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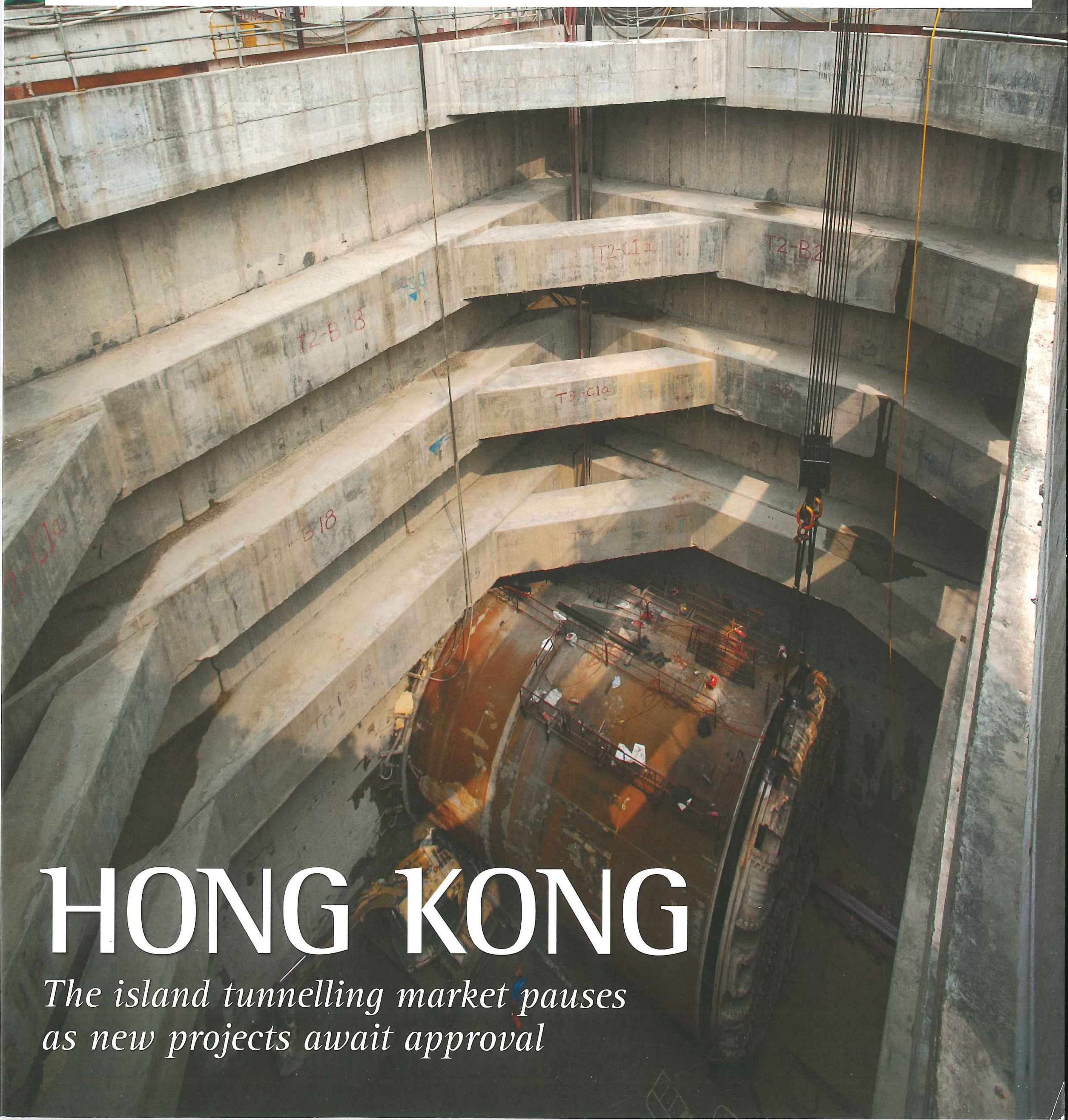
Tunnels AND TUNNELLING



HONG KONG

The island tunnelling market pauses as new projects await approval

WHAT'S THE RISK?

Alex Conacher
The *Tunnels and Tunnelling* editor has been with the magazine since 2010

This month I am stealing a comment hook from the British Tunnelling Society again. At the October meeting, the evening's lecture was on the management of risk in tunnelling and major infrastructure projects. The recording will be available from the Institution of Civil Engineers website, and I bring it up because in this issue of Tunnels and Tunnelling International we have put together a special focus on geotechnical risk in tunnelling. Readers interested in the topic might like to visit the website for bonus content (www.ice.org.uk).

The section in the magazine begins on page 27 and contains five articles. The first is an interview with a geotechnical expert regarding the role of the ground model and the potential for change in how construction plans for ground conditions. It also goes into what the specialists like to see in a project.

The second is an article looking at the relationship between site investigation spending and level of risk, as far as it is possible to work out such a relationship. It touches on the transition to a risk-sensitive approach to such investigation, rather than just a budget planning exercise.

The third is an article that looks at some of the software packages available in the field, and some of the aims of the developers, which include helping designers to achieve a better understanding of lining behaviour, interaction with the ground, and a collective, collegial approach to data use.

The fourth comes from the British Geological Survey's (BGS) Hazard & Resilience Modelling Team, which has developed a new shrink-swell 3D dataset, called 'BGS GeoSure Shrink–Swell 3D' that delivers an insight into the properties of the subsurface. The shrink–swell 3D data is a regional hazard susceptibility map that identifies areas of potential shrink–swell hazard, in three dimensional space, at intervals down to 20m in the London and Thames Valley area.

Finally, we have a case study from Canada, as Toronto is preparing to build 22km of tunnels to improve waterways in the Great Lakes Basin. Mark Bruder of R.V. Anderson Associates Limited, Daniel Cressman of Black & Veatch, and Robert Mayberry with the City of Toronto outline the geotechnical investigation program for the Don River and Central Waterfront Wet Weather Flow System.

Risk management is an important and evolving field in the industry and possibly one that we have not covered enough in recent years. High profile events and legal cases always bring it to the front of everyone's minds, but it has benefits for the technical solution provided for a project, as well as protecting companies and individuals when a project or activity does not go entirely to plan.

Cover

The front cover shows a TBM from XRL contract 820, Mei Lai road to Hoi Ting tunnels in Hong Kong

Next issue

In the next issue of *Tunnels and Tunnelling International* we look at high speed rail projects in California, the Farnworth tunnel project in the United Kingdom, Canadian hydropower work and alternative fuel concerns and risks for tunnel operations

This month...

20 YEARS AGO

The Shanxi Yellow River Diversion Project Corporation has awarded a USD 193M tunnel construction contract to the Wan Long JV. The contract comprises four drives and includes one of 43km, claimed to be the longest of its type in the world. The JV is led by Impregilo with CMC and the China Water Conservancy and Hydropower Engineering Bureau No. 4. The work is part of the USD 1.35bn project to supply water from the Yellow River to Taiyuan, Shanxi Province.
Tunnels and Tunnelling, November 1997, page 7

30 YEARS AGO

Services on the first section of the Singapore MRT started earlier this month, the opening day having been brought forward from the end of the year. Trains now run on the 6.5km section of the north-south phase one line from Yio Chu Kang to Toa Payoh, 2km of which is in tunnel.
Tunnels and Tunnelling, November 1987, page 9

40 YEARS AGO

The British Government has postponed approval of borrowing for the site investigation and design of a tunnel under the River Tees in the county of Cleveland. It has been decided that there is no need for the tunnel in the short term.
Tunnels and Tunnelling, November 1977, page 17

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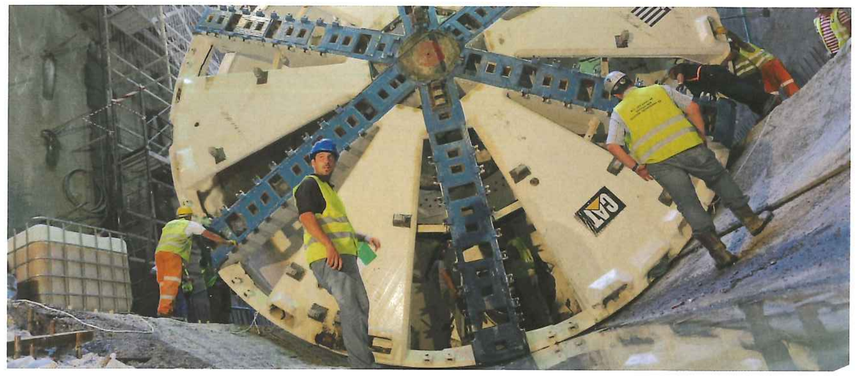

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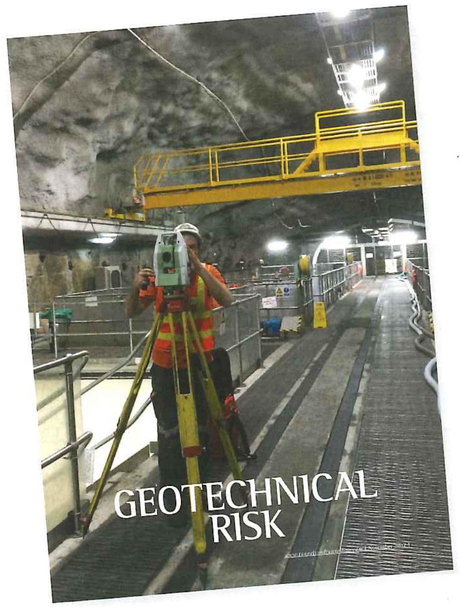
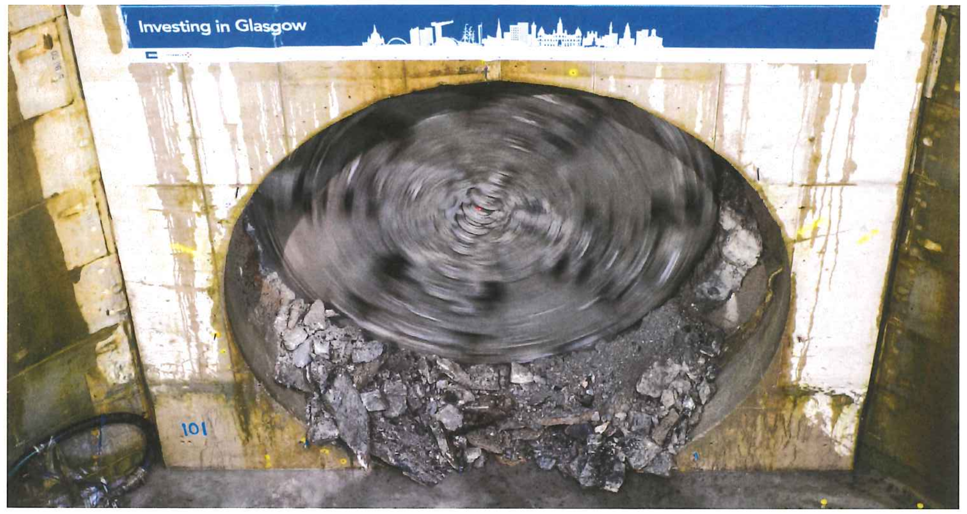


Geotechnical Supplement
In this issue of the magazine we have a special focus on geotechnical risk from a number of perspectives. In this supplement are articles on site investigation, the role of the ground model, the evolving software options available to the sector and more

SHIELDHALL BREAKTHROUGH



Above: Breakthrough on Scotland's largest wastewater project

GREAT BRITAIN — The TBM has broken through on the Shieldhall project. At GBP 100M, Scotland's largest wastewater tunnel has taken 15 months to excavate. The main portion of the works is a 5km-long, 4.7m-diameter segmentally lined tunnel designed by Aecom. It was excavated by a Herrenknecht slurry TBM that will erect around 3,250 rhomboidal rings during its drive, which are each 1.5m long, 250mm thick and reinforced with 35kg/m³ of 4D Dramix fibres supplied by Bekaert Maccaferri.

There was no special inner lining to contend with the waste, just the concrete lining and VIP gaskets making the seal.

The tunnel is relatively flat – a 5km length but only 3m difference in terms of level to satisfy the gravity requirements. In terms of geology, after the clays and made ground of the launch pit, the TBM hit bedrock made of sandstone and mudstone. Cutter wear was higher than expected along the drive.

A spokesperson for the apparently pleased client, Scottish Water, said: "As life above ground in the Queen's Park area continued as normal in the darkness and rain late last night, the TBM completed the installation of the last of more than 3,200 concrete rings that form the tunnel before its giant cutting head emerged at the bottom of a 16m-deep shaft to cheers and applause from some of the workers involved."

The tunnel will be commissioned in 2018, relieving the pressure on the water treatment plant at Shieldhall, increasing the network capacity by 100,000m³ and improving local river quality.

SHIELDHALL FACT BOX

Contractor: Costain-Vinci
Designer: Aecom
Reference design: CH2M
Client: Scottish Water
Machine: Herrenknecht slurry, 4.7m-diameter
Geology: Clays, sandstone, mudstone

Seattle LRT tunnel one-third complete

USA — Tunnel construction has advanced more than 700ft (213m) of the total 2,000ft (610m) drive below Bellevue, Washington, as part of Seattle's East Link light rail project, Sound Transit said on October 3.

When complete, the tunnel will be approximately one-third of a mile long, 27ft (8.2m) tall, 34ft (10.3m) wide, running between the future East Main and Downtown Bellevue stations under 110th Ave. Northeast, turning east near Northeast 6th Street.

Because of the short tunnel length, and to minimise impact on neighbouring homes and businesses, Sound Transit is constructing the tunnel using the SEM with steel lattice girders for support.

Excavation is taking place 12-60ft (3.6-18.2m) below ground, and expected to progress at approximately three to four feet per day.

East Link will extend light rail 14 miles (22.5km) from downtown Seattle to downtown Bellevue and the Overlake area of Redmond via Interstate 90, with 10 stations.

All segments of the East Link extension are currently under construction, and the entire line will be operational in 2023.

3RPort starts to drill

USA — Contractor S.A. Healy Company began drilling on 28 September for the launch shaft on the Three Rivers Protection and Overflow Reduction Tunnel (3RPort) in Fort Wayne, Indiana.

The 7,468m-long, 5m finished diameter tunnel will be located approximately 61m below ground, and lined with precast concrete segments.

Other works includes seven drop shafts and four vent shafts, one pump station shaft, and one retrieval shaft, as well as 536.5m of adits.

Underground space workshop held in London

GREAT BRITAIN — Think Deep UK has held its first workshop. The organisation was set up to consider how to plan, manage and realise underground space. Hosted at Idea London, with social value experts from PwC, HS2, Arup and Volterra, the workshop participants considered "how to define and measure the social value delivered by underground space".

Specifically, the workshop aimed to:

- Define social value and how it applies to urban underground space.
- Provide practical examples and case studies of how social value is delivered through urban development.
- Present tools and methods to quantify the potential social values associated with projects.
- Use real scenarios to apply social value principles, tools, and frameworks to a range of activities that utilise urban underground space.

A spokesperson said of the proceedings: "Listening to Stuart Jefford (PwC) and Bridget Jackson (HS2) it became clear that social value is not clearly defined, that there are many different definitions, frameworks, guides and policy documents for social value which generates confusion and ambiguity. Some define social value in its narrowest sense, others include environmental and economic benefits. Some encourage economic valuation and financial indicators whilst other advocate more qualitative measures. Social value as concept is not mainstream and government projects tend to adopt 'benefits management' as a broader framework.

"The principal drivers to evaluate social value for large infrastructure projects appear to be cost and risk. From the outset the business case needs to be proved and as such the social value assessment is intimately linked with the cost-benefit analysis and the design life of the scheme. As such, only the tractable, evidence-based social benefits can be easily accounted for. Is such a process 'future proof'? How can we go beyond domain-specific objectives and context-specific extrapolations to capture the broader societal need over future generations?

"There was consensus that underground development is currently viewed as problematic, the benefits are not highlighted sufficiently and the evidence for the benefits needs articulating. The challenge to balance individual preferences, community benefits and national interests was acknowledged as was the trade-off between long-term benefits and short-term costs. Communicating the social benefits and impacts was considered key, explaining the value of underground space utilisation and making the benefits more visible.

"Early stage consultation with potential beneficiaries and community-led engagement were considered markers of success, with our speakers highlighting individual successes where public consultation had led to enhancement of social value - and not always with financial implications. Such approaches have potential to refocus project development from purely economic endeavours to socially inclusive processes. In this way the full potential of underground development, which may have a higher initial cost but greater long-term benefits could be realised."

FIRST TBM BREAKTHROUGH IN LUCKNOW

Above: Breakthrough on Lucknow Metro's Phase 1A

INDIA — Crews celebrated breakthrough on the first TBM-driven tunnels in the capital of Uttar Pradesh. A Gulermak-Tata Projects JV was the contractor for the project, which is part of the 22,88km Phase 1A of the Lucknow Metro North-South Line.

A 6.52m Terratec TBM was used for the 3.44km down-line drive, which completed in May but broke through in August after a wait for the official ceremony, according to the manufacturer. A few days later, the identical up-line TBM broke through.

The TBMs mined through geology consisting of stiff to hard clayey silt and medium to dense silty sand, passing beneath historic buildings in the Capital Plaza of Hazratganj (heritage district) without any notable disturbance.

A spokesperson for the manufacturer said: "The EPB machines feature a classic soil configuration and are equipped with a spoke-style cutterhead with a 57 percent opening ratio. TERRATEC has designed the cutterheads with cutting tools that are interchangeable with 17" roller disc cutters, allowing the TBMs to bore through station D-walls and cope with the presence of any unexpected obstacles in the ground."

LMRC's Managing Director, Mr. Kumar Keshav said: "This achievement was only possible due to the hard work and commitment of the Lucknow Metro project team. The tunnelling in this stretch posed an enormous technical challenge as the route passes beneath highly congested areas at a depth of 12 to 15m below ground. With this breakthrough, LMRC has achieved one of the biggest milestones in form of completion of first TBM drive in the construction of underground metro in the state of Uttar Pradesh."

Tata Projects MD Vinayak Deshpande added: "Due to many heritage structures, the stretch was highly challenging. With excellent guidance from the LMRC team, state-of-the-art TBMs, and a dedicated, passionate, project team, the daunting task was completed in a world-class manner with outstanding quality and before-time completion. We all at TATA projects feel very proud of this accomplishment."

California's largest water agency endorses Delta tunnels

USA — The Metropolitan Water District (MWD) of Southern California's board officially endorsed the California Water Fix project, previously called the Delta Tunnels, and approved its USD 4.3bn share of the project on 10 October.

The new intakes and twin tunnels are estimated to cost USD 17bn, with the district covering 26 per cent of the financing.

"Every generation of Southern Californians has to reinvest in our water system to ensure a reliable water future. Today marks one of those historic votes that reaffirms that commitment and vision," Metropolitan board chairman Randy Record said. "We simply must modernise and improve the reliability of our imported supplies as well as meet the needs of growth by developing more local supplies and extending conservation."

MWD said about 30 per cent of the drinking water in Southern California comes from Northern California via the Sacramento-San Joaquin Delta. "The Delta's delivery system, however, is badly outdated, a problem compounded both by a declining ecosystem that is harmful to fish and a 1,770km levee system that is increasingly vulnerable to earthquakes, flooding, saltwater intrusion, climate change and environmental degradation.

The project calls for modernising the delivery system by building three new intakes in the northern Delta along with two tunnels to carry water to the existing aqueduct system in the southern Delta.

