National, Canadian Pacific and VIA Railway lines consolidated into one major double-tracked route. "At the same time, Canadian Pacific has expressed an interest in a new railway tunnel and this would play into that," said Valentinis. The $400 million freight tunnel (developed under a separate bi-national study) would be employed to ease cross-border congestion, allowing two existing cross-border rail tunnels to be converted for use by trucks, paving the railroad right-of-way to provide a controlled access roadway between the US and Canada.

The rail scheme is said to be dependent upon the commitment of Canadian National and Canadian Pacific, who would loose some flexibility in the region as a result of the project. However, both companies have participated heavily in, and partly funded, the Can$290,000 study. The study will be put to the city council in early-September and a public review process will follow.

Lafayette bore imminent: Alyssa, the Technicore TBM that will be used to bore a tank tunnel in Lafayette, Indiana, has now been delivered to site, according to local news reports. The $18.5 million tunnel project features a 2000ft long bore underneath the city to hold sewage from several sewer lines, together with stormwater runoff as a surge capacity until the pump station can discharge it to the water treatment plant. The intent is to protect the Wabash River from raw sewage overflows during periods of heavy rain.

The 12.5ft o.d. machine is owned by the Triad-Frontier Kemper JV that is carrying out the work. At 32ft long, the machine will be lowered in sections into the drive pit using a 240t crane. Boring is expected to take approximately eight months and will be 30ft below the surface. The main leg of the tunnel runs northwards, once this is complete, the TBM will be shuttled back to the original launch pit and used to bore a short southwest leg to connect to the pump station.

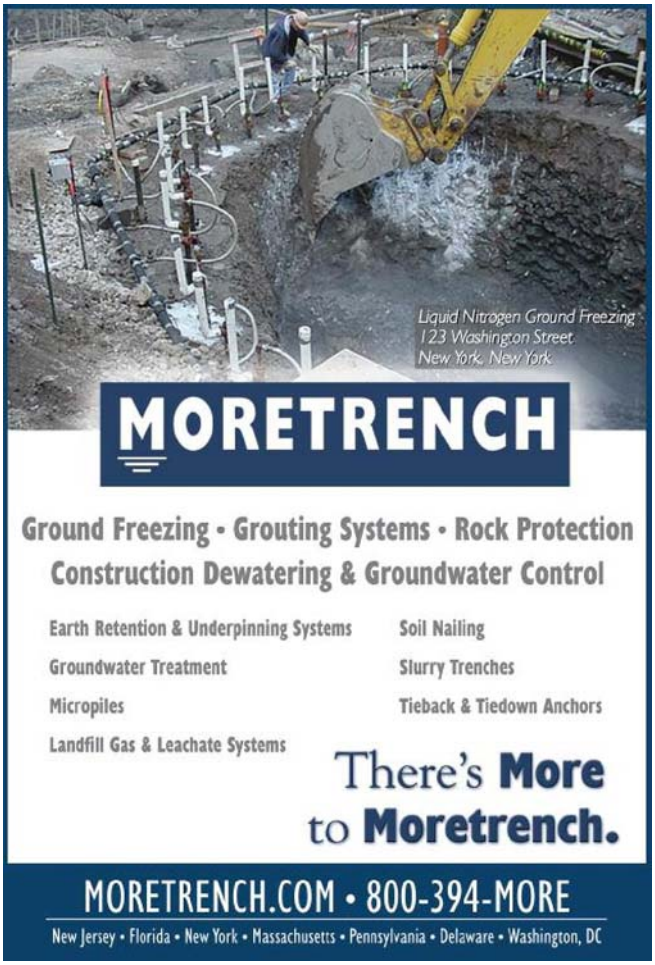
Renovation restarts: In West Virginia, the eastbound tube of the Wheeling Tunnel is about to close with the resumption of rennovation works, which are due to take 14 weeks following an agreement being reached to resume works after problems with cladding tiles adhesion.

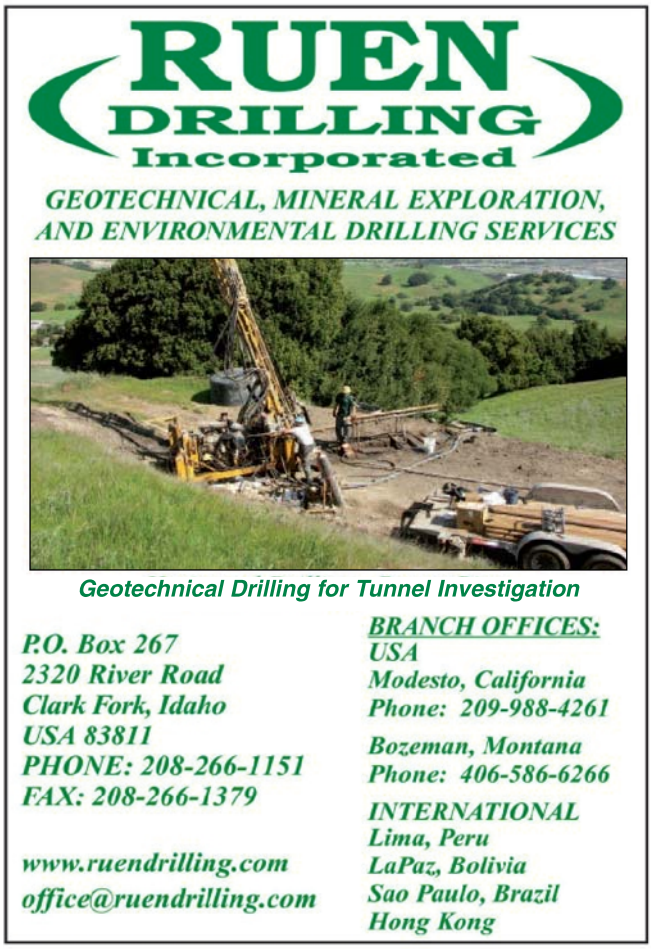
Contractor, The Velotta Company, won the contract in 2006 to renovate both tubes of the tunnel with a low bid of $5,776,989. Reports said the tilework was being completed by Massaro Industries.

Velotta's work got underway in January last year, but problems were encountered with adhesion of the new tiles to the concrete walls and the works were suspended pending assessment. A decision was made to re-open the tunnel with the works unfinished on November 15 last year. Since then, representatives from client, the West Virginia Department of Highways (WVDOH) and Safeco Surety, Velotta's bondholder, have been investigating the situation and reaching an agreement for works to continue.

T&TNA understands that under the terms of the agreement Velotta may resume the works, but under the supervision of Safeco Surety and construction managers from WVDOH for the first six weeks. In addition, Velotta may bring back any contractors apart from Velotta-owned Concrete Restoration Specialists, which was responsible for shotcrete work in 2007. In addition, Velotta will be paid $1.045 million for work already completed in the tunnel. A WVDOH spokesman said plans to renovate the westbound tunnel will not be considered until the current project is completed.

Drug smugglers up their game: There have been many reports of short tunnels built across the US/Mexico border for the purposes of smuggling, but it seems that some smugglers have become quite accomplished, with the latest instance equipped with air conditioning. Talking to the press, Juan Miguel Guilleen, director of police in northern Baja, California, said the 140m long, 1.3m wide tunnel ran across the border at a depth of 5m and was fitted with lights, an "electric rail for container transport" and ventilation including air conditioning. Police officers arrested eight suspects during a patrol in the town of Mexicali, across the border from Calexico in the US. The US Drug Enforcement Administration (DEA) is said to be carrying out excavations to confirm the extent of the tunnel.





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Easing Manhattan's friction

The complex subsurface interchanges of lower Manhattan's Subway lines are currently being restructured to remove a tangled legacy of "friction". At the centre of this scheme is the new Fulton Street Transit Center. Technical journalist Adrian Greeman reports

New York's Subway is one of the oldest, busiest, and most comprehensive in the world - but can be difficult to negotiate. This is particularly true of Lower Manhattan, where the Capital Construction division of the city's Mass Transit Authority (MTACC) is currently in the process of constructing the new Fulton Street Transit Center.

The project will consolidate a dozen existing Subway lines within an attractive light-filled space with logistically clear connections, and also provide a new 400ft long, 25ft wide concourse linking to the World Trade Center PATH station.

Above: The historic Corbin building, which will be incorporated into the Fulton St Transit Center (above)

A legacy of friction

The transit companies that built the original Subway lines in New York were jealous business rivals, with neither wanting the public to ride the other's lines. "Friction" was deliberately built into the system says Craig Covil, Principal and Tunnel Engineer with Arup's New York office, lead consultant for the Fulton Street Transit Project. There were originally no connections at all between the sub-surface cut-and-cover tracks that run under Manhattan, to discourage passengers from changing lines.

As the system grew the friction became more and more of a problem. Although some new connections and pedestrian routes were added after integration of the Subway under the city's Metropolitan Transit Authority (MTA) in the 1940s, these were mainly add-ons as part of other rail projects. At key interchange points, such as Lower Manhattan, where Wall Street and the World Trade Center site are located, it was necessary to leave one line, walk along the street, and enter another to change routes.

The connections have evolved very much as an afterthought, says Covil, and like the surface entrances to the subway system, are relatively invisible. A major link was formed with the construction of the transverse A/C line station (see figure 1), built as a long subterranean box sitting over the slightly deeper A/C platform tunnels; however, this mezzanine footway has multiple ramps and links and is narrow and cramped.

In this long passageway, and on the old narrow street pattern of lower Manhattan, there is daily confusion. One of Arup's Senior Tunneling Engineer's, Michael Deutscher, says he cannot go on site with his official helmet on without being asked for directions by dazed looking visitors and tourists.

Clear connections

It has long been the ambition of the MTA to change all this, and the Fulton Street Transit Center Project aims to do just that.

According to Uday Durg, MTA's project director, the Center will take in a dozen different lines, restructuring four stations and widening or building new underground walkways between them. Further links will be added to the new World Trade Center and PATH stations.

Several contracts make up the project: One for renovation of the 2/3 station (figure 1); a major new connection under Dey Street that includes a new above ground entrance; and two contracts for the Transit Center itself.

Surface demolition and a 80ft (25m) deep secant pile perimeter wall for the Center's two-storey deep basement is now complete but the major work is yet to start. Above ground, this building is to be a four-storey glass and steel building, designed by London-based architect Grimshaw & Partners, providing a main entrance to the east-west A/C line station and the 4/5 line station, as well as the new Dey Street connection.

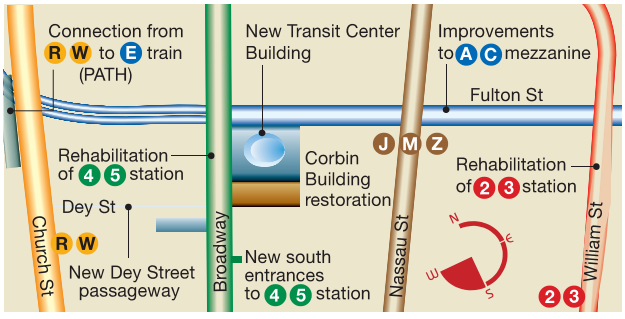
The building will draw a lot of attention with its light airy spaces and the spectacular "occulus" skylight, which sits at an angle at the top of a "dome-shaped" tower (figure 2). The building's interior lining will actually be a sculpture by James Carpenter, an artist who works with glass and metal, and will consist of a web of transparent light-reflecting panels that captures light from the occulus and throws it all the way down into the deepest levels of the building.