"Given our size, Metropolitan is the anchor tenant for any successful California Water Fix, and this vote puts us on record as being ready and willing to participate. We still have a ways to go before we have a final, fully funded project, but this vote keeps Water Fix on the path to finding a viable and lasting solution," Metropolitan general manager Jeffrey Kightlinger said.

In addition to MWD, Santa Clara Valley Water District board voted unanimously on October 17 to participate in the project.

California secretary for natural resources John Laird said, "We commend Santa Clara Valley Water District's board members for taking action today to stabilise their water supply for generations to come.

"Their 7-0 vote adds to the momentum we've seen in the last two weeks as local agencies around the state have seen the value of Water Fix and formally voted to participate in the project."

Among state water contractors the boards of Zone 7 Water Agency, Mojave Water Agency, San Gorgonio Pass Water Agency, Desert Water Agency, San Bernardino Municipal Water District, Crestline-Lake Arrowhead Water Agency and Kern County Water Agency have all voted to support the project.

Other agencies are scheduled to hold a vote. Following the votes by the participating water agencies to identify the initial level of investment, Metropolitan expects further deliberations to identify how to move forward with the proposed existing project, consider phasing the existing project or no project. Any additional level of investment by Metropolitan would require further action by the district's board.

Murphy's new CEO

GREAT BRITAIN — J. Murphy & Sons Limited has appointed John Murphy as its new CEO. Murphy was the company's current chief operating officer as *Tunnels and Tunnelling* went to print, responsible for leading the group's operations in the UK and abroad. CEO Steve Hollingshead will step down at the end of the year (December 2017) and take up a role as non-executive director on the company's board.

Murphy joined the business in 2003 as a civil engineer and has developed a broad range of experience across the company's key sectors capabilities and notable projects such the London power tunnels for the Olympic Park in 2012 as well as the south Wales expansion pipeline for National Grid. Prior to taking on the COO role, he successfully lead Murphy's business across the north of England as managing director and has represented the company on a number of joint venture boards both in the UK and internationally.

On his appointment, Murphy said: "The company is well-known in the construction industry and I want us to continue to grow and thrive, ensuring that we continue to play a vital role in delivering world-class infrastructure.

"To be at the helm of a company that is leading the way in innovation and engineering – a company my grandfather began more than 60 years ago – is a real honour, and I can't wait to get started."

Alastair Kerr, Murphy's chairman, said: "It is with great pleasure that we welcome John's step up into the role of CEO. He takes over the reins at an exciting time for Murphy, where we have a clear long-term plan for where we are going and what we want to deliver. "

GOLDER TO BUY ALAN AULD GROUP

CANADA — Golder announced on 12 October that it had entered into a definitive agreement to purchase the assets and ongoing operations of the Alan Auld Group of Companies.

Headquartered in Doncaster, UK, with offices in the UK, Canada and the U.S., Alan Auld Group is a global provider of specialised engineering design and construction services for underground structures and is recognised for their expertise in complex shafts and tunnels, the engineering firm said.

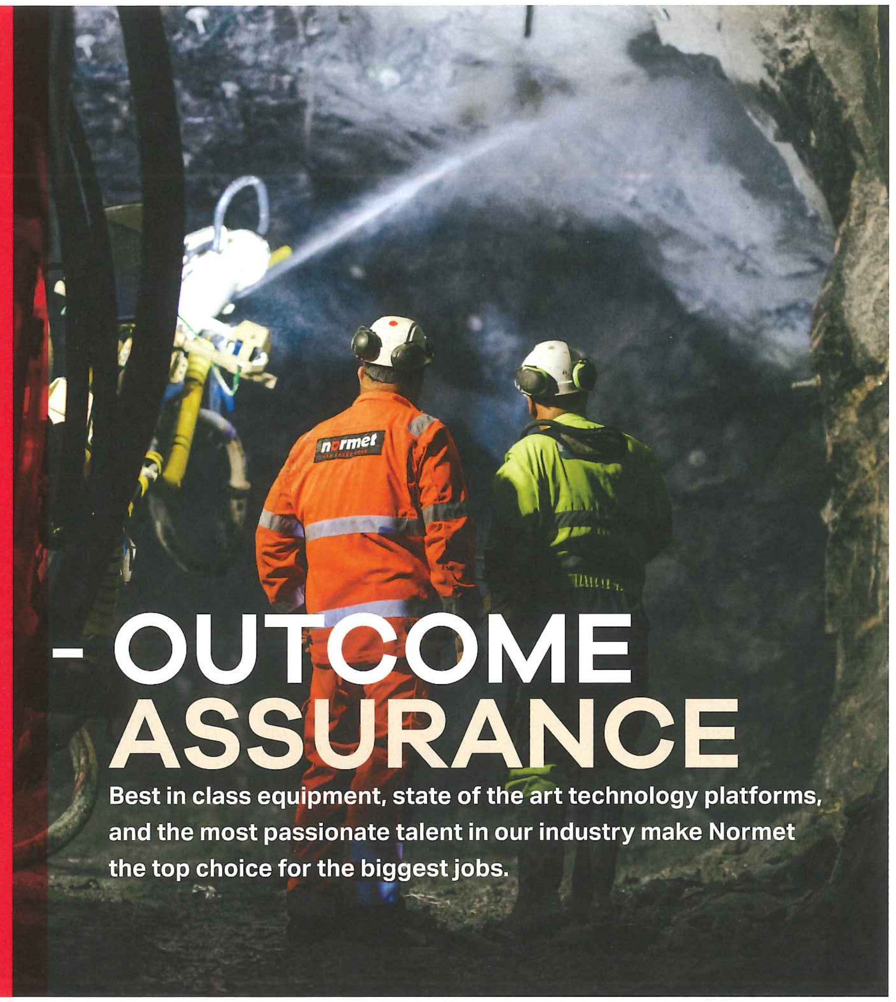
"Like Golder, the Alan Auld Group has built a strong reputation for developing practical solutions to complex challenges," said Hisham Mahmoud, Golder CEO.

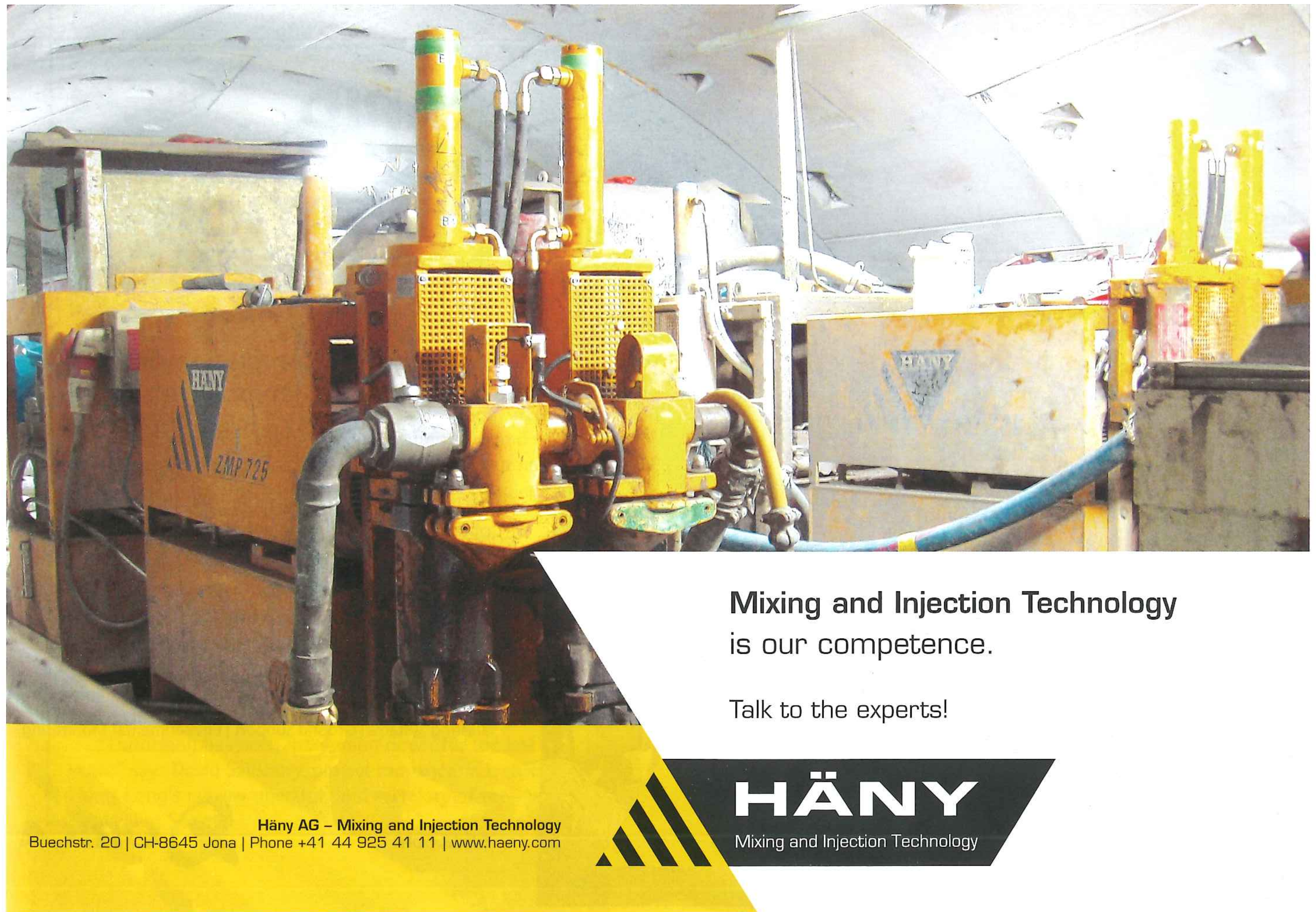
"The Group's skills and resources are highly complementary to ours and will allow us to expand our leadership position and offer greater expertise to our clients globally."

The Alan Auld Group had its beginnings serving the mining sector in the design of mine shafts and has been involved in the design of many of the complex mine shafts sunk around the world in the past 20 years. The group also provides tunnel and shaft design, rehabilitation and project management services for the power, water and transportation markets.

"We at Alan Auld Group are excited to be joining Golder," said John Elliott, managing director for Alan Auld Group. "We see a tremendous opportunity to leverage our expertise and Golder's global footprint and resources to better serve our clients."

The transaction is expected to close by mid-November.





FRAGRANT HARBOUR

Keren Fallwell speaks with expat engineers living in Hong Kong to get a handle on the market

THE MAJORITY OF THE Hong Kong tunnelling market is about to pause as several major projects are completed and others await approval but, despite this, the use of underground space is a big topic in a densely populated area where people, buildings and infrastructure all jostle for space.

The last six years or so have been "seriously busy", says Arup associate director James Rickard, but many of the large tunnelling projects – the MTR West Island Line Extension, South Island Line and Kwun Tong Line extension have been completed. The Express Rail Link high-speed line from West Kowloon to Guangzhou, China, and the first phase of the Sha Tin to Central Link and several major highway tunnel projects – are nearing completion.

"Tunnelling has been quietening down for the last couple of years," says David Salisbury, project manager, SCL civil at MTR, Hong Kong's railway operator, and secretary of the Hong Kong Tunnelling Society.

Keren Fallwell

Keren joined the *Tunnels and Tunnelling* team in 2015 as a contributing editor

Above: ***Shatin to Central Link Contract No. 1103 Hin Keng to Diamond Hill Tunnels Construction, Hong Kong*** © ARUP

Left: ***XRL Contract 820, Mei Lai Road to Hoi Ting Tunnels, Hong Kong***
© ARUP

"MTR has had five major projects on the go but we're now down to the last two, the Express Rail Line [XRL] and the Shatin Central Link [SCL]." XRL and the first phase of SCL are at fit-out stage. The cross harbour second phase of SCL will complete tunnelling works in early 2018.

MTR does have seven other projects in various stages of planning but these are subject to government backing and funding approval which, along with much infrastructure work in Hong Kong, is becoming mixed up in political wrangling between the government executive and legislative branches.

Infrastructure spending has become highly politicised in recent years with some Legislative Council (LegCo) members using their vote to show their dissatisfaction with overall government policy. This was certainly the case during the term of the former chief executive CY Leung, who stood down in June, and it remains to be seen whether attitudes will change under new chief executive, Carrie Lam.

"There's been a lot of filibustering within LegCo and they've been rejecting or not approving funding for a lot of infrastructure projects," says Rickard. "It's hoped that Carrie Lam can get things going again because if she doesn't, work is going to drop off and a lot of people, including local workers, will be laid off."

"Some LegCo members seem to believe that spending on infrastructure is money wasted," says Salisbury. "It's having quite a significant impact on the industry. Several projects are going backwards in terms of funding and start dates."

As the amount of tunnelling work in Hong Kong is decreasing, so too is the number of skilled workers.

"At the moment contractors are starting to shed some of the workforce," says Rickard, adding that the number includes skilled locals who will be lost to other industries, while overseas engineers will be drawn away from Hong Kong to the more buoyant markets elsewhere.

The situation is frustrating when, if it weren't for the political stand-offs, there are a large number of projects that could proceed.

"It's a great shame that we're running down and losing more and more staff towards the end of the year, never mind the workers for all our contractors, and there are projects sitting on the shelf, gathering dust," says Salisbury. "Even when they are brushed off there will be a long lead-in for many of them so I expect there's going to be a lull in the market for the next three to five years.

"We knew this current phase of work was coming to an end but we all hoped there would be more new projects getting moving sooner."

PROJECTS

Among the projects that have faced delays is the Central Kowloon route, a 4.7km-long, dual three-lane road connecting the West Kowloon reclamation and the proposed Kai Tak development on the former airport site. The route includes a 3.9km tunnel and will involve a combination of drill and blast, cut and cover and some TBM work.

An Arup-Mott MacDonald joint venture is carrying out the detailed design. The project is awaiting final approval from the LegCo Finance Committee and construction is scheduled to start early next year and be completed in 2025.

MTR also has plenty of potential work on the drawing board – the North Island line, extensions to the Tseung Kwan O and Tung Chung lines, and a northern extension connecting east and west lines – but progress depends on government support and funding.

MTR is a private company that has traditionally operated a rail/property model to finance the railway construction, although on recent projects other financial models have been used. Although it is not subsidised by the government, the rail/property model is reliant on being granted land rights above and around the stations. As the network expands this method of financing the construction becomes less sustainable and MTR in partnership with government may have to be "more imaginative" in future, says Salisbury.

"It's the law of diminishing returns. When you build something that moves people around more efficiently it doesn't mean you bring more people onto the system; it just means you have more railways to run. There's not a large net increase in revenue to pay for what is often a very expensive piece of infrastructure," he says.

Another project facing possible delays is the relocation of the Sha Tin Sewage Treatment Works to underground caverns. It's in the final design stage and is due to go out to tender by the end of the year.

The plan is to put all the sewage treatment works underground, releasing land for much-needed housing.

"There's such a shortage of land next to major infrastructure this is probably a direction the government will consider," says Rickard.

Salisbury describes Hong Kong's housing demand as "immense" and consequently, prices are eye-wateringly high. "Cheap" housing in a 36-storey block in the New Territories costs around USD 1,987 per square foot; on Hong Kong Island the figure can easily reach USD 5,270 per square foot.

"Houses are getting smaller and prices are extraordinary. It beats London hands down," he says. "There's so much money coming in from mainland China that whenever a new housing development goes up there's a queue of buyers."

Hong Kong's hilly terrain limits the growth of urban areas but the strong granite and volcanic rocks underlying those hills are well-suited to rock caverns. The government has been exploring the possibility of caverns since the 1980s and in 2011 it commissioned Arup to investigate. The study, Enhanced Use of Underground Space in Hong Kong, found that 64 per cent of Hong Kong's land area has high to medium suitability

Geology

Hong Kong's geology is well-documented and it throws up few surprises. There are two main rock types in the urban areas – granite, and the harder, but more fractured and variable volcanic tuff. Both have traditionally been excavated by drill and blast.

"You often pass from one to the other in a fault zone but they're relatively clean passages. There are few real unknowns in the rock formation, certainly in the urban environment," says David Salisbury.

What can be challenging, however, is the completely decomposed granite (CDG) that sits on top of the hard granite. It's one of the causes of landslides in the sub-tropical region and Hong Kong Island is one of the highest risk areas. As a result, soil stabilisation and slope engineering is a big industry.

"CDG is a good material; it tends to be strong but it has a large clay and sand content and can lose its structure very easily in the presence of water and turn to sludge," he says.

There is little that's undocumented, however, as the geology is well charted with a centralised government geological data base that is a great asset when planning future projects.

"Everybody who puts a spade in the ground has to submit what they find so the database logs every borehole, tunnel and excavation," says Salisbury.

Technological advances in TBMs have also made the job easier.

"There is very little ground that can't be excavated with today's closed face tunnelling machinery, whether it's slurry or EPB. The new generation of hybrid and variable density machines offer even more flexibility and greater control," says Salisbury.

In common with many cities around the world, Hong Kong's densely populated urban areas pose another challenge.

"More and more tunnels are being built in urban areas, very close to existing tunnels or buildings, foundations and other utilities," says James Rickard. "It's becoming more challenging, especially if you want to blast or you have low cover with a soft ground TBM tunnel, perhaps going through reclamation or alluvial deposits."

Shatin Central Link (SCL) 1103 contract – Hin Keng to Diamond Hill tunnels – comprised 2.47km of drill and blast tunnel and 1.7km twin tunnels.

"It required some precision blasting works close to an existing water tunnel. There were only 5.5m of rock cover between the unlined water tunnel and the rail tunnel," says Rickard. "The contract required a steel liner to be installed in the water tunnel for protection and then blasted over the top."

The cheek by jowl nature of buildings and infrastructure places constraints on jobsites too.

"Works areas are very small so it makes it difficult for contractors to work in, particularly when launching a TBM or sinking a shaft in the middle of high-rise buildings," says Rickard.

There are also constraints on working hours and noise so some imaginative solutions are needed to operate a site around the clock.

"On the West Island Line Contract 703 the contractor erected a slurry treatment plant that was 3m away from bedroom windows in surrounding tower blocks. It was five storeys high, working 24/7 so the noise containment had to be substantial," says Salisbury.

The densely built-up area has also led to innovations in slurry disposal.

"We can't continue to tanker loads of degraded bentonite to big lagoons; we just don't have the space. Instead we use filter presses to squeeze the water out of the slurry through a membrane, leaving a relatively dry cake. The water is recycled on site so we take very little water from the mains," says Salisbury.

The government Environmental Protection Department, which was established in 1986, and the Civil Engineering Department have recognised the success of these separation plants and filter presses and is considering imposing them as requirements on all government contracts where bentonite slurry disposal is expected.

One spin of off this is that once a consistent byproduct of filter cakes is created, a potential market exists for its industrial use.

Attitudes to health and safety can be another struggle in Hong Kong as some workers consider that fate, rather than their own actions, is responsible for incidents.

"Legislation is in place and on a par with the UK but the frontline supervision and cultural difference within the workforce means that attitudes to safety on many sites is still a couple of decades behind the UK," says Salisbury.

Having said that, Hong Kong has probably the best safety record in Asia – although not as good as some European countries – and attitudes are changing.

MTR is at the forefront of improving safety but there is also a need for an improvement in grass roots awareness towards personal safety that can only come through government and education, says Salisbury.

"It has to start in the classroom because it's the mentality of valuing your life and those around you that's often where the challenge is," he says.

While plenty of legislation does exist, some of it is a knee-jerk reaction to an incident and, as a result, can often be poorly drafted. Salisbury believes this can be mitigated by referring to ITA guidance and European legislation as a benchmark for tunnelling works.

There can also be issues with feng shui and graves, says Rickard, so careful consideration is often required for positioning of tunnels and portals.