In order to integrate the Fulton complex into the local historic district, whose landmark buildings shaped New York City, the Center will also incorporate an existing building on the site. The historic Corbin building was built in 1888 and was reputed to be tallest building in the city at the time, as well as the first to feature OTIS elevators.

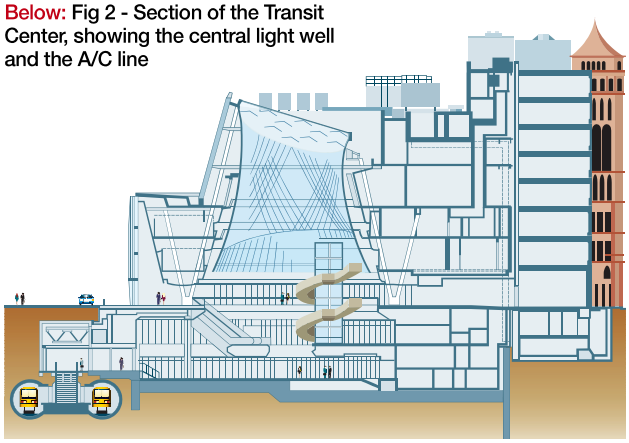
Structuring logistics

Structural design work for the old

Below: Fig 1- Map of the Fulton Transit Center Project components



Below: Fig 2 - Section of the Transit Center, showing the central light well and the A/C line



and new buildings, and the transition structure between, is highly complex and some current wrangling over cost persists in New York. However, below ground work at the site is the real focus at present.

Covil explains: "The central problem is that the connection point with the 4/5 line station is at the end of the A/C line station. Therefore passengers load themselves into the front of the trains in order to be ready for the change to the next train; they have to pass though a limited passageway at the corner of a right angle between the lines to get onto the other platforms."

With everyone trying to make the change in the same corner at the end of the platforms, queues and congestion prevail. Train "dwell time" in the stations is extended at rush hour, with a knock-on effect to the whole system. The solution is to widen this right-angled changeover.

To do it, the MTA took over a city block on the corner between Fulton Street and the downtown section of Broadway, where the two stations meet. "Strictly speaking it is a half block" says Covil, this is where the Transit Center is located. Within the new building, an open space will drop to platform level, with stairs and escalators connecting to the platforms along half their length.

The whole space, enclosed by the secant pile walls, will be much more free flowing, with passenger ways through a series of arches and entrances to the platforms. Escalators will be fitted between unusual inverted arch spread footing foundations, which support the tie-in to the Corbin building.

The lower Transit space will reduce the strain on the existing narrow mezzanine connection over the top of the A/C tunnels. But this will be widened with new ramps and staircases installed, to comply with disabled access standards and fire regulations.

Construction challenges

All this is easier said than done says Deutscher: "The first issue is the water table, which is 33ft (10m) down." The ground in this part of the city is not the hard schist that made Manhattan so suitable for skyscrapers, but sedimentary deposits "of silt and sand, beneath 6-9ft (2-3m) of soil with utilities."

The first Subway lines, from about 1905, were built by cut and cover above groundwater level, but by the 1920s the use of compressed air excavation had increased. The A/C line, which cuts across the older lines, comprises twin tubes that sit below the watertable. Above these is the mezzanine, a two level concrete box with ramp and stair connections to the platforms and stations it crosses. The box is an important load on the tubes below, resisting uplift.

To demolish and rebuild it is a complex task. There is no room to establish diaphragm walls between the major buildings either side, or to do anything to the tunnels below. The solution adopted is to complete the enlargements in sections, carefully calculating potential movement below. Essentially, for short sections at a time, temporary internal walls will be built to support the roof, then the old walls demolished, leaving room to widen the mezzanine outwards. That done, new permanent walls can be built and the temporary walls removed.

This means the load on the tunnels below is always present, "but shifts its position," says Covil. "It creates a slow moving wave of altered stress along the box, but hopefully not suddenly. It will be spread out over time, a year and half of construction in this case." A complicated 3D and time analysis is made even more complex by the changing cross section of the box as ramps and staircases are encountered.

Analysis of the impact of works on passenger flows has also been carried out. Arup has studied the changes the new ramps and stairs will make during construction using Pedflow software. "We have done this not only in absolute terms to ensure no blockages, but also to establish optimum flows and to determine exactly what 'level of service' will be provided," says Covil, who thinks this magnitude of pedestrian analysis is unique or, at least, unusual for a construction phase.

Current activity

The contract for all this work and the Transit Center above, worth over $1bn, was initially put out for bid early this year. However, the tender has been withdrawn following higher than expected costs. The MTA is currently deciding whether to modify the project, possibly by altering the above ground building. More likely is that the work will be re-packaged into smaller contracts.

Meanwhile, work has been ongoing on the other contracts. The first of three contracts let in December 2004, for renovation of the 2/3 station, new entrances, and upgrading of platforms and stairways to contemporary standards, has been completed.

A second contract at the west side of the project includes work on the R/W line station, which is closest to the WTC site and has been closed since 9/11. "The tracks are in use and trains pass through without stopping," says Deutscher. Several outages were required for these works, which involved underpinning the tracks with micropiling to allow construction of new underpasses through to the WTC, PATH and Line E stations beyond.

These new connections will be linked to the Transit Center via a pedestrian underpass along Dey Street. The tunnel spans the full 33ft (10m) width of Dey Street, which has historic buildings on both sides including the original AT&T building, where the transatlantic cables from Europe used to be connected.

On the southern side of the street is a 1905 building that houses the famous Century 21 department store, a favourite for tourists. The store insisted on retaining street use for its delivery vehicles throughout construction, this was achieved with a heavy steel temporary deck initially and eventually via a secant pile wall.

The underpass is now nearly complete. Meanwhile, at the end of Dey Street the structure widens - with an additional box formed within secant piles - to become the stair and escalator well for a new glass and steel street level entrance.

The walkway will also connect through into the basement of the Transit Center, currently a large excavation in the ground where a third demolition contract has been completed, secant pile wall built on one side, and the site made ready for the main contract.

The project is now awaiting discussions by the MTA on the main works and the go-ahead for the largest part of the scheme. ■

Above & below: Renderings of the new Fulton St Center

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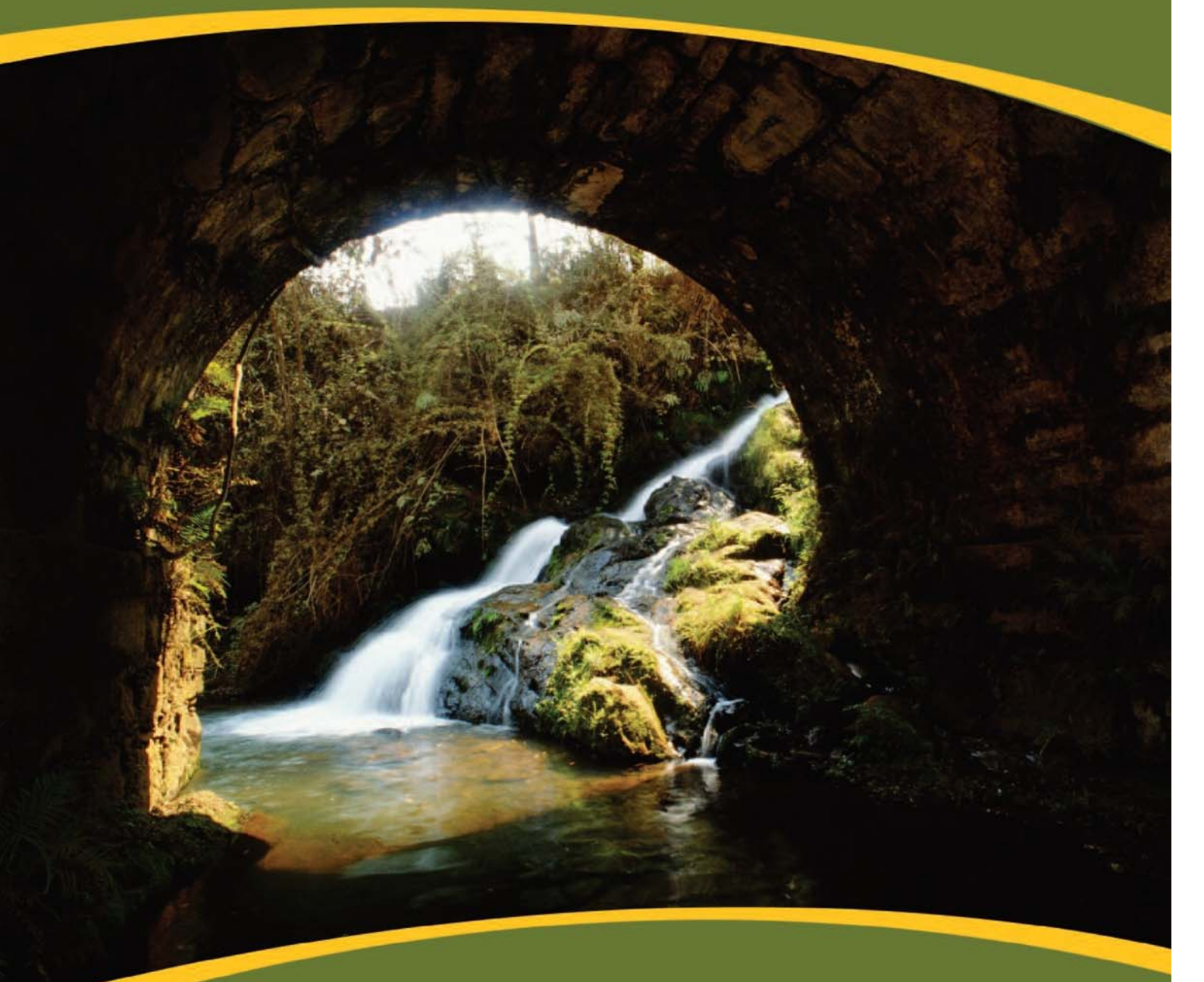

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Sey Cap saga gains impetus

In Canada, the saga continues over the fate of the twin water tunnels underneath Grouse Mountain as part of Metro Vancouver's Seymour-Capilano scheme (*T&TNA* May p5). The client recently issued a request for qualification to contractors to finish work on the tunnels following the termination of its contract with the Bilfinger Berger /Fru-Con JV. Meanwhile, the contractors have issued a lawsuit and lien against the client, its engineers Hatch Mott MacDonald (HMM) and local municipality landowner, the Corporation of the District of North Vancouver,.

T&TNA contacted Metro Vancouver to discuss some of the statements made in the contractors' claim and plans for moving the tunnel project forwards. A spokesman would not comment on legal matters - but was more forthcoming on plans to re-let the balance of the contract, saying that a request for qualification had been issued to 15 possible replacement contractors, with a response expected as *T&TNA* went to press. Following this, a request for proposal will be issued to qualified bidders, and it is hoped works could resume as early as mid-November.