"For road or rail transport, the cheaper solution may be to construct a flyover or elevated road but local residents are often very vocal in their opposition to such schemes. They will say it's cutting through the life of the village," says Rickard.

"Underground solutions usually cost far more but they can produce a far more environmentally sustainable solution. Elevated structures often require extensive noise barriers to mitigate the sound impact. In a typhoon-prone place like Hong Kong these can be massive structures in themselves, increasing the main structure, column and foundations size. When these costs are added in, tunnel solutions start to make economic sense even in the less dense new town areas," Salisbury added.

Below: ***Shatin to Central Link Contract No. 1103 Hin Keng to Diamond Hill Tunnels Construction, Hong Kong*** © ARUP

for large-scale cavern development. Facilities located close to these areas and in the urban fringe are particularly suited for relocation to rock caverns.

The study also identified five strategic cavern areas that could accommodate multiple government facilities, with good accessibility and sufficient area to allow integrated strategic cavern development.

"A square foot of real estate in Hong Kong is about as valuable a piece of land there is on the plant so the finances of underground caverns works; the challenge is getting people to buy into it," says Salisbury.

The concept is not new. The University of Hong Kong relocated two reservoirs underground and there are other small capacity sewage treatment and waste transfer facilities, but the Sha Tin project would be the first on a large scale.

Caverns could also be used to accommodate columbarium, which at present are often on prime real estate. One existing disused underground explosives magazine is being developed for such use.

"It's considered lucky to have your relative's ashes on a hillside with mountains behind and sea in front. There are cemeteries sitting on some nice promontories which could be considered high-value real estate," says Salisbury.

"Underground columbariums hark back to Roman times so there's nothing new about the concept, it's just reinventing it."

One transport project that is under way, and has been making headlines, is the Tuen Mun-Chep Lap Kok link for which contractor Dragages has used the world's largest diameter TBM – a 17.6m diameter machine – as well as two mix-shield TBMs of 14m diameter. The project involves construction of a 9km dual two-lane carriageway between Tuen Mun South and North Lantau and includes Hong Kong's deepest, largest and, at 5km, longest sub-sea road tunnel between Tuen Mun Area 40 and the Hong Kong-Zhuhai-Macao Bridge Hong Kong Boundary Crossing Facilities. At Tuen Mun Area 40 around 16.5km of land has been reclaimed to provide the northern landfall for the tunnel.

It has also required 42 cross-passages which have mostly been driven with two mini TBMs.

"They've been driving short 10-12m headings between the two very large diameter tunnels using a TBM with a six-week cycle time so every three weeks they're producing another cross-passage. It's a fascinating and very impressive project," says Salisbury. Added to this, the work is being carried out at up to 6 bar hydrostatic pressure so Dragages is using saturation diving techniques to undertake maintenance on the TBM cutterheads The machines are equipped with a number of Bouygues' patented technologies which enable real-time mapping of rock faces and robotic detection of damage on the cutterhead, reducing the need for manual inspections under hyperbaric conditions.

Real-time face mapping using instrumented disc cutters has been used by Dragages HK (a subsidiary of Bouygues) on several of the MTR projects for the past eight years or so. Salisbury was initially sceptical about its efficiency but is now a convert.

"It puts money into the cost of the machine but it's proved itself very reliable. As well as giving a good indication of the hard spots and the general wear on the cutters, especially when you're in mixed ground, if you hit anything square or vertical you know you've hit something manmade," he says.

An unexpected benefit of the technology is the positive PR it can provide. It can reassure stakeholders that everything is going to plan and show site visitors a real-time comparison between the actual and expected geology at the excavation face, says Salisbury. On SCL, a 17km stretch linking existing lines on MTR's rail network, a variable density TBM was used for the first time in Hong Kong.

Dragages HK and Bouygues Travaux Publics used the machine to excavate one 540m-long tunnel.

"The drive was very shallow (only one diameter of cover along much of its alignment) in very challenging ground, with undocumented fill material in the crown. It's been very successful," says Salisbury.

After delays in funding approval work is now under way on the Tseung Kwan O – Lam Tin tunnel. The 4.2km-long dual two-lane highway, which includes a 2.6km tunnel, is designed to accommodate the anticipated increase in traffic resulting from housing developments in Tseung Kwan O District. The tunnel passes under Cha Kwo Ling village and will be excavated by drill and blast. The USD 1.1bn construction contract was awarded to Leighton Contractors (Asia) Ltd in joint venture with China State Construction Engineering (Hong Kong) in July last year.

Below: ***XRL Contract 820, Mei Lai Road to Hoi Ting Tunnels, Hong Kong*** ***© Arup***

TBM FACE SUPPORT CALCULATIONS

Zdenek Zizka and **Markus Thewes** of Ruhr Univeristy Bochum explain the new recommendations for face support calculations published by the German Tunnelling Committee (DAUB)

Above: ***Photo of the Piraeus extension TBM (illustrative)***

Acknowledgement

The recommendations, which are going to be introduced in this report, were published by DAUB (German Tunnelling Committee) in December 2016.

VARIOUS EXISTING OPINIONS FOR evaluating the tunnel face stability in soft soil in the tunnelling industry were the inspiration for publication of this document. The recommendations aim to offer a guide to the available methods for tunnel face stability assessment in mechanised tunnelling and to provide a best practice guideline for face support pressure calculations. Furthermore, the recommendations intend to help with the choice between available calculations methods depending on the expected ground conditions. In the recommendations, it is also specified the difference between two tasks, which are sometimes mixed. These tasks are:

- Face stability calculation
- Analysis of machine ground interaction to evaluate surface settlements

The recommendations consist of seven chapters (excluding the introduction and reference chapters). The second chapter introduces the general aim of a tunnel face stability assessment and briefly describes soft ground mechanised tunnelling technology, with a focus on tunnel face stability. The German safety concept regarding the face stability assessment is outlined in the third chapter. Following this, the most important scientific approaches dealing with face stability calculations are discussed in chapter four focusing on support pressure due to earth pressure at the tunnel face and in chapter 5 summarising support pressure due to groundwater pressure. The most relevant calculation methods for shield tunnelling practice are presented in detail in chapter 6. Additional aspects regarding face stability are discussed in chapter 7. Two examples of face support pressure calculations are provided at the end of this document in chapter 8.

The recommendations can be downloaded in English through the following link:
http://www.daub-ita.de/fileadmin/documents/daub/gtcrec1/gtcrec10.pdf

Following abstracts are providing a short overview about the content of the published recommendations.

VIEWPOINTS ON FACE STABILITY CALCULATIONS

The aim of a tunnel face stability assessment is to investigate groundwater pressure and earth pressure acting at the tunnel face, and to analyse the bearing capacity of the tunnel face. If the self-bearing capacity of the tunnel face is insufficient, tunnel face support has to be provided. For this, the support medium must counter the earth and groundwater pressures to stabilise the tunnel face.

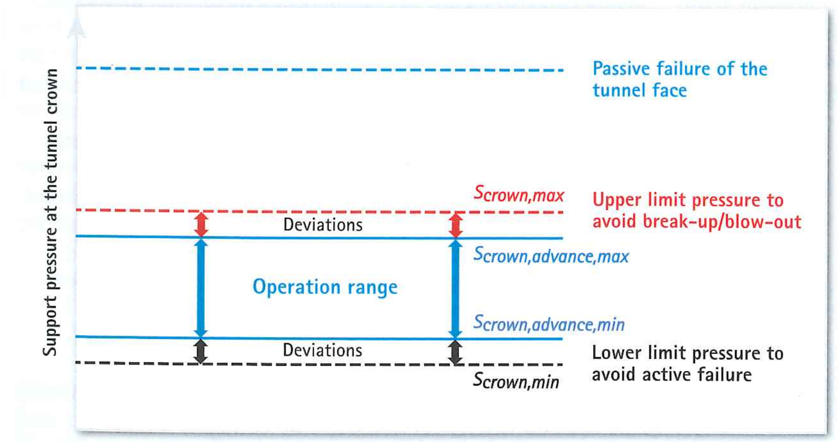
Two fundamental points of view are called on for tunnel face support design. With the first viewpoint, the tunnel face pressure calculations deal solely with tunnel face stability. These types of calculations are the midpoint of the document. The calculations do not consider the development of ground deformations as a relevant criterion when calculated support pressure is applied to the tunnel face. This approach is called the "Ultimate Limit State Approach" since only a minimal required face support pressure is determined to avoid a tunnel face collapse.

The second point of view focuses on keeping the ground deformation below a pre-determined limit. Thus, this defines the support pressure (and consequently the tail void grouting pressure) based on the required ground deformation limit. This approach may be termed the "Serviceability Limit State Approach" since it considers ground deformation during excavation to be the main design criterion.

GERMAN SAFETY CONCEPT IN FACE STABILITY CALCULATION

Two operational limits for the support pressure are defined in the German regulation ZTV-ING (2012): the lower and the upper limit. It is to note that RiL 853 (2013) references ZTV-ING regarding support pressure calculations. The lower support pressure limit (Fig. 1) has to ensure a minimal support force (S_{ci}), which consists of two components and their respective safety coefficients (Eq. 1). The first component of the support force ($E_{max,ci}$) has to balance the earth pressure, and is calculated here based on active kinematical failure mechanism of the tunnel face. The second component of the support force (W_{ci}) has to balance the groundwater pressure and is determined based on the elevation of groundwater level above the tunnel crown.

Below: ***Figure 1, Allowable operational pressures at the tunnel crown of a shield machine***



1) $$S_{ci} = \eta_E \cdot E_{max,ci} + \eta_W \cdot W_{ci}$$

with

η_E	Safety factor for earth pressure force (= 1.5) [-]
η_W	Safety factor for water pressure force (= 1.05) [-]
S_{ci}	Required support force (circular tunnel face) [kN]
$E_{max,ci}$	Support force due to earth pressure (circular tunnel face) [kN]
W_{ci}	Support force due to groundwater pressure (circular tunnel face) [kN]

The upper support pressure limit ($s_{crown,max}$) is defined as a limiting pressure to avoid a break-up of the overburden or blow-out of the support medium (Eq. 2). Therefore, the maximal support pressure has to be smaller than 90 per cent of the total vertical stress at the tunnel crown ($\sigma_{v,crown,min}$). It is necessary to point out, passive failure of the tunnel face due to high support pressure is unlikely to happen. Before reaching this limit, support medium will blow-out from the excavation chamber.

Break-up/blow out safety:

2) $$1 \le \frac{0.9 \cdot \sigma_{v,crown,min}}{s_{crown,max}}$$

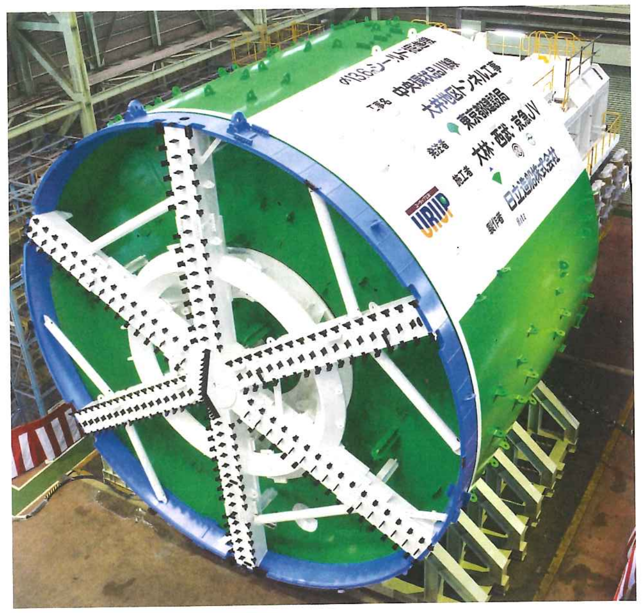
with

$\sigma_{v,crown,min}$	Total vertical stress in the tunnel crown considering minimal unit weight of soil [kN/m²]
$s_{crown,max}$	Maximal allowable pressure in the tunnel crown due to break up safety/blow-out safety [kN/m²]

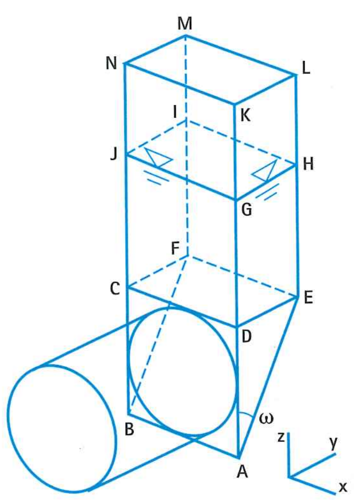
OVERVIEW OF CALCULATION METHODS

Various methods to determine the required support pressure due to the acting earth pressure can be found in the literature and are presented in the recommendations. All available approaches calculation approaches can be divided into four fundamental groups:

- Analytical methods
- Empirical methods
- Experimental methods
- Numerical methods



***Both:** Illustrative photos of EPBMs manufactured by Hitachi Zosen (above) and Herrenknecht*



***Left:** Figure 2, Sliding mechanism after Horn (Anagnostou & Kovari, 1994)*

In this short overview, however, the focus will be given only to analytical and experimentally/empirical methods. The group of analytical methods includes limit equilibrium and limit state methods. These methods assume a possible failure mechanism of the tunnel face or a stress distribution in the ground respectively and from that determine a support pressure at collapse. Common features of most of the analytical methods are based on the adoption of two widely used laws of failure in soil mechanics. On one hand, the Mohr-Coulomb law of failure is broadly adopted for frictional or frictional–cohesive materials where the associated flow rule is dominating among the formulations. On the other hand, Tresca law of failure (associated) is mostly applied for purely cohesive materials.

The limit equilibrium methods can be characterised by the required assumption of a kinematical failure mechanism of the tunnel face. The first limit equilibrium failure mechanism was suggested by Horn (1961) and assumes a sliding wedge in front of the tunnel face that is loaded by a rectangular prism stretching up to the terrain surface level (Figure 1). This sliding wedge mechanism for investigation of tunnel face stability was introduced to mechanised tunnelling by Anagnostou & Kovari (1994) and Jancsecz & Steiner (1994). Additional improvements of this method have been conducted by Anagnostou (2012) or Hu et al. (2012). On the sliding mechanism, the equilibrium condition for acting forces is formulated and required support force is determined.

Other solutions for the tunnel face stability have been formulated based on bound theorems within the plasticity theory. This group of approaches are often known as "limit state methods". The solution for the tunnel face stability can be obtained by adopting the upper or the lower bound of the plasticity theory. The bound theorems were employed in methods suggested by Davis et al. (1980), Leca & Dormieux (1990) or Mollon et al. (2010).

The stability ratio method by Broms & Bennermark (1967) represents the most important calculation approach from experimentally/empirical methods. Broms & Bennermark (1967) conducted laboratory experiments that investigated the extrusion stability of a clayey soil through a vertical circular opening in a sheet pile wall. The stability ratio depends on the subtraction of the pressure supporting the opening from the vertical stress at the opening axis then divided by the undrained shear strength (cu) of the soil. Consequently, they suggested to apply the developed method for investigation of tunnel heading stability.

Depending on the soil type, the soil can show drained or undrained behaviour during excavation, stoppage or standstill. Therefore, particular calculation methods are fitted to certain ground conditions. The theoretically calculated pressures at tunnel face collapse were mostly not validated in practice with real scale experiments. Only laboratory experiments were used to validate the particular calculation methods. For drained conditions, the best fit between theoretical calculations and experiments was found for limit equilibrium methods formulated by Anagnostou & Kovari (1994) or Jancsecz & Steiner (1994) and the limit state upper bound solution by Leca & Dormieux (1990). However, the upper bound calculations become complicated when the failure mechanism is close to the reality. Thus, various formulations of limit equilibrium on the sliding wedge are commonly used in practice. Note that for drained conditions, the output of models represents only the required support force due to earth pressure (Eq. 1).

For undrained behaving soils, the lower bound limit state method assuming a cylindrical tunnel model was the best predictor of the support pressures at collapse (Davis et al., 1980). The authors determined required support pressures by using the stability ratio approach (Broms & Bennermark, 1967). This calculation method is very straightforward, and its concepts have become a standard for excavations in purely cohesive soils with undrained behaviour.

THE MOST IMPORTANT RECOMMENDATIONS FOR CALCULATION PRACTICE

Beside non-cohesive soils, the limit equilibrium method is employed in practice also typically when cohesive and non-cohesive soil layers are alternating at the tunnel face. The effective (drained) shear parameters of a soil are assumed in this case. It is generally not recommended to use the limit equilibrium approach for calculations with undrained shear soil parameters. Further, it is necessary to note that limit equilibrium approach delivers a minimum support pressure at which the ground theoretically becomes unstable. It is achieved only due to the application of safety factors that ground deformations are relatively acceptable when obtained support pressure is applied. Since the adopted safety factors are generalized for every soil, the amount of obtained displacement is varying based on the actual stiffness of ground.

The minimal calculated support pressures exhibit relatively wide scattering in non-cohesive soils depending on the adopted formulation of the limit equilibrium approach. The scattering was highlighted by Vu et al. (2015) or Kirsch (2009). In cohesive-frictional soils, the size of calculation scattering will decrease. It is recommended to ensure that any assumptions used to calculate variables in limit equilibrium methods are consistent with regard to the adopted mobilisation of soil's shear resistance.

For face stability calculations in undrained conditions using stability ratio method, the assumptions for critical stability ratio and amount of undrained soil cohesion are key factors that determine the results. The critical stability ratio should be adopted based on a case by case basis and local experience. Furthermore, the amount of undrained cohesion should be conservatively assessed. Nevertheless, the critical stability ratio method often shows the acting groundwater pressure as the decisive factor for support pressure calculations.

When designing the support pressure for excavation in the particular ground conditions, it is necessary to consider also the extent of possible consequences such as failures or settlements, due to an inappropriate design. The extent of the worst case scenario determines how conservative the calculation approach should be. A general rule of thumb is that inappropriate support pressure may lead to immediate failure up to the surface for a combination of slurry shields and non-cohesive ground. With a combination of EPB shields and cohesive soil, it may lead "only" to extensive surface deformations without failure up to the surface. The height of the overburden plays a significant role for the extent of consequences. Thus, it is recommended for excavations in difficult ground conditions, e.g., in complicated weak ground or under surface constructions, that the analytical calculation of the support pressure should always be supplemented by the numerical analysis of machine – ground interaction.

Final important aspect of the calculation is the adopted support pressure deviations during excavation. Support pressure deviations must be considered in calculations, which are performed according to ZTV- ING (2012):

+/- 10 kN/m² for slurry shield and for compressed-air support mode of both shield types
+/- 30 kN/m² for EPB shield

For the EPB shield, the range of deviation was defined to be larger because of a higher degree of uncertainty for the support pressure regulation. The deviations are added to the lower support pressure limit and subtracted from the upper pressure limit (compare Figure 1). However, the large range of deviations for an EPB shield may in some cases lead to a limited feasibility of EPB shield drives. Thus, EPB shield deviations may be reduced for special cases upon proper justification. Reduction of the deviations range should focus especially on the deviations at the upper pressure limit, since the risk of overburden break-up or support medium blow-out in the case of EPB is comparably lower. A good shield operation, process controlling and good design of excavation process (e.g., soil conditioning) are fundamentally required for such a reduction.