Although Metro Vancouver refused to be drawn on budget, it did release a list of companies in receipt of plans relating to the prequalification (including subcontractors): Frontier-Kemper Constructors; Flatiron Construction; McNally International; SELI; Kiewit & Sons; Dragados; Strabag; Obayashi; Kenny Construction; JF Shea; Balfour Beatty; Traylor Bros; Collings Johnston; SAK; Procon Mining & Tunnelling; Tyam Construction; Sandwell Engineering; Karyo Edelman; Vancouver Reg Construction; Pennecon Heavy Civil; Jewel Holdings; C&M Mcnally Engineering; NAC Constructors; and Roktek Services.

When asked about the termination of Bilfinger Berger's contract and the contractors' claims of hazardous conditions, *T&TNA* was told that Metro Vancouver: "disputes so-called "hazardous" conditions exist and has a plan that includes rock bolt and mesh, shotcrete, and, where appropriate, steel sets to manage ground conditions."

When pressed as to whether these recommendations constituted a revised design, and how they differ from the prevailing ground support recommendations - together with a request to clarify its position of refusing to recognise the conditions, but then seemingly acknowledge them with a plan - the Metro Vancouver spokesman stated: "As this is likely to be the subject of court deliberations, I decline to comment."

T&TNA also contacted Bilfinger Berger for comment and received clarification from Contracts Manager, John Penner, who said Bilfinger Berger claim: "Significant damages against Metro Vancouver, the engineer HMM and the landowner The District of North Vancouver".

These claims cover losses, costs and expenses suffered by Bilfinger Berger from the time of the tender, in 2004, to present. Claims for specific unpaid labour and materials that have been physically incorporated into the lands to date, amounting to Can$22,549,579, have been secured by Claims of the Builders Lien and placed against title to the lands.

T&TNA asked Bilfinger Berger why its original bid was so much lower than the other two bids at the time and was told: "In 2004, Metro Vancouver and its engineers estimated the cost of the Twin Tunnels project at roughly Can$100 million. Bilfinger Berger submitted its tender for the project in August 2004 at Can$100 million, based on the tender documents, which state that all risks unknown, and more adverse than those contained in the geotechnical report forwarded to bidders, are accepted by Metro Vancouver."

There have been rumours that Bilfinger Berger used the unsafe ground and refusal to change working practices, as proposed by the client, as a means to get out of an unprofitable contract. When *T&TNA* put this to Penner, he responded: "The decision to stop work was a safety issue. Bilfinger Berger was at all times ready, willing and able to continue the work, but only once a safe and viable design was provided by Metro Vancouver."

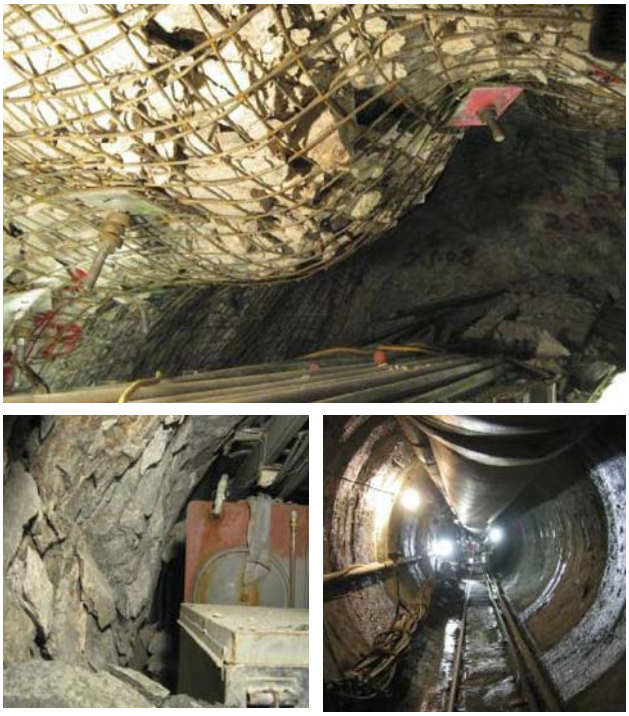
Penner says that since work stopped in January, Bilfinger Berger has repeatedly advised Metro Vancouver that any design must take into account the risk of rockfalls, running ground, rock bursts and other manifestations of unexpected overstress rock failures.

The client however, has refused to acknowledge the occurrence of rock bursts and has not provided a design solution to meet the safety needs of the workers, which Bilfinger Berger maintains is a contractual requirement. Instead, Penner said the client had provided a "range of recommendations, not a design to complete the tunnel".

Bilfinger Berger has garnered support from unions representing workers at the jobsite. Business managers of the International Union of Operating Engineers Local 115, Construction & Specialised Workers' Union Local 1611 and the International Brotherhood of Electrical Workers Local 213 wrote a joint letter to the Greater Vancouver Water District on May 30.

T&TNA obtained a copy of the letter, which says: "It is ludicrous to suggest that [Bilfinger Berger], with its expertise in engineering and its safe completion of many similar projects, is unable to adequately evaluate and manage the safety of the Twin Tunnels project." The letter went on to say that after workers were injured and exposed to unsafe conditions, the contractor made, "the correct decision to temporarily suspend the work pending a review and analysis of the rock behaviour".

The letter continues: "Inexplicably, instead of commending Bilfinger Berger for their commitment to safety, the GVRD [Greater Vancouver Regional District] has cancelled the entire contract." In closing, the letter asks GVRD to review its decision to terminate the Bilfinger Berger contract. ■



Clockwise from right: **Seymour Capilano photos showing "stable" rock conditions; "fractured" rock conditions; and the "hazardous" conditions that caused Bilfinger Berger to halt the TBM drives**

One of the project's TBMs prior to launch

Powering in Portland

Slurry excavation is progressing for the East Side CSO, in Portland. *T&TNA* recently visited the site to discuss the impressive advance rates being achieved

Slurry excavation is progressing well on the Portland's East Side Combined Sewer Overflow (CSO) project, with the third of six TBM drives on track for breakthrough at the end of next month.

Following the launch of its 25ft (7.7m) diameter Herrenknecht Mixshield TBM 'Rosie', in mid-July last year, the Kiewit/Bilfinger Berger (KBB) contracting JV managed to double scheduled production on its first drive, reaching an average of 400ft (120m) a week.

This initial progress, which is partly attributed to experienced local labour garnered from the West Side CSO project (*T&TNA*, June 2004, p12), has set the project up for a promising duration.

Project set-up

Portland's $381 million East Side CSO tunnel scheme is the final and largest of its Clean River Program projects, which aim to eliminate untreated sewage and storm water overflows into the Willamette River by 2011. The main component of the project is a 5.5-mile (8.9km) long, 22ft (6.7m) i.d. tunnel, running along the east bank of the river, at depths of 85ft (25m) to 165ft (50m), predominantly through the cemented gravels of the area's Troutdale formation.

The tunnel is currently being driven north from the Opera Shaft to Port Center Shaft, near the Swan Island Pump Station, where it will be eventually be disassembled and returned to Opera for a final southbound drive to McLaughlin (figure 1).

In addition to the tunnel, a network of open-cut and microtunnelled pipelines are also being constructed in order to intercept flows from existing outfalls and divert them to the seven shafts along the route.

Building on experiences gained from its West Side CSO project, which went into operation at the end of 2006, the City of Portland Bureau of Environmental Services (BES) aimed to reduce risk exposure on the scheme by adopting a comprehensive risk management strategy during the pre-design phase[1]. A primary component of this strategy was the adoption of a fixed-fee cost-reimbursable contract, involving extensive contractor participation during final design development.

BES and its designer Parsons Brinckerhoff also undertook a series of workshops throughout the project implementation phase, to identify and mitigate design, construction and planning risks. Based on the ethos of the UK's Joint Code of Practice for Tunnelling Works, this combined approach aims to minimize risk for all the parties involved with the project.

Tunneling progress

Ironically, one of the primary risks identified during this process as having potential for delaying the start of tunneling works was groundwater control at the slurry wall shafts. With the launch of the JV's Mixshield delayed by seven weeks, as leak-sealing operations were undertaken at the project's main Opera mining shaft, things didn't get off to the smoothest of beginnings (*T&TNA*, December 2007, p6).

However, with a spectacular first drive, KBB pulled this delay back by doubling, and at times tripling, predicted advance rates to reach the Alder Shaft on schedule at the beginning of December 2007.

The team credits this success to both the suitability of the chosen excavation method and also the unique experience of the local union workforce, which came straight from the West Side CSO project – the first slurry tunnel of its size in the US.

"Once we had the machine fully commissioned, we were basically up into full production within a week's worth of mining," explains Niels Kofoed, Assistant Tunnel Manager for KBB. "There definitely would have been much more of a learning curve involved if it hadn't been for the training the guys had on West Side."

Working three 8hr shifts per day, sustained progress rates of

Far left: Figure 1 - Route of the East CSO tunnel and shafts; Top left: The 25ft diameter Herrenknecht Mixshield is readied for launch from Steel Bridge Shaft; Left: View of the universal precast tunnel lining

Left: **Grout ports mark the tunnel's interface with Steel Bridge Shaft's slurry wall, which was sealed before draining the shaft for free air cutterhead access**

400ft per week were achieved during this run, with a best day of 24 rings or 120ft, and a best shift of nine rings or 45ft.

Of course, these advance rates had a major impact on segment manufacturing. Production in the casting yard had been based on an eight segment, steel fiber or rebar reinforced (depending upon the prevailing geology) Universal ring, at an average advance of eight rings per day. With the TBM tripling these rates, additional moulds had to be purchased keep up with the demand.

Production settled back down to an average of 16 rings/day with the commencement of the second drive from Alder in January of this year, as the JV began to approach a number of bridge footings and the complex Banfield Interchange area, beyond Burnside Bridge.

The Interchange consists of a series of interconnecting elevated highway ramps, some with piled foundations as deep as the tunnel alignment. "In the design stage, there was one pile located very close to the tunnel, at roughly 10ft," says KBB's Tunneling Manager, Christof Metzger. "So we realigned this section to avoid the narrow passage through the piles."

Despite this, a cautious approach was nevertheless adopted towards tunnel induced movement throughout the section, with an automatic alert system in place if settlement trigger limits were approached. Fortunately, this proved not to be an issue, with the drive reaching Steel Bridge in mid-May on schedule and without incident.

At the time of *T&TNA*'s visit in late June, free air inspection of the TBM's cutterhead tools had just been completed, following an underwater breakthrough and draining of Steel Bridge Shaft. However, with 8600ft (2.6km) of tunnel completed, the focus of the works was on replacement of the 14" slurry discharge pipes and maintainence of the pumps.

"The TBM is not the driver here for power consumption, it is mostly the slurry system and the pumps themselves," explains Metzger. "There are five 923HP discharge pump units in the tunnel and one on the TBM. The intermediate booster pumps alone weigh approximately 20t each. It's definitely a very expensive part of our drive and also a tricky one, as they require maintenance on a daily basis - checking, pegging adjustments, replacement of wear parts, etc."

An additional issue with the pumps has come from the Troutdale cobbles. "You transport a lot of large stones, whatever passes through the cutterhead," says Metzger. "Twice so far pump impellers have become clogged." When this happens the pumps have to be stripped down and repaired.

Although the grizzly bar openings on the cutterhead are 6", many of the cobbles that make it through the machine are oval and much longer. "Some of the larger cobbles that make it through are eight, maybe 10, inches long," says Kofoed.

On the whole, the slurry system has been performing extremely well for the JV. However, the 6000 gallon/min Schauenburg MAB separation plant was designed primarily for the Troutdale formation, which makes up about 85% of the route's predicted geology.