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CAMBRIDGE SERVICE TUNNEL

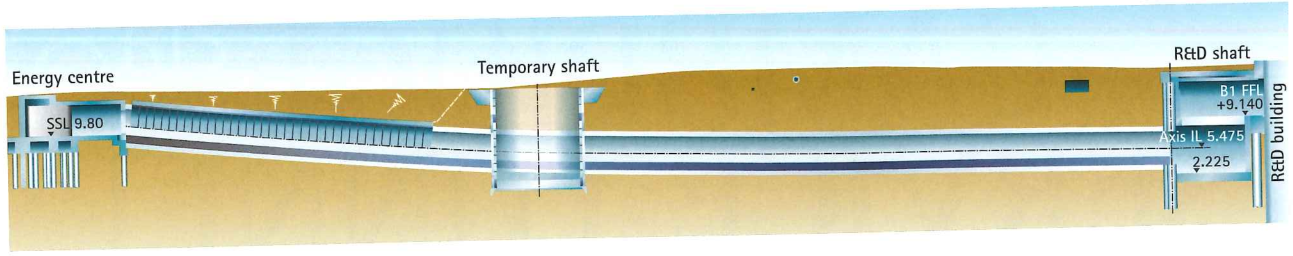
AstraZeneca's global R&D headquarters in Cambridge calls for a new tunnel. This report from a BTSYM presentation by **Lloyd Rew** of Skanska was written by **Cameron Blackwell** from Mott MacDonald

***Above:** Artist's concept of the completed centre*

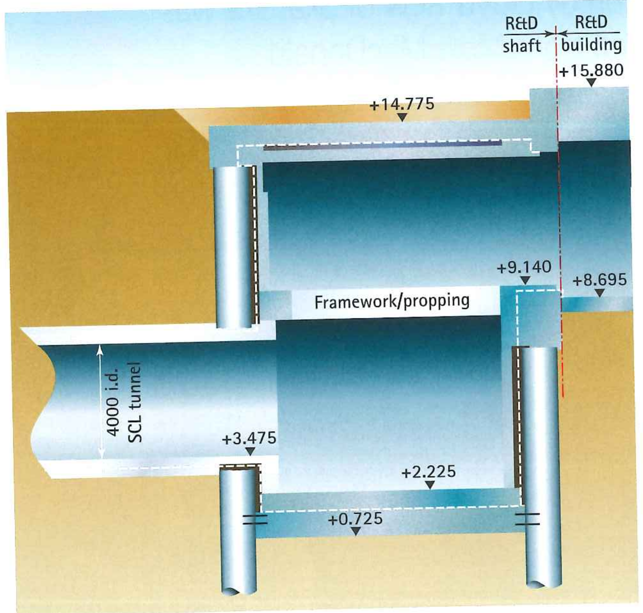
Lloyd Rew
Lloyd is Skanska's senior construction manager at AztraZeneca's Global R&D Headquarters project in Cambridge

ASTRAZENECA'S R&D CENTRE, being constructed in Cambridge, is an impressive new building. Transparent and clear, it's vision is to be open to collaboration and open to the public. Underground it is striking too; the basement excavation is larger than the building in footprint, supported by 7.2m high cantilever walls with no propping, it required the removal of 120,000m³ of clay. The multi-level basement will house loading areas and many of the centres laboratories, some of which will be capable of operating without any direct supervision. Architectural input has provided some key challenges for the construction team including very large roof spans, and very tight specifications for architectural concrete features, which required an on-site batching plant for quality control.

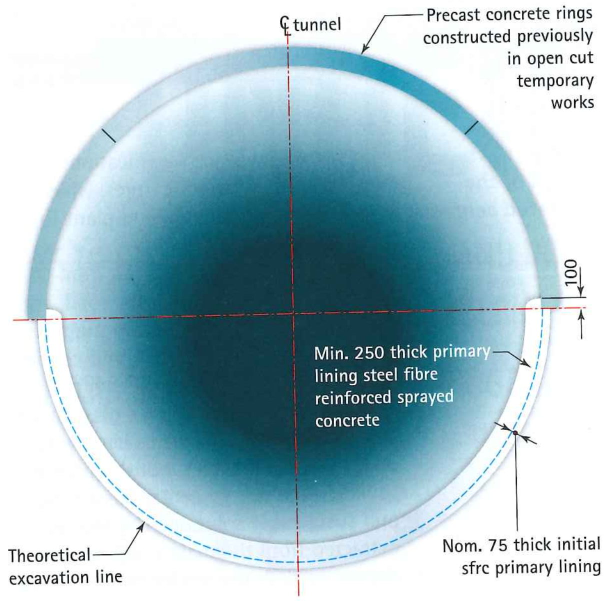
The service tunnel will run from the new R&D building, under the road, and to the energy centre; its main purpose will be to providing heating and cooling alongside all other ancillary energy services. The R&D building's glass façade means the structure creates large volumes of heat in the summer months, a problem to which the energy centre has a novel and sustainable solution. The heat is extracted from the main building and drawn through the service tunnel with a cooling system to the energy centre where, through a dense water hydrothermal ground source heat pump system, the heat is transferred to the ground via 140, 250m deep boreholes. The system allows storage of heat in the



Above: ***Longitudinal profile of all underground structures***



Above: ***The research and development shaft and tunnel connection***



Above: ***Cross section of the tunnel, showing sprayed and precast concrete lining against theoretical excavation line***

summer, offering cooling, and extraction in the winter for heating, which makes for a very efficient system. The system is in fact so efficient that some of the R&Ds heat output has to be dumped to the environment via heat exchangers in the roof.

The service tunnel itself is 128.6m in length, 4m internal diameter, with a total lining thickness of 550mm. The lining comprises of an SCL primary lining, with a membrane providing class II waterproofing specification, and a cast in-situ secondary lining. Tunnelling took place from a 10.5m diameter caision shaft at the energy centre side, mining downhill to maximum invert level below ground level was 12.4m at the R&D piled shaft. The tunnel will contain hot and cold-water pipes for the building, as well as for heat exchange. It will also carry fire suppression systems, gas mains, and power cables from generators, and the tunnel will contains a walkway, but this is for maintenance rather than a means of access between the buildings.

A number of construction methods were considered but discounted for site and client specific constraints. Methods considered included cut and cover, pipe jack, or a service bridge. Cut and cover might have been the simplest solution, however, the tunnel passes underneath Francis Cric Avenue, an important link into Cambridge and vital for access to Addenbrooke Hospital; closure of the road was therefore not an option. Pipe jacking was not considered feasible considering the gradient required to get underneath the road; and the option of a service bridge, discounting a tunnel entirely, was deemed to be too at risk of malicious interference. The chosen construction method was therefore an SCL/cut and cover hybrid; cut and cover between the energy centre and the caisson shaft, and SCL to the R&D centre. This allowed construction of the energy centre to continue whilst the rest of the tunnelling took place.

STRUCTURAL COMPONENTS AND CONSTRUCTION METHODS

Precast section

Construction of the cut and cover section took place before the erection of the frame for the energy centre. It consisted of 36 precast half rings, 5m in diameter, setting out the crown of the tunnel. Rings were set on a layer of blinding in the trench, concrete poured to shoulder level, and reinforced set on top. The reinforced slab was poured in one go, before the trench was back-filled. This allowed the team to excavate and spray the invert at a later date without impacting the construction programme at surface. During excavation of the trench groundwater was encountered at 3.5m BGL, much earlier than expected, and indicative of the problems the project was to face in its main excavation.

Caisson shaft

From the caisson shaft the majority of the tunnelling work was completed. The tunnel was offset from the centreline as this allowed more workable space within the shaft. Four pressure relief wells were bored to eliminate ground heave if any pressure pockets in the ground were come across. Alongside the precast concrete sections an FRC jacket was also cast behind segments

and forced down as the shaft was sunk. Once the FRC had achieved strength the segments were taken away at the base of the shaft to allow soft eyes to be formed; the presence of the FRC removed the need for a steel frame to reinforce lintels and jambs. A bar reinforcement cage was bolted into the FRC jacket to form the portals, and sprayed ahead of tunnel commencing.

R&D shaft

The shaft at the R&D building, receiving the tunnel, was built using top down construction with secant pile walls. Piles were connected with a capping beam cast of waterproof concrete, over the areas of breakout in the shaft the piles were suspended from the capping beam. In order to maintain site access above ground for the construction of the R&D centre the shaft was not left open for the duration of the works. This meant construction of temporary works and the delivery of reinforcement and other materials had to be done in small packages and largely by hand.

SCL lining

As described previously, on the energy centre side of the caisson shaft it was only the invert that needed spraying because of the precast crown. The support already being in place meant that advances of up to 8m were achieved and this section of the tunnel was completed in just over a week. On breakout into the crown cavity there was a visible high-water mark where the void had filled with water and drained again between back filling of the cut and cover section and excavation from the caisson shaft.

The remainder of the tunnel was excavated in three steps; top, top, invert. Crown excavation advances were one meter, invert advances two meters. Spiling was attempted in the excavation of the tunnel but was found not to offer a significant benefit. The run to the R&D shaft was downhill, meaning the water collected at the face and had to be pumped out.

Waterproof membrane

The waterproofing system was a welded membrane, consisting of a geomembrane with a nailed waterproof membrane connected to the concrete, sealed with additional patches and waterbars between secondary lining pours. Welded sections of membrane were pressure tested for quality control. A key challenge was linking the tunnel waterproofing to the R&D shaft waterproofing, where the cylinder had to be connected to the square opening, which required intricate details. Between waterbars the waterproofing system also included resin injection hoses to isolate leaks, and also inject behind the lining to seal them. In addition to measures to combat future water ingress, there was also active management of external groundwater pressure through perforated ducts which were cast into the primary lining invert. These were tied into the waterproofing membrane to isolate the groundwater and enable pump out, until it was cast in and grouted up.

Secondary lining

The secondary lining was cast in-situ onto the waterproof membrane. The shutter consisted of 196 pans bolted together by hand, and through the teams' hard work they were able to achieve an average of one pour per week. The lining was set out to achieve a circular shape inside the less-than perfect primary lining by use of spud bars. These were threaded to enable fine tuning of the placing of the shutter. The point loads that they exerted on the lining however, did potentially contribute to some problems with the integrity of the waterproofing. The perfect circular shape of the finished interior of the lining was required for the modular pipe fixings which were to be installed on completion. When the secondary lining approached the R&D shaft the entire shutter was extended into the opening, and the lining wall and tunnel lining were cast at the same time. This required a significant piece of temporary works, but achieved an impressive result.

Top: ***The caisson shaft, from which the majority of tunnelling work was executed***

Above: ***Applying the welded waterproofing membrane***

GEOLOGY AND GROUNDWATER

Geology

The area around Cambridge in which the project was situated is predominantly underlain by a crumbly white chalky clay called West Melbury Marley Chalk which doesn't behave well in water, turning into a very gloopy slurry. The tunnel dipped through the Cambridge Green Sands and at the R&D shaft entered the Gault Clay which is a very good blue shiny clay. Towards the end of the excavation the team encountered pockets of heavily saturated sand. Water was encountered much earlier than expected, and water pressures in the excavation exceeded what was anticipated. At several points, where there were leaks in the primary lining, significant water ingress was observed. Water flow at the face of the excavation was also prevalent; borehole data had suggested 0.4 l/s, however at times the team was pumping 4-8 l/s from the tunnel.

Water ingress - leaks and repairs

There were areas where the waterproofing system had been compromised. The image on page 26 shows a leak through the secondary lining via a spud bar hole which has been plugged with grout. It

Questions and answers

Cameron Blackwell – Mott MacDonald: What was the reason for only constructing the crown of the pre-cast rings, instead doing a full cut and cover to bury whole circular or box sections?

Answer: It's a good questions. Part of the problem was the requirement for a circular tunnel; forming a curved invert would have been challenging and time consuming. It was all to do with programme. By not having to excavate the full depth of the trench we were able to progress faster and hold up construction of the energy centre for less time. Also, the excavation and primary lining construction under the cut and cover section only took a week, so I don't think there would have been much saving in time using full rings.

Benoit Jones – Inbye Engineering: What were your lesson learnt from the project? If you had to build another tunnel next to it, what would you do differently?

Answer: If money was no issue there would be two main options, use a shield, or go deeper and tunnel in the Gaulk Clay. Cheaper options would be to do more in depth analysis on the water levels before hand, and to push for a programme that allowed us to tunnel uphill to avoid the issues of water collecting at the face.

Andy Crawford – J.Murphy & Sons: With you driving downhill into the Gaulk Clay were you expecting to encounter more water in the invert?

Answer: There would have been some perched water on top of it, but when we excavated the R&D shaft, which was deeper than the tunnel, it was it was the sort of ground we would have liked to have excavated the tunnel in, but yes, the interface between the clay and the sands was very wet.

Rapporteur: Cameron Blackwell

was not possible to tell by observation whether this leak was as a result of the spud bar puncturing the membrane, or if a fault had occurred elsewhere and the water had travelled behind the lining to the grout plug, however drilling into it released a large amount of water. The solution was to inject a europhane based acrylic, which expands to somewhere in the order of 30 times its volume, into the hole to plug the leak.

Separately, the piled construction of the R&D shaft was also leaking as the waterproof membrane was being installed. Initially this didn't present any problems, but as the tunnel drainage (perforated pipes and manholes as described previously) was back grouted the water table rose and leaks could be seen to 'climb' the walls over a 24 hour period, up to a cold joint between the secondary lining and the waling beam. The resolution was the same as with the shaft lining – injecting sealant into the leaks to plug them. At the top of the shaft the interface with the main frame contractor building the southern superstructure meant two different waterproofing systems needed connecting. The answer was to come up short with the shaft concrete, put in couplers, and to leave the waterproofing membrane exposed. This would allow the other waterproofing membrane to be welded on before being cast in. However, the action of resin injecting the leaks in the shaft meant that the water table continued to rise to the level of the exposed waterproofing, and started to 'inflate' it. The pressure on the underside of the membrane risked it failing catastrophically, so the decision was taken to cut a series of holes in the membrane to release the pressure. Over the run of the strip there was approximately 2 l/s coming out of the holes and, understandably, the contractor responsible for pouring concrete on top of it was not willing to do so.

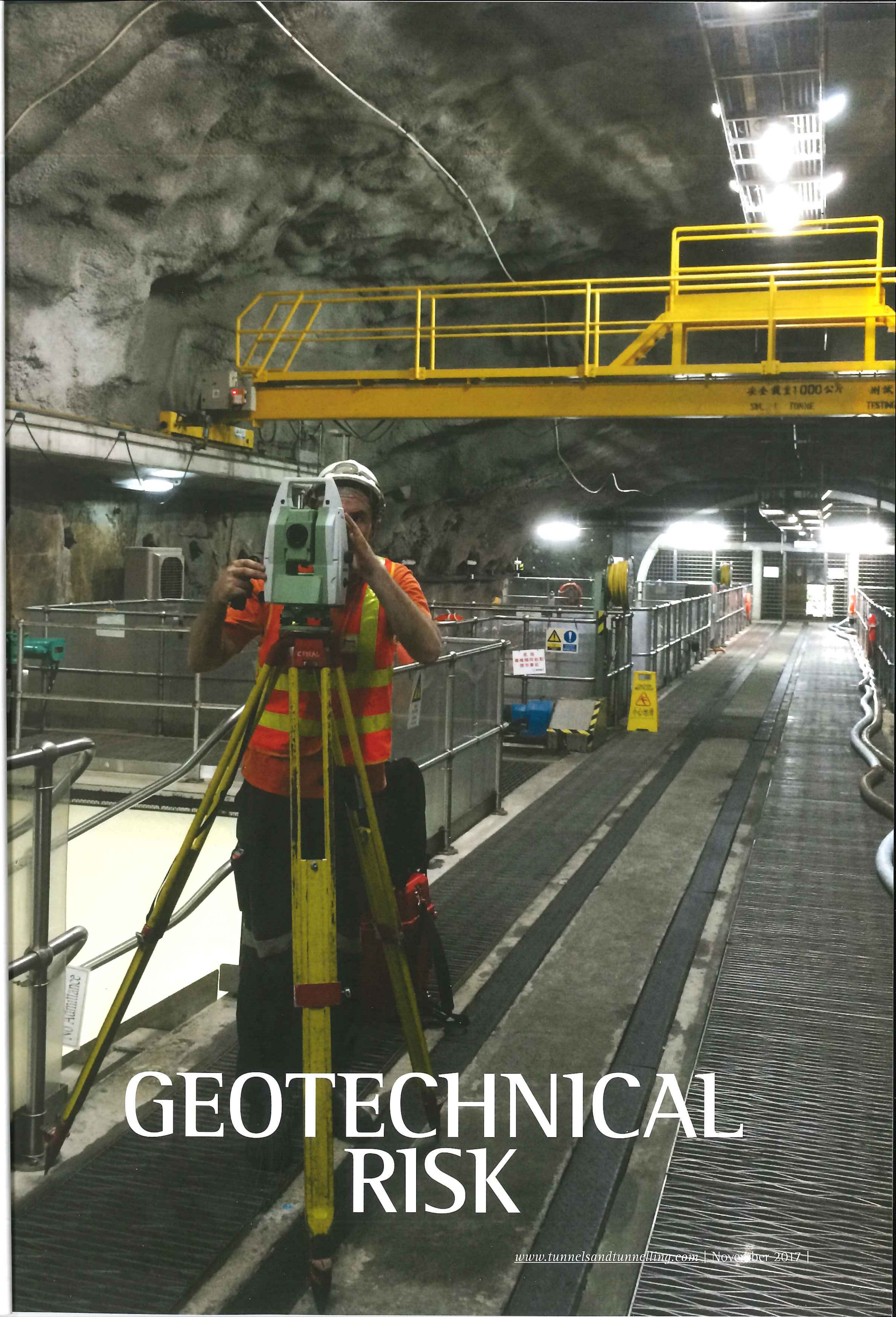
Their suggestion was to drill a hole in the shaft wall to drain the water, and plug it after the concrete had been poured, but it was decided this was not an optimum solution given the shaft had only recently been repaired. Instead a series of trumpet flanges were welded onto the membrane to drain pocket and relieve the pressure. Once this was done the other contractor was prepared to install and bond their waterproofing membrane and concrete was poured. Water continued to be drained until the concrete was set, at which time the hoses were resin injected, cut back flush, and grouted up.

Settlement - data and analysis

The focus of the settlement analysis was for the protection of the road and services within it. The analysis initially used a Gaussian Distribution Curve method and then progressed to an Oasis FEM system to determine settlement profile and trough of the alignment, and set trigger levels. Designers specified the monitoring arrays to be used as the tunnelling progressed underneath the road. Taking one of the arrays as an example it is possible to illustrate the relation of the theoretical values to real world values. Plotting the initial inputs, assuming 1.5 per cent volume loss and a k value of 0.4 creates the blue line on the curve, almost equivalent to the yellow trigger level. As the tunnel progressed the actual ground level can be seen. The first thing to note is the slight drawdown, which is attributed to the amount of water being removed from the ground. As the tunnel passes under the array the ground level drops over the tunnel, a little more off-set than predicted by the excel model but the profile is similar to what is expected, with a significant amount of draw down. Total actual volume loss was 3.7 per cent and a measured maximum settlement of 39mm. The numbers are slightly misleading because of the amount of drawdown, the convergence monitoring was confirming that the movement in the tunnel wasn't as significant. As the settlement prediction calculation is only designed to take inputs 2.5 times the diameter from the point of inflection, the data could be clipped and the effects of the drawdown removed.

The result of this data analysis gave values, and a plot, much more akin to the prediction. Volume loss was now 1.5 per cent, maximum settlement reduced to 28.5mm, understandable, given that the original calculations didn't take account of the effects of the groundwater.