Therefore, the setup inevitably needs adjusting when the TBM encounters the less frequent sections of finer sand/silt or gravel alluviums. "It's always tricky to design a system that works 100% for all soils," says Metzger. "But Schauenburg have done well on this project, on the whole we're very pleased with the system's performance."

Logistics

As with many urban tunnel projects, space is at a premium around the Opera site and much effort has gone into scheduling truck movements so as not to impact upon other businesses local to the area.

The proximity of the river has assisted greatly in this, with a conveyor leading straight from the separation plant to a muck holding area on the edge of the riverbank. From here, another overland conveyor loads directly onto three or four 1000t barges per day, which transport the muck to the nearby Ross Island lagoon, where it is being used for reclamation works.

However, more of an issue at present is space at the JV's three warehouses in the Terminal 1 area, to the west of the river. While two of these warehouses are used by KBB for equipment storage, the third is home to the segment casting yard.

Half way through its total scheduled production of 6000 rings, the yard is currently manufacturing about 16 rings per day. To date, TBM advance has more than matched this production - with each 32t ring being delivered to the machine's erector, installed, bolted and back grouted, faster than the trucks can deliver them to site.

During planned TBM downtime however, space at the yard is a big problem and storage capacity will almost certainly be exceeded following the next breakthough at River Street Shaft. At that point, there will be a further six week break in production, in order to prepare the TBM for its longest, 8700ft (2.7km), drive on the scheme.

Future drives

The Mixshield is scheduled to begin its final northbound drive to Port Center in mid-November. Assuming everything continues going to plan, it will reach the shaft in May 2009. "At that point we do a complete refurbishment of the TBM," says Metzger.

Disassembly and refurbishment will last for four months, up to September 2009, with the majority of the machine being brought back through the tunnel to the Opera shaft.

Only two major elements are exempt, the cutterhead and the tailshield, both of which the JV hopes to transport via the surface. "We have confirmation that the cutterhead will be brought back in one piece," says Metzger. "We would also prefer not to have to cut the tailshield. It needs to be perfectly round when rewelded, to retain a proper seal, which is always tricky." KBB is currently assessing the costs of various options, including transportation along the river by barge.

Once reassembled, the machine will restart from Opera in the second half of September 2009, driving south to the McLoughlin Shaft.

The project team hopes to build on its current success, staying below budget and ahead of schedule - and with a pro-active partnering approach to risk management, combined with realistic production goals, tunneling, so far, seems to be on track for completion in 2010.

REFERENCES

1. T Pennington et al. "A case study in Risk Management" NAT 2006, Chicago, SME

Right: **A custom made platform supports one of the project's 20t Warman booster pumps**

Micro challenge

Not to be overshadowed by the large bore tunneling, the East Side CSO project also includes some 7820ft (2.4km) of microtunneling works. With eight specific microtunnel drives in KBB's base contract and also a ninth change order drive, the JV are basically collecting existing outfall flow and bringing it to the main construction shafts, explains KBB's Micro Tunnel Manager, Matt Roberts. At the time of *T&TNA*'s visit the JV had completed four of these drives, including a continuous run of 3055ft (932m) - North America's longest to-date.

The JV first launched its 102" (2.5m) diameter Herrenknecht AVN slurry machine on a short 275ft drive from Steel Bridge Shaft in July last year. Installing 84" i.d. concrete pipe, which comes from Hanson Pipe & Precast just south of Portland, the team were initially achieving progress rates of approximately 30ft/day.

This was the first of two drives from Steel Bridge, both excavating through the cobble-rich Troutdale formation. "We learned a lot on that first drive," says Roberts, who found they were spending a large amount of time clearing rock plugs in the 6" slurry return line.

As witnessed on the large bore drive, many of the long, oval, Troutdale cobbles were passing directly through the AVN's circular cutterhead ports before encountering the stone crusher. These cobbles were tumbling and twisting in the pipe and getting stuck. Following breakthrough, it transpired that wear on the machine's carbide cutter tools was also an issue in the gravels.

The team therefore made a number of modifications to the AVN before launching it on the second, much longer, 1100ft drive from Steel Bridge. "We throttled down the cutterhead ports, putting some inserts in to make them a bit smaller," explains Roberts. This resolved the jamming problem and the team began to see quite a few cobbles coming through that had been cut in half.

"We ended up doing quite a bit better than the first drive in the same sort of ground," says Roberts. The AVN was almost twice as productive with the modifications - with progress rates increasing up to around 50-55ft/day. "We also went to more of an alternating carbide/hardface cutterhead tool configuration, and it's worked out really well," he says. Compared to the first bore, the second 1100ft drive saw virtually no wear at all.

Following these initial Steel Bridge drives, the team undertook a third 724ft run from the Alder Shaft through sand/silt alluvium with some gravels. The transition from the Troutdales to a much softer material proved good practice, giving the team a chance to refine the 400m^3/hr Schauenburg MAB slurry separation system prior to embarking on their 3055ft drive from Port Center. "We learned a lot of lessons on the separation," says Roberts. "Going from the Troutdales to the sand/silt alluvium we ended up adding on some bolt-on components, including another centrifuge and a gumbo box from Brandt, to help separate out the softer materials."

Other changes were also adopted in preparation for the recording breaking drive (shown on figure 1), which began on February 14 this year. Rather than the standard laser guidance system used for the other drives, a VMT water level and gyro system was retrofitted for the launch. As the drive progressed, intermediate jacking stations and a high-voltage transformer were also brought into the pipe.

Running south from Port Center along the Willamette shoreline, which has seen quite a bit of industrial development over the past century, the team suspected that some debris would be encountered along the drive - this proved precisely the case. About half way into the drive, the JV hit a substantial number of wooden piles and also quite a bit of steel and other fill material. "There actually was an old dock that used to be in this area, there were old foundations for a boardwalk and some docks that used to be in the river and that's what we were mining through," explains Roberts.

Above: **Completion of the record-breaking 3055ft drive**

Surprisingly, however, there was minimal damage to the machine. "We did actually go in and do a free air inspection about halfway through and thought we would have to replace tools," he says. "Actually, although there was a fair amount of wear on the carbides, the hardface components were still in pretty good shape, which was a surprise, a nice surprise, after hitting all that steel and wood."

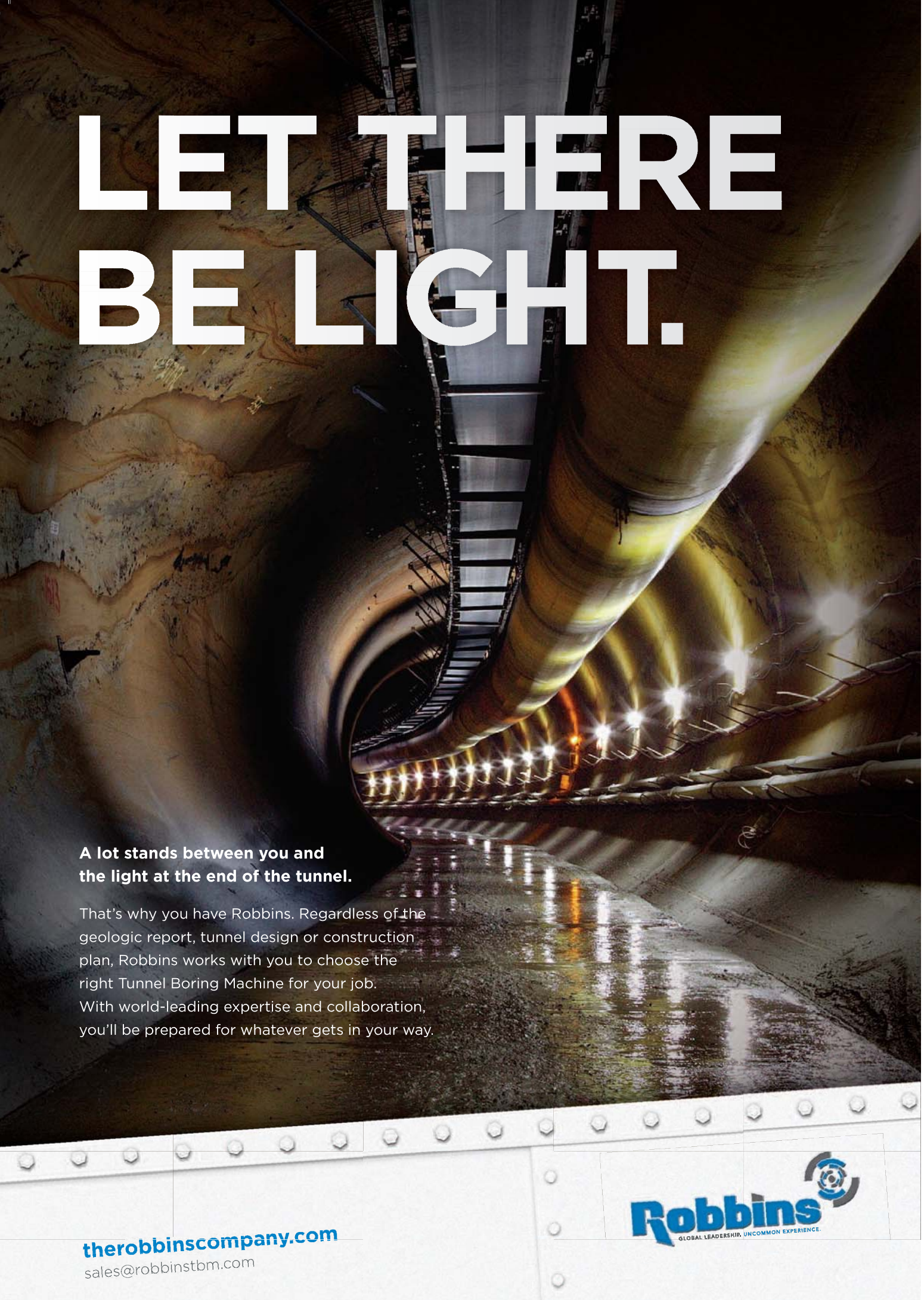
With limited space available at the shafts, planning and scheduling has been a key factor. Only about a day and a half's worth of pipe is stored on site, with Hanson bringing in a daily delivery of 10-12 pipes, and the majority of materials are delivered just-in-time to reduce storage requirements as much as possible. The containerized Schauenburg MAB separation plant has also assisted in keeping space to a minimum. "It's pretty compact," explains Roberts. The system discharges waste directly into muck bins, which are then loaded straight to trucks and disposed of at landfill.

Following a total of 60 drive days, the AVN successfully completed its landmark drive on April 19 and, at the time of T&TNA's visit, was about to relaunch on a short 75ft run out of the same shaft. Next will be two further short sand/silt alluvium drives out of Alder, a 125ft and a 85ft drive, which tie in Outfalls 36 and 37, and from there the team will relocate to McLoughlin for a 900ft drive through the Troutdales, to Outfall 28. The final 1400ft, change order, drive will be out of the River Street Shaft, to Outfall 44a.

With 80% of the drives in the original contract now complete, KBB are also on track to achieve some impressive results on this major 'micro' side of the project.

Below (L-R): **The AVN's narrowed cutterhead ports; Jacking setup in one of the secant pile shafts; View of face during free air intervention**

Photos: M Roberts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