Right: A leak through the secondary lining via a spud bar hole which has been plugged with grout



GEOTECHNICAL RISK

GROUNDED THINKING

Alex Conacher speaks to **Rod Eddies** and **Simon Brightwell** of *Fugro*, a geotechnical services provider, to get a handle on the latest thinking around the ground model approach

THE GROUND MODEL APPROACH does two things. It improves the technical deliverable by reducing uncertainty in the ground conditions enabling risks to be managed (and creating opportunities for good decisions to be made), but also optimises investigation work to avoid wasted cost.

"Let's take an example," says Rod Eddies, geophysics expert for Fugro, a leading geotechnical and survey services company, "let's take a very simple example of a brownfield site, somewhere remote and a couple of hectares in size where the client wants to locate and investigate old mine shafts.

"You could start drilling on a grid to locate the shafts, or you could actually do an investigation that locates them beforehand by remote means or by a desk study using legacy data.

"That clearly has a technical and commercial outcome; reduced effort and optimised investigation in terms of cost and time."

He adds: "This approach isn't restricted to mine shafts of course, but to a spectrum of situations where potentially unforeseen ground conditions could present risk."

Alex Conacher
The *Tunnels and Tunnelling* editor has been with the magazine since 2010

Above: ***Ground investigations ahead of the Thames Tideway tunnel construction utilised jack-up platforms to undertake geotechnical drilling and in situ testing.***

Above: **Preparations for the Sirius Minerals MTS tunnel design (Yorkshire) included a programme of geotechnical drilling, in situ testing and seismic reflection surveys to characterise the geology to a depth exceeding 400 m**

Early investigations can be as simple as legacy data or desk studies, then fatal flaw analysis to see if a site should be left alone – possibly due to faulting, instability.

Moving on from this, engineers might obtain data from the site itself to find out about the layering, the stratigraphy, what the structural discontinuities are and so on. This allows for the creation of domains in the site, each being of a particular character. A borehole programme can then be set up to better sample these domains. Then as boreholes go down, the data is fed into the model, refining it, and eventually the engineers have sufficient detail to produce an informed design.

"So for me the ground model is not a single concept, it describes an iterative process where its evolution depends on the ability of the client to budget and pay for further investigation, dependent on the changing needs of the project. It is something that evolves through the lifecycle of preconstruction, and even beyond," says Eddies.

CONVINCING CLIENTS

A live topic at the company is persuading clients to adopt model-based investigations. Larger, more complex projects warrant it more than smaller, simpler ones, but there is a trend towards increasing complexity as construction becomes more sophisticated.

"We feel that there is often an advantage to the client adopting a ground model. But not every project is a nuclear power station, so one of the challenges is how to scale this approach to small and medium sized projects where appropriate."

Client interest in the ground is risk, and uncertainty is risk. If there is no information, contractors price for that risk accordingly (or at least they should) and this potentially inflates the market price.

To the geotechnical experts, the starting point is 'what does uncertainty in the subsurface contribute to the risk profile'. In the chalk geology of Southeast England, , a key uncertainty is the presence of solution features.

"That's the interest to the geologists. But the risks associated with the solution features are the chance of collapse or other surface disturbance, and that is the part that is of interest to the client.

"In order to manage the risk, you have to step back and manage the subsurface uncertainty. It is subsurface uncertainty that needs to be addressed first. It's the same as in, for example, faulting.

"A fault isn't inherently a significant issue, but a fault that presents onerous geotechnical conditions, or one that is potentially capable of movement, presents risk. But you need to find out first, and characterise it."

"The construction sector often has a fairly traditional approach to evaluating ground risk. Many site developments still go ahead without desk study or geophysical investigations. It might be that for a fraction of the cost, a lot of the first order problems might be found well in advance.

"Foreseeable problems become foreseen and assumptions of ground uniformity are much less frequently adopted."

Above and below: **High resolution seismic reflection surveys played a key role in the Doha Metro project in reducing the risk of tunnel boring machines encountering unforeseen cavities in the local strata**

EARLY INVOLVEMENT

The plea of all specialists is to be involved in projects at an earlier stage, and geotechnical engineers and geophysicists are no different. Early involvement pre-empts problems and provides solutions for a fraction of the cost of bringing fixes to the job later in the construction cycle.

Simon Brightwell, a business development executive at Fugro adds, "In a perfect world it would always follow that collegiate, early involvement process.

"When people get around the table with cups of tea years before a piece of infrastructure is built they can informally look at the pros and cons of different options, but it isn't always like that.

"Companies do still have to operate in both ways and sometimes business is much more contractual, with a more formal, tendered setup."

FUTURE CHANGES

However, technology and thinking are moving on. Eddies reflects: "I think – I'm an optimist – we have maintained a campaign over the last few years focused around the benefits of reducing uncertainty in the early phases of projects and I see that as an evolving process.

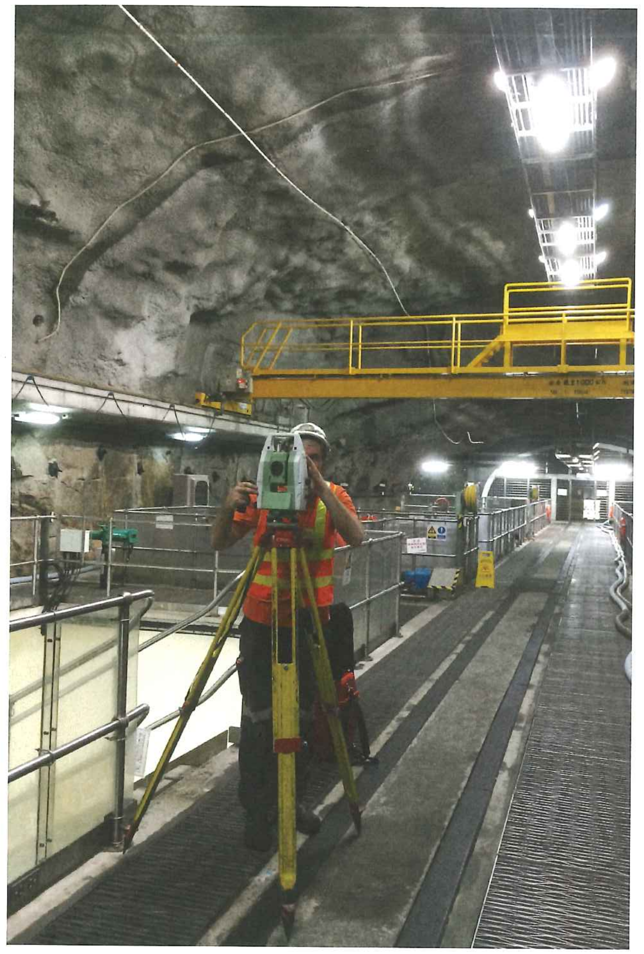
"It's a hearts and minds campaign basically, convincing traditional areas of business to undertake investigation that is different to what they do now.

"But I think the other part of it is that there are certainly new technologies in the wings for, let's say investigations for tunnels."

"I guess what we might see is a better use of legacy data – but I think certainly we are going to see gradual improvements in near surface investigation tools.

"One example we are developing is a way of imaging stratigraphy and structure and deriving geotechnical properties with one pass. Using technology that has come from the oil and gas exploration sector and adapting it. This is broadband seismic multi-component technology.

"The big difference is the use of instrumentation that can record all parts of the wave field so you can extract geotechnical properties and imaging at the same time. The benefit of that is that everything is geo-referenced in the same place, it shortens your field programme, reduces HSE exposure and reduces cost – and produces a better technical deliverable."



***Above:* Deformation monitoring of underground sewage treatment works, Hong Kong. There are considerable benefits in integrating pre- and post-construction measurement programmes**

Near surface

"From my perspective, in the geophysical group, a lot of the discussion we have revolves around how to improve near-surface information. It is a lot harder to try to characterise the top 50 m or 100 m than the next 3 or 4km."

"This is because the near surface is highly variable, it's where the surface meets the ground and where water is, weathering is, where chemical reactions take place. Where anthropogenic processes take place. It's a dynamic environment and especially variable.

"If we could strip away the top 100m and then do our geophysics, we'd be a lot happier. But that's also the depth within which tunnels are built, foundations and piles are put down etc. It is our reality.

"A couple of guys in the states made the prediction there would be more spent on characterising the top 100m than on oil and gas exploration in the near future. It might well come true before too long.

"One of the holy grails is bringing the oil exploration technology, know-how and experience into the near surface work environment."

Visualisation

The industry is also moving towards visualisation and BIM in a big way. It is the information age, and with the wealth of data that can now be collected, users further along the construction cycle can be helped with newer ways of presenting it.

It has been a complaint in the past that not all information provided to the construction tiers is not adapted as well as it could be for their purposes.

In geotechnical terms, geophysical, airborne and historical documentation can all be collated into one large dataset and presented in 2D (and now 3D) formats.

This sector still has some way to go to catch up with other industries, but things are heading in the right direction. There is more thought in how data is packaged for downstream use.

Eddies adds: "A particular challenge with geophysics is taking data that isn't formally depth-referenced and making it depth-referenceable with confidence, then presenting it in 3D.

"In the exploration sector, no one will put an eight-figure borehole down in the Gulf of Mexico without a full 3D picture of the ground down to several kilometres. But unfortunately the near surface environment is more complex and engineering projects work on a different cost base.

"We're working on it."

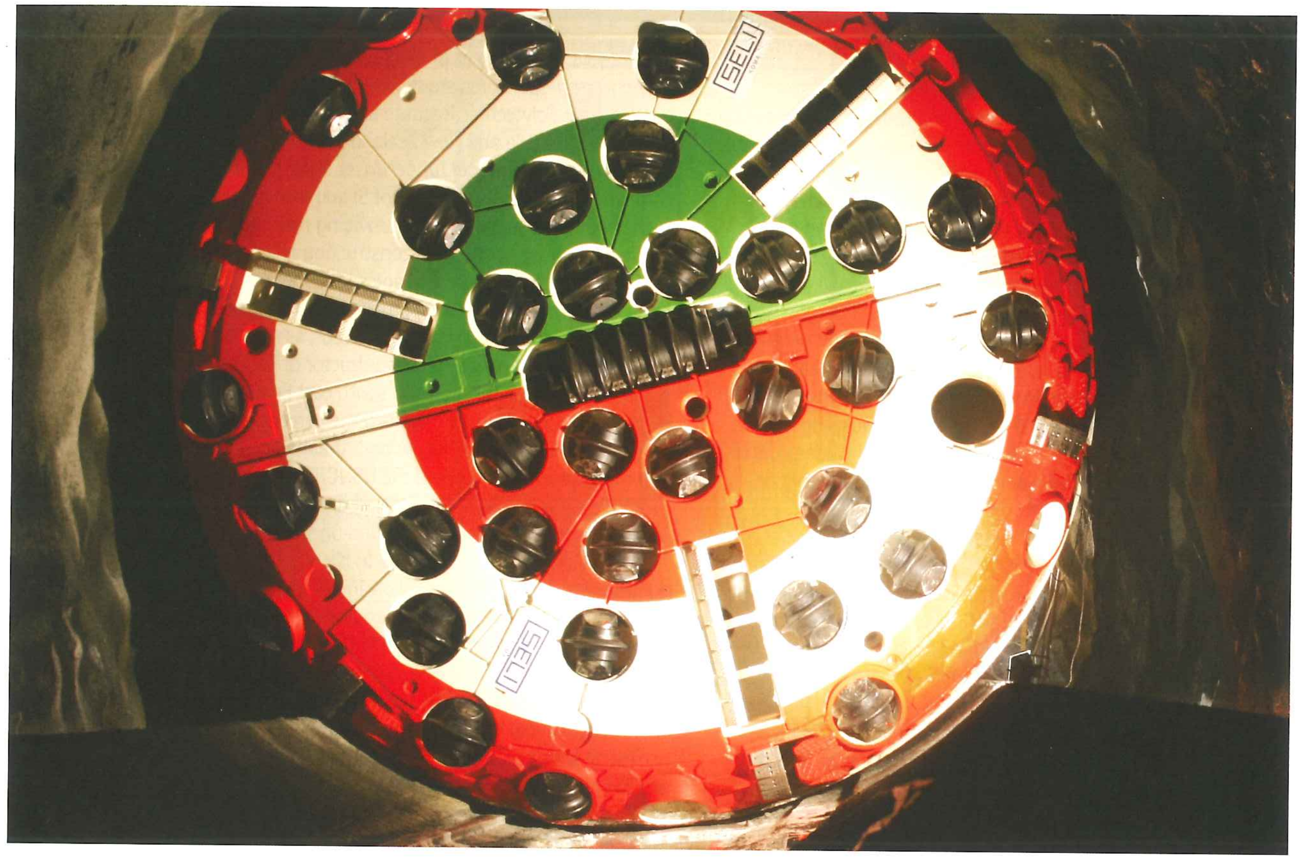
FINAL THOUGHTS

Brightwell concludes with later stages of the construction cycle: "Assessment and analysis of the ground should not just be confined to pre-construction as has been traditional. One of the key developments in modern engineering is the idea of intelligent structures.

"I think monitoring and understanding the condition and behaviour of your structure, the ground around it and possibly its interaction with other things that may be for example built above it or in the vicinity of it will become increasingly important."

"This is something that starts at pre-construction, but if you are installing systems why not install them to help you build the asset and also to look after it through its lifecycle. So I think there's a key thing here, that increasingly structures will be intelligent. The sensible strategy would be to integrate the way we look at their behaviour, movement and other parameters through the lifecycle, as opposed to separating monitoring regimes before and after construction."

The thinking around the ground model approach is evolving, with ideas from inside and outside the industry driving it forward.



SPENDING PROBES

Perspectives on the relationship of SI spending and ground risk. Report by **Patrick Reynolds**

Above: ***TBM bored southern tip of Brenner exploratory tunnel, 2008-10***
PHOTO BBT

ASK TUNNELLERS AND GEOLOGICAL or geotechnical experts about how thinking on spending for site investigation (SI) has developed over recent decades and it is clear that, for the most part, the approach to identifying ground risk has moved on significantly.

The argument to seek a sliver (even up to 5 per cent was uncommon) of a construction budget has given way to a more targeted approach, where SI is framed within risk assessment (RA) and supported by ever more knowledge shared of geological experience of strata.

The outcome of the RA approach is a technically justified, but never exhaustive, tactical tally of data and information that should be more than enough to answer questions about ground risk. The approach should deliver up a "cost effective" SI spend – a budget that has been developed rather than debated.

Project teams always face site-specific challenges. The ground on any site cannot ever be completely known, even after excavation of a tunnel alignment. The aim of the SI spend, therefore, is to get sufficient knowledge of ground conditions to hone the design and construction enough to judge an underground concept able to be safely, economically, financially and efficiently – and profitably, ideally – developed with, and not for, a client.

SHIFT IN APPROACH TO SI

David Fawcett, an international tunnelling consultant and past president of the British Tunnelling Society, tells *Tunnels and Tunnelling*: "Site investigation was difficult to sell in the '70s and probably into the '80s. Clients were reluctant to spend up front and rules of thumb were used to persuade clients of the sense of spending from 2 per cent to 5 per cent of the anticipated construction cost." (See box, page 10)

The transition from budget pleading to a more efficient, risk-sensitive development of SI spend today was not a foregone conclusion, but gained impetus from various factors, including ground problems on some projects that got the financial community and insurers more involved. (See box, page 12).

The change in approach also has had support from a combination of factors, observes Fawcett, such as: accumulation and useful holding of more data generated from projects; the increase in information sharing ("internet very

Probing, not pleading

Longer than a while back, the geotechnical industry urged clients to see the value of site investigation (SI) spending to reduce ground risk in projects. It was budget pleading to the basic principle.

Even then, sums sought for SI were relatively miniscule – barely touching mid-single digit percentage of the construction budget on SI, and varying with project size and location (urban sensitivity or rural remoteness). As tunnelling consultant David Fawcett notes, talk was around 2 per cent to 5 per cent and is still a challenge.

In the US, the general literature spoke of SI spend at 0.5 per cent - 1 per cent, and up to 8 per cent such as for hazardous (non-nuclear) waste schemes, reported tunnelling consultant and past president of ITA, Harvey Parker. He briefed on the data in his 2004 paper *Planning and Site Investigation in Tunnelling* to the 1st Brazilian Congress of Underground Tunnels and Structures and the South American Tunneling International Seminar.

Against that historical background, he said the US National Committee on Tunneling Technology (USNC/TT) of the National Research Council recommended in its report, *Geotechnical Site Investigations for Underground Projects*, in the 1980s, that the budget be increased to about 3 per cent as a useful threshold. It also recommended total length of boreholes be a multiple (around 1.5) of the tunnel length.

Referencing the USNC/TT report, IL Whyte, in a 1995 paper *The Financial Benefit from a Site Investigation Strategy*, for Ground Engineering, said the research found that more SI spend led financial uncertainty on out-turn costs "to decrease rapidly."

Shortly before Whyte's paper, in 1993, the UK's Site Investigation Steering Group (SISG) showed in *Without Site Investigation Ground is a Hazard* the corollary – that cost or time claims were related to ground model uncertainties arising from poor SI. Whyte's paper also said too low SI spend could see instances of wide spreads in of any cost-overruns.

An Aecom-sponsored study was undertaken within the last 10 years by Worcester Polytechnic Institute and looked at comparative costs of projects in Australia and New Zealand to wider markets. The study reports, in *Analysing International Tunnel Costs*, 2012, that they found "a direct correlation between the amount of SI and cost savings," and to spread such benefits they recommend "providing more comprehensive education to clients who are considering constructing any type of subsurface works."

Over time, the blunt percentage spend tool has given way to a more forensic and technically-led approach, using risk assessments (RA) to focus in on sharper details of information needs, as required in key locations.

Still, a recent review by a UK contractor of SI spend across a number of tunnel projects in London and south east England over the last few decades, and shown to *T&T*, showed the percentages to be in low single digits. They were typically below both the magic 5 per cent ideal, and while a number were even less than the USNC/TT threshold of 3 per cent.

While some low levels may have particular justifications they cannot be seen as presenting a normalisation on spend ratios, and if so would add to the challenges of discussions with clients, perhaps unless the financial community and insurers get solidly involved.

More recently, Pål Drevland Jakobsen of NTNU, in his *Geological and Geotechnical Investigations for TBM Projects* paper, showed the 5 per cent level sits well in the midst of a cluster of SI spending ratios from a number of tunnel projects (both TBM and drill & blast excavations), though they match against low single-digit tunnel lengths.

The SI spend ratio is, however, slightly higher than for most cases of TBM bores where tunnels are notably longer, typically. Jakobsen's information was based on his most recent sourced data added to the original cluster from the Norwegian roads authority, NPRA, in its publication 101, *Riktig omfang av undersøkelser for beranlegg*, 2003, after Palmstrøm et al.

important here," he says), despite the site-specific nature of project challenges; advances in excavation technology; and, not least, the bigger say of the financial community and insurers in project development, if clients want funding and coverage.

"In my experience, tunnel projects in particular have changed from being a risky gamble with the ground to being low risk," says Fawcett. "This sea change is partly due to more versatile tunnelling equipment and partly due to a much better understanding of ground conditions."

Below: ***SI at West Link rail project***
PHOTO TRAFIKVERKET

KNOWLEDGE

Not considering the old rules of thumb percentages in use any more, Fawcett says the approach to SI has shifted to "where available knowledge is utilised to target learning about potential risks so that they can be managed in advance and time and cost predictions become quite accurate."

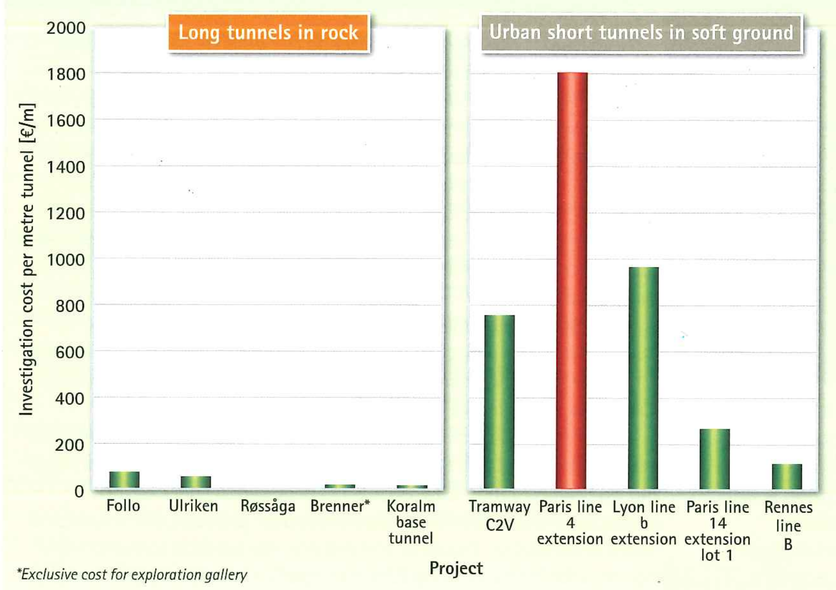
Fawcett adds: "Anticipated driving conditions are much better defined and tunnelling equipment is much more versatile."

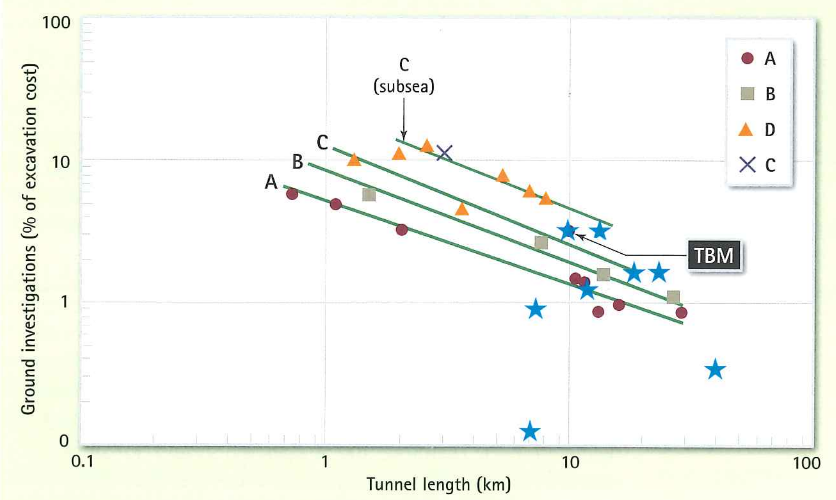
The better time and cost accuracy comes, he says, from: more knowledge from experience working in particular strata; greater sharing and availability of such knowledge in the internet era; SI techniques being more sophisticated and focused on ground risks; and, lessons learned over the last 30 years having improved interpretation techniques.

The point on information sharing is agreed by Eivind Grøv, the chief scientist with a tunnelling focus at Norway's research body SINTEF, an Adjunct Professor at the Norwegian University of Science and Technology (NTNU), and one of the country's key figures in the underground sector.

Grøv says: "Improved sharing of information would lead to more cost effective SI." And, hopefully lessons are not forgotten when a team disbands and individual move to the next project, coming together as new multi-disciplinary groups.

The development of plans for the Crossrail project, in London, over some years saw a gradual accumulation of the geological and geotechnical information from desk gathering of data to ongoing refinement of the SI works, Mike Black, geotechnical manager with the client has said. The project was able to draw on information from other projects as well as that held by the British Geological Survey (BGS). Part of its legacy is putting extensive information back into the BGS system, informing the "toolbox of options" for future projects.





Top: ***Figure 1, Costs for GI (ITA and NTNU data)***

Above: ***Figure 2, Site investigation spend (NTNU)***

PROCUREMENT

There are also progressions in procurement that concentrate the mind anew and revitalise discussions and activities around planning – and who ultimately pays – for ground risk. These include efforts at partial risk transfer from the client (though not necessarily cost transfer, ultimately) on procurement taking the like of design-build or public-private partnership (PPP) routes.

As an underwriter told the Geological Society, in 2012, contractors don't accept risk – they price risk.

Other approaches can see valuable insights brought to planning through early contractor involvement, and also uncovering various sensitivities and establishing limits and needs by liaison with third party stakeholders, especially in zones of expensive urban real estate, like London.

But procurement and contract form should also be strategically considered in light of the geological uncertainties, a recommendation given by professor emeritus Håkan Stille when giving the Sir Muir Wood Lecture 2017, *Geological Uncertainties in Tunnelling: Risk Assessment and Quality Assurance*, earlier this year at WTC 2017, in Norway.

Stille says, "Many claims and construction mistakes have their roots in the fact that the contract and organisation have not been adapted to prevailing geological uncertainties."

Last year, Pål Drevland Jakobsen of NTNU, in his presentation *Geological and Geotechnical Investigations for TBM Projects* to the TBM Application II conference, in Norway, observed that pre-investigation is "highly dependent" on various factors, including the "selection of contract type."

The ITA, which says in *Strategy for Site Investigation of Tunnelling Projects*, 2015, recommends it be the case that each client "retains the final responsibility for the ground conditions, irrespective of the contractual framework that is chosen for the project."

CLIENT EXPERIENCE

Fawcett says: "I believe it is now accepted by clients that significant money being spent on SI is necessary to manage project risk."

However, even with RA-first approach, and with some recent ST spend data showing the up-to-5% ratio sits square in the data field of data obtained by Jakobsen (see box, page 10), questions on spending can come from some quarters, such as recently experienced by a UK contractor, *Tunnels and Tunnelling* was told.

Perhaps some may be less experienced clients, questioning the bang for bucks or how a cap can be put on SI spend. Basically, why pay for more? Such questions would be less expected from seasoned clients, perhaps.

Grøv says owners might be, in a simplified way, split into two types – those who are multiple tunnel project owners and others with only a few or even one underground asset to develop.

"They have, in my view, a significant different approach when it comes to SI," he says.

Grøv says multiple owners often have their own approach to SI, the content and comprehensiveness based on their own experiences, and taking into account the likes of Eurocode 7. In Norway, as briefed in *The Principles of Norwegian Tunnelling*, 2017, published for the Norwegian Tunnelling Society (NFF) when hosting WTC 2017, the national road authority (NPRA) phases its SI programme to match its four stages of planning and designing for tunnels, tightening cost estimates through the steps while noting

Guiderails on the SI journey

A series of publications addressing site investigation (SI) and risk have grown over the last two decades, building upon each other as a growing, increasingly unified, conversation. They are increasingly turned to and set the bar as viewed by the financial community and insurers, in many cases.

Perhaps understandably, and as they involve different project parties, their structure and language unfold in broad elements and principles, and with a sense of overlapping awareness with procurement and contractual concepts.

In 1988, ITA published its *25 Recommendations on Contractual Sharing of Risks*.

Then, in 2003, came a landmark report *The Joint Code of Practice for Risk Management of Tunnel Works in the UK* from The Association of British Insurers (ABI) and The British Tunnelling Society (BTS). For context, it had reference to BSI's *Code of Practice for Site Investigations* (BS5930:1999)

Out of the US, in 2007, came the Geotechnical Baseline Report (GBR) approach, after Essex. It is a single source document of contractual statements, each of which are called baselines, and difficulties materially exceeding those threshold statements fall as risks to the project client.

Building upon the ABI/BTS Joint Code, the International Tunnel Insurance Group's (ITIG) took the work further in *A Code of Practice for Risk Management of Tunnel Works* (2nd ed, 2012). The modification followed talks with ITA and the International Association of Engineering Insurers (IMIA), and said the code should be a project management tool.

More recently in the US, the Underground Construction Association of the Society for Mining, Metallurgy, and Exploration (SME) has built upon ITIG's Code to publish its *Guidelines for Improved Risk Management*. SME also acknowledges the backing broadly given by ITA to taking a risk management approach.

In 2012, AFTES published its *Characterisation of Geological, Hydrogeological and Geotechnical Uncertainties and Risks*.

Recent years has also seen publication of *Eurocode 7 – Geotechnical Design – Part 2: Ground Investigation and Testing*.

Most recently, ITA's Working Group 2 published its report *Strategy for Site Investigation of Tunnelling Projects*, 2015. That work highlights further the perspective of fundamental and systematic engagement with risk management in underground space. WG2's study emerged from a call made by ITA's Executive Council, in 2001, then led by Prof Andre Assis. It also builds WG2's prior report, *Guidelines for Tunnelling Risk Management*, 2004, which placed SI firmly within the global strategy of risk management.

The report is a concise document but succinctly covers four case studies: two hydro projects (Kuhtai in Austria, and Porce III in Colombia); a major rail tunnel (Gotthard Base Tunnel, Switzerland); and, a metro scheme (Cityringen, in Denmark).

ITA's report discusses the value of phased SI in consecutive "campaigns" from feasibility through to construction. It says data should be centralised and maintained during excavations, and reviewed to check design assumptions and help with "contractual issues." Later still, the SI data plus record of excavation should be comprehensively available to support any maintenance, operation, upgrades and repairs – having whole life value to the asset, in other words.

In its conclusion, the report says SI is "one key component of the global strategy for project risk management"

The report adds that while it is necessary to rely on relevant and sufficient SI there needs also to be "respect for the potential variations of nature" – foreseeable and unforeseeable, respectively. It further advises to have active external and independent project reviewers.

As said in *The Principles of Norwegian Tunnelling*, 2017, published for the Norwegian Tunnelling Society (NFF), and referencing papers by Grøv and Blindheim, "Independent of the type of contract, it is important not too become too confident about the results or rather interpretations from the site investigations prior to construction."

more may be needed for tenders.

"For the one-time owners, the approach to me seems to be a little bit different," says Grøv.

While they may not necessarily have the same regulations to follow, they often have to attract overseas investors to secure project funding. His recommendation, then, is to apply the guidelines of ITIG to demonstrate the project, and its approach to SI, is adhering to international norms (see box, page 12).

Like many in the tunnelling industry, though, he also finds International Tunnelling Association's (ITA) 25 *Recommendations on Contractual Sharing of Risks*, 1988, a useful touchstone.

Grøv says: "Predictability is a key issue, particularly in those projects which are financed by funders and not governments."

At the end of the day, however, it all filters back to the client – the owner being the party with the ultimate risk, he adds.

A huge project in its early stages of construction, and where the client is taking the ground risk, is the Lyon-Turin Base Tunnel between France and Italy.

RISK: A FRAMEWORK FOR DISCUSSIONS

RA is integral to the strategy of project risk management that clients and funders and insurers increasingly understand and deliberate over. Therefore, the SI question should not sit in strained isolation. Risk management, therefore, gives the framework for discussions about everything, including SI.

The parties can heed the advocacy of the ITA, in *Strategy for Site Investigation of Tunnelling Projects*, 2015, saying: "Geology affects every major decision to be made in designing and constructing a tunnel." But its report then cautions, "it is not possible to predefine the ground conditions in detail," and therefore "geological risks exist on any tunnelling project."

Highlighting the strategic value of risk management (ways to mitigate and management hazards identified through RA), the report says the "purpose" of SI is to get "adequate and reliable" information, and early, to help sift the design and construction options and so "better cope" with the "identified potential risks."

Grøv says: "If SI does not provide additional value or reduce risk, then it is not worth doing."

In his Muir Wood Lecture, Stille said: 'The full knowledge of the actual geological conditions will first be revealed after excavation and even not then. This implies that the final design cannot be established in advance.'

Fawcett emphasises that this point made by Stille is very important.

GROUPING RISKS

On risk in rock engineering, Stille notes arguments against the use of risk matrices due to matters of objectivity and definitiveness. However, in observing the widespread use of the system, and its value as a communication tool, he comes to the view that "carefully used I believe it has its place."

Stille advocates avoiding a mass grouping of all risks in a large single matrix or register, and instead to separate and group them into categories based on engineering issues – and he considers that rock engineering issues emerging from geological uncertainties should be so grouped.

'This will have a good overview of the risks related to geology (geotechnical risks),' he says.

Citing a variety of headline hazards (contractual, design, organisation, geological, technology, environmental, human and political), he notes they are not mutually exclusive and in many cases emanate from geological uncertainties.

But he emphasises there are many successful projects, and they are characterised by: clear objectives; experienced, knowledgeable and competent personnel; comprehensive view of risk; adequate management and information systems (including field monitoring); and, quality assurance (do the right thing, and properly). Having a geotechnical team on site is also necessary, he adds.

Stille further notes, to support those efforts, the value of Geotechnical Baseline Reports (GBR) to give "transparent communication of the geotechnical uncertainties," and separately that ground characterisation should be split in line with design and construction considerations, respectively – unless its general characterisation then it must cover both.

In a perspective on risk management, Fawcett says is nothing new, "it was always the constant tool of the professional." With more documentation these days, however, more stakeholders are able to be briefed on the insights of the experienced tunnelling professionals. However, he cautions that highlighted risks need to be mitigated and not only documented.

ICELAND

In Iceland, where geology presents varied challenges, Bjorn Hardarson of consultant Geotek and who provides site supervision services to clients on many projects, tells *Tunnels and Tunnelling*: "It is a never ending debate how much you should spend on investigations.'

Hardarson says the main parts of SI are "rather similar" for typical road projects but depends on tunnel length, location, landscape, etc. The SI typical involves a general surface geological survey, some geophysical measurements and usually core drilling as the most expensive part. Our biggest concerns are the potential inflow of water (hot or cold), the volume of weak sedimentary layers and weak fault zones," he adds.

The most recent project and the one that called for most core drilling – 1,660m, in total – is Vadlaheidi road tunnel which is also Iceland's longest, at 7.2km. But the excavation only recent finished, having been delayed by unexpected and extreme geological and hydrogeological events – both hot and cold water, the latter at a collapse and flood behind the face. Quantity is not always the solution to reduce risks," observes Hardarson, in terms of pre-construction SI. He adds there is a tendency at present to increase investigation during excavation, such as routine probing.

Commenting generally on ground investigations during excavations, Grøv says "probe drilling ahead of the tunnel face" has been an important trend that is a change "to the better." It particularly helps in performing geological and geotechnical mapping, allowing for continuous evaluation and, therefore, informing any modification needed to the geological model.

VALUE OF EXPERIENCE

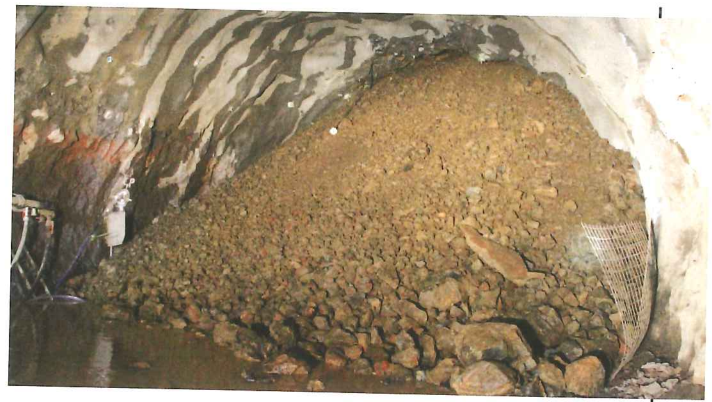
Whatever the path to the start of excavation, out there waits the ground, barely seen and mostly untouched. The challenge of seeking more detailed insights will continue with each step in tunnelling and with probing ahead and around the face, until the end.

That the ground cannot be fully known may be a gripe for the beancounters and spreadsheet meisters. However, the challenge of excavating every foot and metre grips fast and tight in the minds of seasoned, long-term tunnellers and geologists, and the younger ranks rising up. Sometimes the problems can only get solved at the face.

As Stille says in the tag to the title of his Muir Wood paper, "There is no substitute for experience."

The value of experience was underlined in early September by Dr Chris Menkiti of Geotechnical Consulting Group, answering the Q&A when speaking on *Tunnelling Ground Risks – A Client's Perspective* to the Engineering Group of The Geological Society, in London. He had discussed project successes, such as Crossrail, but also challenges met by two projects in Poland and Turkey, respectively.

Tenacity and experience will see challenges through, sooner or later, but getting a project started also demands insights and resources from client and financial experts. The sides are interwoven as will be their discussions around resolving risk through SI.



***Top:* Challenges in volcanic geology: Progressive collapse during excavation Vadlaheidi road tunnel, Iceland**
PHOTO BJORN HARDARSON (GEOTEK)

***Above:* Directional core drilling used SI at Romsdal subsea road tunnel, Norway**
PHOTO NPRA

INTERFACE POWER

Trends in geotechnical data and software. Report by **Patrick Reynolds**

Above: Shawn Sismondi of FLO JV - taking AGS format to SCL tunnels
PHOTO PATRICK REYNOLDS

AMONG THE DEVELOPMENT TRENDS in software and data services to the geotechnical sector of tunnelling, the topic of how to achieve better interfaces in the digital sphere is emerging as a prime area of focus.

In terms of products, and in one area of classic challenge in civil engineering – the soil-structure interface, Plaxis has introduced new software: the Geo-Structural coupling tool which works with its Plaxis 3D program.

Bentley notes that asset tagging of boreholes is a coming feature among its suite of software offerings, resulting from rising construction industry expectation in the era of Building Information Modelling (BIM) and greater power and flexibility of computing solutions for the construction sector.

An important aspect of what the software can achieve, though, is how it can take data. Consequently, a perennial but increasingly important topic of discussion and effort is data formatting and what can be done to improve it further.

The data format topic was the focus of a conference held by The Association of Geotechnical and Geoenvironmental Specialists (AGS) in late September. The event took place as it celebrated just over 25 years of making its AGS digital data transfer format (now in its 4th version) available to the construction sector for ground information management.

Speaking to *Tunnels and Tunnelling* at the conference, Shawn Sismondi, a senior geotechnical engineer with Laing O'Rourke and Ferrovial JV (FLO JV) on the central contract of the 25km long, super-sewer Tideway project, in London, said: "I would love to see a non-proprietary format to transfer as-built geotechnical construction data for tunnels."

The possibilities around interfaces also gives rise to pooling data into larger databases, held by others, to form regional stores of geological and geotechnical intelligence as a resource for future infrastructure developments. Among a number of such projects, UK software developer Keynetix is working with the British Geological Survey (BGS) on some possibilities for pooling data.

Visions and care

The topic of how to cautiously and practically visualise varied subsurface conditions based on sampled data was looked at in the third step of the *BIM for the Subsurface* research project. It was noted that drawing continuous, interpolated, geological boundary surfaces between data from boreholes can give an illusion of more accuracy than is the case.

To help minimise this perception, and therefore the associated risk around ground conditions, the research focused on editing the 3D visualisations to produce, instead, more linear Fence Diagrams along the corridors of data particular to key alignments of interest on a project.

The questions of visualisation could become even more important in future where pooled data and their representations might become more available and taken by others who were not deeply involved in producing past visualisations.

Prof Eivind Grøv is a key figure in the Norwegian underground sector, the chief scientist with a tunnelling focus at SINTEF, and an adjunct professor at the Norwegian University of Science and Technology (NTNU). He says that industry basically has the same tools for SI as earlier but notes there is more ability to process, analyse and visualise the data that are collected.

"All in all, we are able to grab more information out of a set of traditional investigation methods," Grøv tells *T&T*.

But Grøv underlines the potential problem from visually interpolating between points of ground investigation data as it can generate a perception of more accuracy of the geotechnical knowledge across a site than is the case.

While acknowledging the power and benefits of visualisation tools, and the increasing importance of BIM, he cautions on the need to understand information to help "draw the right interpretations and conclusions."

Grøv adds: "That is where the experienced and competent rock engineer is important." And, he asks further: "'What are the consequences of all information gathered?' That's the key question."

STEPS IN SOFTWARE

Jasper Van Der Bruggen, sales manager North America for Plaxis, tells *Tunnels and Tunnelling* that the North American market for geotech and tunnelling software "is steadily growing, mainly due to new companies and offices joining this market."

He adds, as a general statement, North America is late in the widespread acceptance and use of advanced software programs. Therefore, designs in North America tend to be over-conservative, leading to unnecessary high construction costs. Using advanced software programs can optimise designs and, therefore, save considerable costs.

He says there are widely varied experience levels among those using software which feeds into the many targets and objectives of developers. He says that, on one hand, there are new users starting to use software or numerical modelling, while on the other hand some very advanced software users push the envelope, such as developing highly complex 3D models.

To help meet increasing calls for even more powerful software capabilities, Plaxis is developing more interoperability for its Plaxis progam. Its latest 3D version is capable of exporting CAD geometry via the user interface, which Van Der Bruggen says is useful in BIM workflows or even 3D printing.

Plaxis has also introduced its Geo-structural coupling tool to work across both Plaxis 3D and SAP 2000, a program widely used in structural engineering. The company says it's the first commercial software tool of its kind, able to bridge structural and soil mechanics models.

Van der Bruggen says the market response has been "positive and enthusiastic."

Plaxis 3D is among software programs used by Norwegian engineering consultancy, Multiconsult. Tunnels and dams engineer Bruce Ashcroft tells *Tunnels and Tunnelling* that the program is used for its underground seepage and 3D analysis. The consultancy also uses Rocscience products, including RS2, Unwedge and Rocdata.

Another program available is Itasca's FLAC3D, a numerical modelling tool for geotechnical analysis. At Version 6.0, the program allows for explicit continuum modelling of non-linear material behaviour in 3D.

WORKING TO INTERFACE

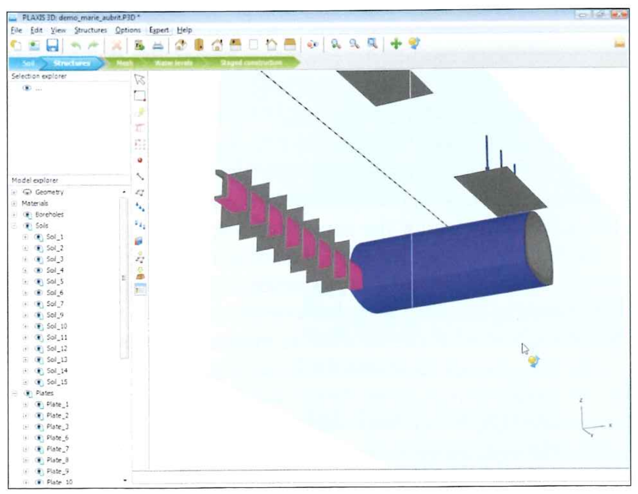
Geotechnical interests are pushing for greater ease in data sharing, and so get more leverage from software systems and therefore more speed and efficiency in design and construction operations. Discussions are taking place on a number of fronts.

BIM

In the era of BIM and ever cheaper and more powerful computing power, the desire to get more out of IT is only increasing – as are expectations and conversations to be able to do so. Such dialogue has led to Bentley to be introducing asset tagging for boreholes, treating them only as objects rather than historical geotech data points in themselves, *Tunnels and Tunnelling* learned. The result is boreholes would not hold data locally, as the risk of being superceded, but as objects would call down the latest collected, and always-up-to-date, information from the central database.

While BIM is framing the context of conversations, Plaxis' Van Der Bruggen says the movement doesn't seem to be a game-changer, so far, in the geotech sector. However, he expects interoperability to gain even more importance, with or without BIM.

Interoperability is a key part of the message in BIM, which Stanford University professor Martin Fischer says is as much about process and communication as technology. It would then enable the widest choices of tools for concurrent design development, and the continuing evolution of geotech information from site investigation (SI), allowing data to move freely in non-proprietary formats. Such data would be easily usable in a team member's own choice of software for a project – unless prescribed otherwise by the project owner or project manager.



***Right:* Still from Plaxis 3D Tunnel movie**
PHOTO PLAXIS

AGS for SCL tunnels

While the AGS format is a spreadsheet listing and therefore highly readable digitally, the data would need additional formatting to be usable by software systems to help plan or control excavations on tunnel projects.

The ideal would be to have such a common data format system to be easily taken up by any software platform used in the underground space sector.

To that end, in part, research is getting underway on part of the Tideway project in London to look at taking AGS format forward for tunnelling.

"I'll be undertaking the development of an extension of the AGS format specifically for SCL tunnels," Sismondi tells *Tunnels and Tunnelling.*

The aims is to achieve better understanding of the lining behaviour, shotcrete fallout and SCL interaction with the ground, he says. Information will be inputted on tablets and reviewed during shifts, helping further with quality as well as health and safety. The system would enable quick evaluation of SCL data versus geotechnical data, and the pre-construction model would be updated with the as-built construction data.

"It becomes very important having data sets in a common database and with a common format," Sismondi told delegates in his presentation to the AGS Geotechnical Data Conference. The contractor hopes to share what is learned across the entire Tideway project.

The initiative aims to take forward that discussion through making a recommendation to the AGS committee to consider around mid-2018 after a paper is produced on lessons learned. Discussions on the possibilities were held earlier this year.

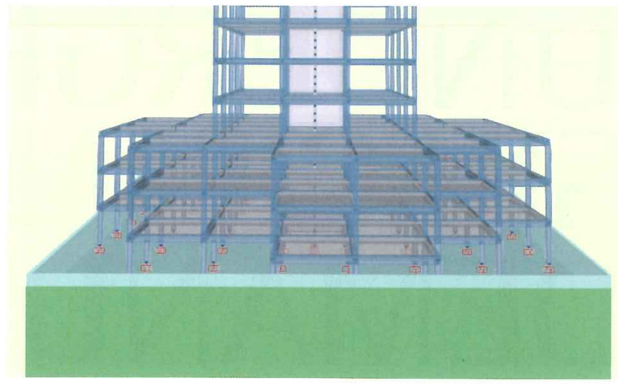
The SCL works will be undertaken at the Kirtling Street launch shaft in advance of the TBM launches. The work is being jointly funded by FLO JV and the Tideway client as part of the project's Innovation Forum. For the task, the contractor will be using Bentley software products, including ProjectWise, MicroStation and gINT.

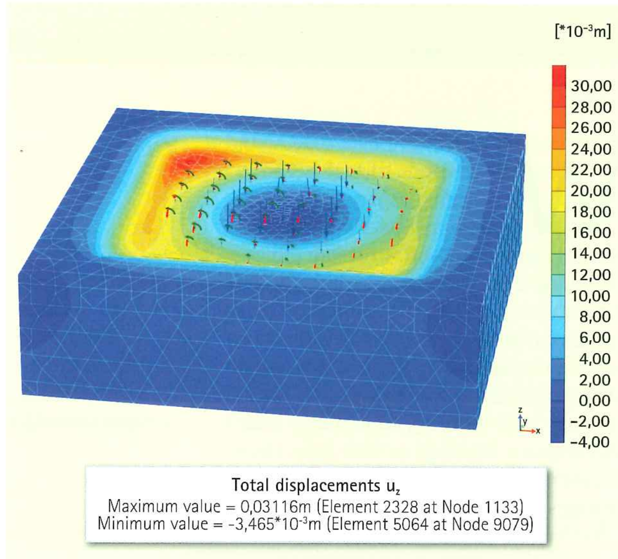
Pooling together

In another aspect of interfaces, Crossrail drew upon pooled data held by BGS to complement its own SI probing, and held the information in the AGS format, and which was stored in the project's Asset Register. After the project, the client plans to send all its geological data to the BGS, further contributing to the pool of subsurface knowledge of London and to benefit later project development. The Tideway project and so many others draw upon the data held on London by BGS.

BGS is also part of a research initiative – *BIM for the Subsurface* – along with Atkins and Keynetix, the latter using its HoleBase software platform along with plug-ins from AutoCAD. Keynetix's technical director, Gary Morin, briefed the AGS conference on the research project. The research initiative has had three core steps: the first two being data access and cloud service hosting, respectively, and allow the research partners to collaborate and share information; and, the third step is 3D geological modelling using AutoCAD Civil 3D.

The data pooling system used HoleBase to upload data in AGS format to BGS databases for sharing with others, as is the core aim. Keynetix notes that the system developed by the partners is independent of its software platform.





***Above:* Plaxis coupling tool for ground-structure interaction with Plaxis 3D**
PHOTO PLAXIS

A further aspect of the research was in the 3D model visualisation, and that is part of an interesting, wider topic around ways of conservatively utilising geotechnical data collected for any project, anywhere (see box).

To close the AGS conference, Garry Baker of National Geoscience Data Centre of BGS promoted the possibilities around pooling of information for its Open National AGS Data Store. He said the NGDC is trying to hold the geotechnical data 'for the longer term,' which in effect would be helping to hold some description of the "natural capital" stock of what is known of the geology in an area, based on prior ground investigations.

Here, the interface is with time, the benefits to be gained by a more collective engagement trend are to be found by data owners and users opting to pay-it-forward, and see cumulative shared gains to society, and industry, down the line. It was recognised in Q&A, though, that questions remain over turning over data and to what degree, especially as such pooling is not mandatory.

UNDERGROUND SPACE IN HIGH DEMAND

L D Jones, K A Lee, A J Hulbert, all of the British Geological Survey present a new 3D dataset that represents the properties beneath London

WITH INCREASING DEMAND ON the sub-surface beneath the capital, space is at a premium. Space is restricted not only by current infrastructure (pipes, cables, tunnels, foundations), but also by the natural geological hazards that co-exist. One of these hazards is the volume change potential, or shrink-swell, of clay and clay-rich lithologies. These can vary from lithology to lithology and also within a lithology or rock type. Once uncovered by excavation or disturbed, any changes (e.g., weather, groundwater) affecting the lithology could cause new or exacerbate shrink-swell hazards.

NEW 3D DATA INSIGHT

The British Geological Survey's (BGS) Hazard & Resilience Modelling Team have developed a new shrink-swell 3D dataset, called 'BGS GeoSure Shrink-Swell 3D' that delivers a unique insight into the properties of the subsurface. The shrink-swell 3D data is a regional hazard susceptibility map that identifies areas of potential shrink-swell hazard, in three dimensional space, at intervals down to 20m in the London and Thames Valley area. The data is classified on an A-E range of hazard susceptibility. The data have been produced by geologists, geotechnical specialists and information developers at the BGS, and are derived from the London geological model.

Using data, knowledge and expertise, it combines geological data from boreholes, 3D models and laboratory test results of plasticity to interpret the Volume Change Potential (VCP) of all rocks and deposits.

The dataset contains the following information at each 50m x 50m cell: Depth (0m-20m), Formation (a BGS Lexicon Code), Dominant Value (A-E), and Range Value (A-E).

This new data product is designed to assist in the preparation of tenders, the planning of groundworks and the compilation of ground investigation desk studies. In particular, the dataset is highly relevant to the utility, engineering works, and tunnelling industry in terms of route planning, installation and network management.

SHRINK-SWELL HAZARDS

Swelling clays can change volume due to variation in moisture, this can cause ground movement, particularly in the upper 2m of the ground, or where excavated and exposed, that may affect many foundations or underground services. Ground moisture variations may be related to a number of factors, including weather variations, vegetation effects (particularly growth or removal of trees) and the activities of people that might cause changes to the water content and hence the ground conditions.

Properties of earth materials are important for all engineering projects and the classification of shrink-swell potential provided by this dataset can be used in all ground developments to give a generic assessment informing engineers and planners at the pre-tender and desk study stage of likely ground conditions at their site or along their route. This allows for a far more efficient tender preparation, planning and execution of subsequent ground investigations.

USEFUL TO A RANGE OF SECTORS

The dataset is a key data resource for all assets and infrastructure developments and maintenance. Natural ground stability hazards may lead to financial loss for anyone involved in the ownership or management of assets, including developers, construction or local government if suitable measures are not taken. These costs could include increased reinsurance, additional engineering works to stabilise land or developments. These hazards may also impact on anyone involved in the construction of large structures (deep foundations, basements), infrastructure networks (road or rail) or utility companies. The 3D properties of these materials can be used to identify potential problems at surface, in the shallow sub-surface or deeper underground (e.g., tunnels). Armed with knowledge about potential hazards, preventative steps can be put in place to alleviate the impact of the hazard to people, property and infrastructure. The cost of such prevention may be very low, and is often many times lower than the repair bill following ground movement.

Table 1. Volume change potential classification, modified from BRE Digest 240 (BRE 1993)

Shrink-swell 3D Classification	Modified Plasticity Index (per cent)	Volume Change Potential
A	<1	Non Plastic
B	1-20	Low
C	20-40	Medium
D	40-60	High
E	>60	Very High

Table 2: Percentage classifications of VCP at depth intervals calculated from the model

Hazard Level	Interpretation	% present at 0m depth	% present at 5m depth	% present at 10m depth	% present at 15m depth	% present at 20m depth
A	Ground conditions predominantly non-plastic.	51	47	42	42	43.5
B	Ground conditions predominantly low plasticity	14.9	5.5	5	5	5
C	Ground conditions predominantly medium plasticity	9	8	5	3	2
D	Ground conditions predominantly high plasticity	25	39	47.5	49.5	49
E	Ground conditions predominantly very high plasticity	0.1	0.5	0.5	0.5	0.5

SHRINK-SWELL 3D FACTS

Through development of this model, we have found that on average some 42.5 per cent of London and the Thames Valley is potentially susceptible to shrinkage and swelling (classes D and E) if exposed by development and construction works.

Some 10 thousand different geological units are identified and classified in the dataset.

1. Each of the geological units were allocated a VCP classification based on its upper quartile value. These units were then converted and, in some cases, combined or broken apart so they could be allocated to one of the 10,000+ geological LEX-ROCK (Lexicon and lithology code system) codes in BGS Geology 50k.
2. The Modified Plasticity Index (IP') (Table 1) was calculated using the method proposed in BRE Digest 240 (1993). This method was used where the particle size data, specifically the fraction passing through a 425μm sieve, were known or could be assumed. Firstly, this method required the Plasticity Index (PI) values to be calculated from the Liquid Limit (LL) and Plastic Limit (PL) data, as follows:

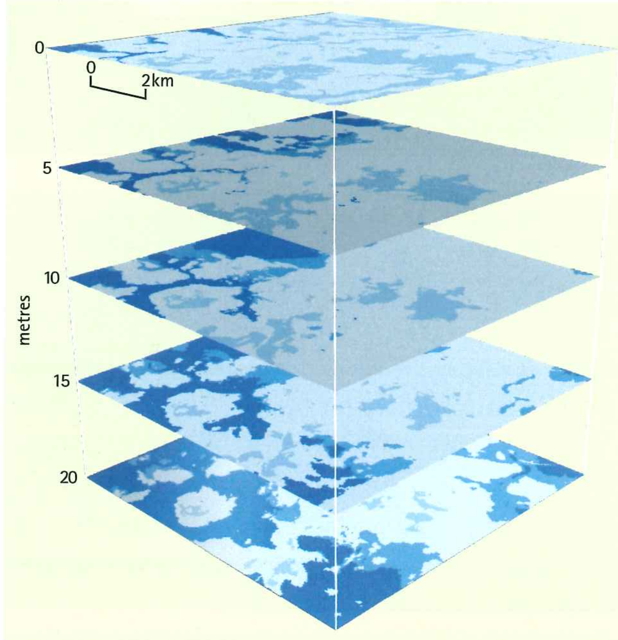
$$PI = LL - PL$$

The Modified Plasticity Index (IP') could then be calculated from the PI and the amount of fines passing a 425μm sieve, as follows:

$$IP' = PI \times \frac{\text{percentage less than } 425\mu m}{100}$$

The model was interrogated to determine the percentage presence of shrink-swell at the different depths shown in Table 2. Approximately half (51 pre cent) of the surface coverage in the model area (London & Thames Valley) has a Class A rating, i.e., deposits are non-plastic, and only 25 per cent of surface deposits are high or very high plasticity. However with depth, this high – very high proportion increases considerably with some 48 per cent of deposits being susceptible to shrink-swell at 10m and 49 per cent at 20m depth. This highlights that even across this relatively large region, there is much variation with depth that needs to be taken into account for any engineering project. An example of these changes in hazard potential can be demonstrated in Figure 1.

***Below:* Figure 1, Example of variation in shrink-swell potential at different depths**

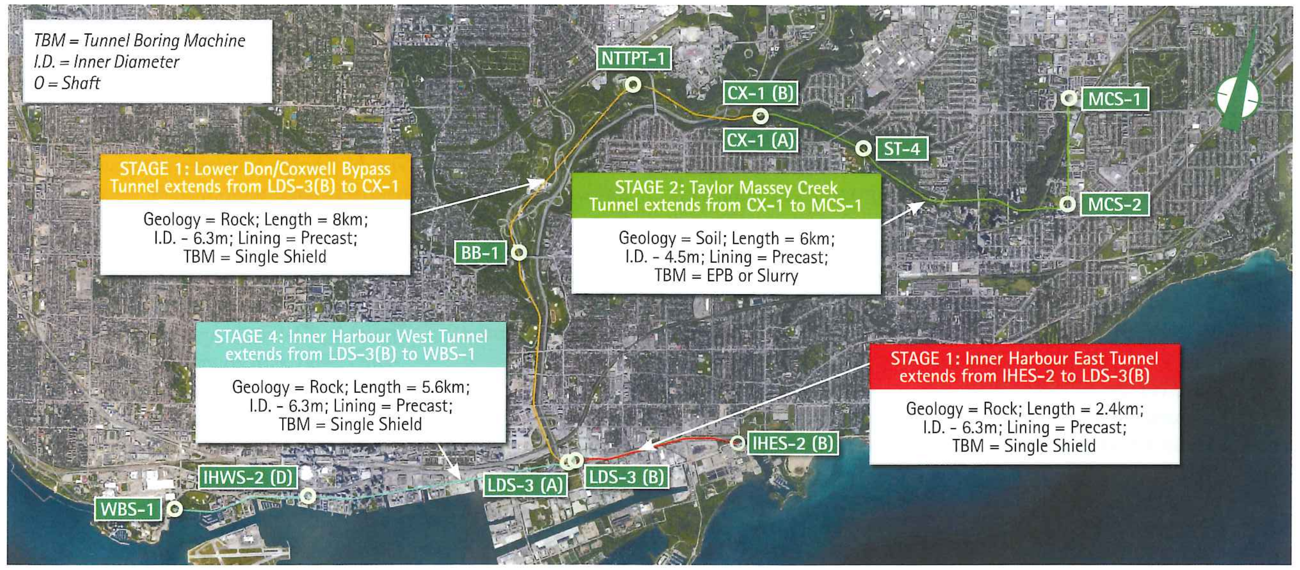


Further reading

Building Research Establishment. 1993. Low rise buildings on shrinkable clay soils: Part 1. BRE Digest 240
http://www.bgs.ac.uk/products/geoSure/geoSureLondon.html

INVESTIGATE AND IMPLEMENT

Toronto is preparing to build 22km of tunnels to improve waterways in the Great Lakes Basin. **Mark Bruder** of R.V. Anderson Associates Limited, **Daniel Cressman** of Black & Veatch, and **Robert Mayberry** with the City of Toronto outline the geotechnical investigation program for the Don River and Central Waterfront Wet Weather Flow System



***Above:* Overview of tunnel stages 1, 2, and 4 for Toronto's DR&CW project**

Mark Bruder
Mark is a structural engineer with R.V. Anderson Associates Limited, and based in Toronto

Daniel Cressman
Daniel is part of B&V's heavy civil group in Toronto, currently acting as design manager for the Coxwell Bypass Tunnel

Robert Mayberry
Robert is project manager, engineering and construction services, for the City of Toronto

THE CITY OF TORONTO is implementing the Don River and Central Waterfront (DR&CW) Project to reduce Wet Weather Flow (WWF) into Lake Ontario, the Don River, and Taylor Massey Creek. A primary goal is to de-list the Don River and Inner Harbour as an International Joint Commission "Areas of Concern" in the Great Lakes Basin.

Black & Veatch in association with R.V. Anderson Associates Limited (design team) has been contracted by the city to complete preliminary design of the project and detailed design of construction Stage 1, and to scope and manage the geotechnical investigations. The geotechnical program is currently under way and is being completed to support preliminary and detailed design of all five construction stages.

The DR&CW Project encompasses design and construction of the following components: 22km of tunnels in both rock and soft ground with 12 shafts and 27 connections, seven detention tanks, and a high rate treatment facility at Ashbridges Bay. The project is expected to cost CAD 1.5bn (USD 1.23bn) and be implemented over the next 25 years in the following five construction stages:

- Stage 1: Inner Harbour East (IHE) and Lower Don (LD) Tunnels (i.e., Coxwell Bypass Tunnel),
- Stage 2: Taylor Massey (TM) Tunnel,
- Stage 3: Offline Storage Tanks,
- Stage 4: Inner Harbour West (IHW) Tunnel, and
- Stage 5: WWF Connections (WWFC) to tunnels.

For Stages 1, 2, and 4, refer to Figure 1 on page 39 for an overview of tunnel properties. Shaft internal diameters range from 8m to 22m, and the maximum shaft depths in soil and rock are 60m and 43m, respectively.

GENERAL SUBSURFACE CONDITIONS

Across all five construction stages of the DR&CW Project, quaternary soil deposits overlie shale bedrock of the Georgian Bay Formation.

The soil was deposited during the Wisconsinan glacial period. It is a complex distribution of glacial till layers separated by interstadial deposits of sands, silt, and clays. These deposits were laid down by glaciers and associated glacial rivers and lakes. (Golder, March 2017)

The bedrock is an Ordovician-aged shale from the Georgian Bay Formation. It is generally classified as a weak rock with a low hydraulic conductivity and hard interbeds of limestone and siltstone.

The upper 3m to 5m layer is more fractured and weathered. Buried bedrock valleys exist and have been subsequently infilled since the last glaciation. (Golder, March 2017)

Regional groundwater flow in city aquifers is mainly to the southeast with an ultimate discharge to Lake Ontario. Local groundwater flow deflections occur in proximity to surface water or valley features, particularly in shallow hydrostratigraphic units (Golder, March 2017).

While the behaviour of the shale bedrock within deep shaft and tunnel excavations is well understood by local consultants and contractors, for the scale of the DR&CW Project it was prudent to both confirm past knowledge and search for site specific anomalies.

GEOTECHNICAL INVESTIGATION PROGRAM

The ongoing geotechnical investigation program is intended to define the top of bedrock elevation and obtain subsurface properties relevant to the design of the various components of the DR&CW Project.

As of mid-July five phases of field work are complete, one phase is under way, and various reports are being written/finalised.

Quality assurance and peer review

The design team engaged Dr. K. Y. Lo to act as a high-level QA/QC advisor. His scope of work includes continual review of ongoing geotechnical investigation results, guidance on preliminary tunnel designs and construction monitoring, assistance in developing the Geotechnical Baseline Report (GBR), and providing expert opinion on local in-situ stresses and rock swelling.

Prior to initiating the geotechnical program, the design team conducted a pre-consultation with five geotechnical companies. This was to assist the design team in determining the broad scope of work required for the DR&CW Project. The five companies were AMEC Foster Wheeler, Golder Associates Ltd., SPL Consultants Limited, Terraprobe Inc., and Thurber Engineering Ltd.

Through multiple competitive bids, three of these companies have been retained as sub-consultants to the design team to carry out the phases of geotechnical work.

Table 1: Routine field activities

Routine field activity	*Description / Quantity*
Full-time supervision of drilling	Visit site each day by APGO or PEO licensed professional
Soil drilling	Minimum depth; majority are top of rock
SPT sample	Space at 1.5m in soil for vertical boreholes
Thin-walled tube sample	Minimum of two where cohesive soil is found
Rock drilling - vertical and inclined	Minimum depth; majority are deep rock
Borehole imaging - ATV or OTV	Full length of rock for vertical boreholes; obtain discontinuity and lithology data
Groundwater sampling	Tests as specified in Table 4
Piezometer	Monitor groundwater for minimum of one year
Decommission borehole	Backfill full length with grout as per O.Reg. 903; clear and restore site
Survey	Determine ground surface elevations

Table 2: Specialized field activities

Specialized field activity	*Description / Quantity*
Rock - In situ stress test	50 tests along the IH/LD Tunnels; conduct at the tunnel horizon; test method as per ASTM-4623 (96)
Rock - Packer test	3.5m spacing for all vertical deep rock boreholes; determines hydraulic conductivity of rock
Soil - Slug test	One test per type of overburden soil; conduct at shafts; determines hydraulic conductivity of soil
Geophysical survey - Seismic refraction or electrical resistivity imaging	To help delineate areas of deep bedrock valleys along the LD Tunnel; conduct for total length of 8.5km above tunnel alignment and near boreholes

Table 3: Geotechnical laboratory tests

Geotechnical laboratory test	*Standard*
Soil - Atterberg limits	ASTM D4318
Soil - Consolidation	ASTM D2435
Soil - Density and dry unit weight	ASTM D7263
Soil - Grain size analysis	ASTM D422
Soil - Moisture content	ASTM D2216
Soil - Sieve and hydrometer analysis	ASTM D422
Soil - Unconfined compressive strength	ASTM D2166
Soil - Undrained triaxial compression	ASTM D4767
Rock - Bulk density	ISRM
Rock - Cerchar abrasivity	ASTM D7625
Rock - Direct shear	ASTM D5607
Rock - Elastic moduli uniaxial compression	ASTM D7012
Rock - Moisture content	ASTM D2216
Rock - Petrographic analysis	ISRM
Rock - Point load index (axial)	ASTM D5731
Rock - Point load index (diametral)	ASTM D5731
Rock - Punch penetration	ISRM
Rock - Slake durability	ASTM D4644
Rock - Splitting Brazilian tensile strength	ASTM D3967
Rock - Swell index	Non-Standard
Rock - Triaxial compressive strength	ASTM D7012
Rock - Unconfined compressive strength	ASTM D7012

Program methodologies

The program follows common industry standards for the various components included in the DR&CW Project, as described below. Note that for all boreholes (BHs), if bedrock is encountered then drilling is extended at least 3m into competent rock.

Boreholes for tunnels

The target BH spacing for proposed rock tunnels and soft ground tunnels is 300m and 100m, respectively. The minimum BH depth below the tunnel invert is twice the tunnel diameter. Whenever possible, the horizontal offset of the BH to the centerline of the tunnel is reduced but not to the point where the BH overlaps the tunnel horizon.

Boreholes for shafts

The minimum number of BHs for proposed shafts is two within the shaft footprint. This consists of one deep rock and one top of rock BH. The minimum BH depth below the shaft invert is one-and-a-half times the shaft diameter.

Boreholes for off-line storage tanks

The minimum number of BHs for proposed off-line storage tanks is two within the tank footprint (although the average is four), and one near the interception chamber. The target BH spacing for open-cut connecting sewers is 150m. The minimum BH depth below the lowest tank invert is 10m.

Boreholes for WWF connections

The minimum number of BHs for proposed WWF connections is one within the chamber footprint (although two are preferable). The target BH spacing for open-cut connecting sewers is 150m. For preliminary design, the target BH depth is to the top of rock. For detailed design, to account for the deep rock deaeration chambers and adits, the target BH depth is twice the tunnel diameter below the tunnel invert.

Field activities

The field program includes drilling more than 280 boreholes with a comprehensive sampling and testing schedule. In total, the program includes more than 6.2km of vertical soil drilling, 3.2km of vertical deep rock drilling, 1km of inclined deep rock drilling, and 215 monitoring wells.

In addition to routine soil/rock testing, the program includes specialised sampling and advanced tests to define the geotechnical parameters that are critical in the design of tunnels and shafts. The routine and specialised field activities are summarised in Tables 1 and 2.

Geotechnical laboratory testing

The laboratory program includes both routine and specialised geotechnical testing for both soil and rock. This is summarised in Table 3.

A comprehensive program of non-standard rock swell tests is under way. This aligns with the recommendations of Lo, who is an expert on rock swell testing and rock squeeze issues in the Georgian Bay Shale. The specific tests in the program include Null Swell, Semi-Confined Swell, and Free Swell in both the horizontal and vertical directions. The test elevations correspond to the tunnel obvert, springline, and invert. The test locations are targeted at tunnel extremities, shafts, and locations of in-situ stress measurements.

The rock swell tests will support the design team's evaluation of the costs and risks of different tunnel lining options (for example, one-pass versus two-pass). Upon completion of the geotechnical program, roughly 180 swell tests will have been conducted for the deep rock IHW and Coxwell Bypass Tunnels.

Geo-environmental laboratory testing

The laboratory program includes geo-environmental testing of soil, rock, and water for a variety of chemicals. This is summarised in Table 4.

Reporting

The following is a list of reports and studies that were either base scope or added after the engagement of various stakeholders.

- Geotechnical Data Report (GDR)
  - A factual account of data collected from each phase of the geotechnical investigation.
- 2D Subsurface model
  - Plan/profile drawings along the tunnel alignment showing the interpolated stratigraphy between boreholes, the interpreted water table, and the bedrock elevations.
- Preliminary Geotechnical Design Report (PGDR)
  - An interpretation of design parameters from the GDR for a particular construction stage. This report is primarily used by the design team.
- Hydrogeological report
  - Documentation of recorded groundwater levels and an estimation of dewatering rates in support of a Permit to Take Water application for construction.
- Geotechnical design report for construction activities at shaft sites
  - Commentary on the depth to competent subgrade material that would be suitable to support heavy tunnelling construction equipment, soil parameters required to design temporary structures, recommendations for off-site disposal of soil, and the necessity for ground improvement complete with potential alternative solutions.
- Phase I & II Environmental Site Assessment (ESA)
  - Assessments conducted at the five Stage 1 shaft sites to identify potential sources of contamination, limitations on soil disposal, and to help develop a soil management plan. The scope of the Phase II ESA reports includes sufficient detail to help support a future record of site condition.
- Excess soil management plan
  - A summary of procedures to be implemented for the management of excess materials during construction. Written by a qualified person, this report is informed by the most current best practice guidelines and MOECC regulations.
- Tunnel and shaft lining evaluation study
  - A study to characterise the rock mass, swelling behaviour, and rock-structure-time interaction at the tunnel horizon. This helped the design team choose the most appropriate lining systems.
- Environmental management plan
  - A detailed summary of environmental concerns with a plan for monitoring and adaptive management of impacts to the environment caused by the construction activities.
- Preliminary and detailed geotechnical design reports for rail crossings by the Coxwell Bypass Tunnel
  - A report to describe the subsurface conditions at the crossing locations with recommendations for settlement monitoring under the railway tracks.
- Letter on tunnel muck reuse
  - Preliminary geological, geotechnical, and geo-environmental commentary on the potential reuse of the tunnel muck (shale bedrock) for lakefill or general fill applications.
- Letter on Ground Improvement
  - An assessment of the feasibility of ground improvement at the mouth of the Don River where the IHW Tunnel crosses a buried bedrock valley.

Phases of geotechnical investigations

Geotechnical investigation work has been separated into six phases. The first three phases were intended to support preliminary design of the DR&CW Project. Preliminary design was completed in September 2015. These phases were issued sequentially and awarded to geotechnical sub-consultants through a competitive RFQ process. As of mid-July, the final three phases are supporting ongoing detailed design of the DR&CW Project.

To stay organised and prioritise the data collection, the scope of work for each geotechnical phase focuses on only a few construction stages. This is summarised in Table 5.

When scoping the work, the estimated duration to complete a phase was assumed as one to two months for mobilisation and permit acquisition, six to eight months for field work, and one to two months for draft submission of all deliverables. However, during execution, these durations fluctuated in response to the availability of drill rigs and challenges encountered through permit acquisition.

Table 4: Geo-environmental laboratory tests

Geo-environmental laboratory test	*Standard*
Soil - Ignitability of a sample	O.Reg. 558/00
Soil - Leachate preparation	O.Reg. 558/00
Soil - Metals and inorganic parameters	O.Reg. 153/04
Soil - Petroleum hydrocarbons	O.Reg. 153/04
Soil - Polycyclic aromatic hydrocarbons	O.Reg. 153/04
Soil - Sulphates	N/A
Soil - TCLP inorganics package	O.Reg. 558/00
Soil - TCLP volatile organics	O.Reg. 558/00
Soil - Volatile organic compounds	O.Reg. 153/04
Rock - Benzene, Ethylbenzene, Toluene, Xylenes (BTEX)	N/A
Rock - Metals (Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Zinc, and Mercury)	N/A
Rock - Sulphates	N/A
Rock - Organic carbon	N/A
Rock - Phosphorus	N/A
Rock - Polychlorinated biphenyls	N/A
Water - Limits for discharge into storm and sanitary sewer	City By-Law 457-2000
Water - Metals (arsenic, cadmium, chromium, copper, lead, nickel, zinc and mercury)	O.Reg. 153/04
Water - Sulphates	N/A
Water - Polycyclic aromatic hydrocarbons	O.Reg. 153/04
Pavement - Asbestos in asphalt	O.Reg. 278/05

Table 5: Phases of geotechnical investigations

Phase	*Sub-consultant*	*Focus of investigation*
1	Golder	Preliminary design Stage 1 - IHE/LD Rock Tunnels Stage 4 - IHW Rock Tunnel
2	AMEC	Preliminary design Stage 2 - TM Soft Ground Tunnel Stage 5 - WWFC for IH/LD
3	Terraprobe	Preliminary design Stage 3 - Off-line Storage Tanks Stage 5 - WWFC for TM
4	Golder	Detailed design Stage 4 - IHW Rock Tunnel
5	AMEC	Detailed design Stage 1 - IHE/LD Rock Tunnels Stage 5 - WWFC for IHE/LD
6	AMEC	Detailed design Stage 2 - TM Soft Ground Tunnel Stage 5 - WWFC for TM Final "clean-up" for all Stages

GEOTECHNICAL FOCUS

Depending on the scope of work for a particular phase, the approved budgets have been in the order of CAD 750,000 to CAD 2,800,000 (USD 614,600 to USD 2,294,000) not including HST. These budgets include allowances for traffic control, daylighting, cold-weather protection, and a 10 per cent contingency on the grand total.

Since some of the geotechnical investigations are ongoing, the exact final distribution of work within each phase, and the final number of phases, is variable. This is for maximum flexibility and is influenced by conditions encountered in the field, updates to the preliminary design concepts during detailed design, and the availability or performance of the retained sub-consultants.

MANAGING THE GEOTECHNICAL PROGRAM

The design team's management approach focuses on keeping the geotechnical program on track within the overall context of the DR&CW Project. The primary managerial goals have been to swiftly provide useful geotechnical data to the design team throughout preliminary/detailed design and to be mindful of scope changes to the DR&CW Project. This helps to minimise gaps in the geotechnical data.

Initiating the geotechnical program

The City's core deliverables for the geotechnical program include collecting sufficient data to support preliminary and detailed design of all five construction stages, and to develop a comprehensive GBR for Stage 1. However, the city recognises that since the design team is completing preliminary design of all five construction stages but only detailed design of Stage 1, 100 per cent of the necessary geotechnical data cannot be collected and some additional work may be required in the future. Nevertheless, the city aims to be as close to "shovel ready" as possible for the DR&CW Project.

Prior to awarding the DR&CW Project, the City had undertaken multiple project specific geotechnical investigations. This includes a GDR, PGDR, and microgravity survey in 2010 and 2011, all conducted by Golder as part of an EA, and a follow-up GDR and PGDR in 2014 by AMEC.

The city required that the design team directly retain qualified geotechnical companies as sub-consultants through a competitive process. The design team used a Request for Quotation (RFQ) for each phase. A minimum of three companies were to be solicited to submit RFQs. To pay for the geotechnical program, the city allocated provisional allowances to the DR&CW Project base scope of services, as summarised in Table 6. It was the design team's responsibility to effectively use these allowances for their intended purpose.

Table 6: Provisional allowances for geotechnical work

Provisional allowance	*Amount (USD)*
Preliminary design	CAD 3,500,000 (2,870,000)
Detailed design	CAD 8,000,000 (6,500,000)
Services during construction	CAD 1,000,000 (820,000)
Total	CAD 12,500,000 (10,190,000)

Scoping and executing the phases

A variety of historic background information is being used, including a 1961 bedrock contour map from the Ontario Department of Mines, the 2015 York-Peel-Durham-Toronto (YPDT) regional borehole database from the Conservation Authority Moraine Coalition, and 2D profiles from the 2010 Golder EA.

A free version of Google Earth helps conceptualise and communicate potential drilling sites. The program is useful for storing Geographic Information System data in Keyhole Markup language Zipped (KMZ) files, which can then be imported into AutoCAD or Microstation base mapping files.

Phases of work are assembled into RFQs that are reviewed by the city prior to issuing them to geotechnical companies for competitive bids. Estimated quantities of work, such as total drilling depths, are rounded up in anticipation of variations in subsurface conditions. Phases are activated through City-issued change orders which are drawn from the provisional allowances noted in Table 6. On average, a new phase has been activated every three to four months.

At the beginning of the DR&CW Project, a dedicated Project Controller (PC) from the design team was appointed to manage the retained geotechnical sub-consultants and to satisfy the city's core deliverables. Additional PC responsibilities are discussed below.

Controlling and monitoring the phases

Ongoing controlling and monitoring of the geotechnical phases helps to promptly identify potential issues so that corrective actions can be taken. In this effort, it is important to maintain strong communication between the design team, the city, and the geotechnical sub-consultants.

At the inception of each phase, the PC develops a full monthly invoice forecast in conjunction with the estimated work plan schedule. This facilitates the tracking of actual progress versus invoiced amounts. The target frequency of formal progress meetings, either in person or over teleconference, has been every two weeks. Discussion topics include scope, schedule, and budget verification. These meetings are interspersed with correspondence between the PC and stakeholders. Online live-tracking spreadsheets are used to efficiently document the progress of permit acquisition, utility locates, and ongoing field work.

Closing the phases

The geotechnical phases will be closed when all deliverables are completed, such as the issuance of a final version of a GDR/PGDR or other scoped reports. Since all phases include year-long monitoring of piezometers, addenda will eventually be attached to final reports summarising this extended recorded data.

Table 7: Measured rock parameters

Parameter	*Value*
Uniaxial compressive strength - Intact rock	18.7 MPa (mean) 5.3 MPa (standard dev.)
E-modulus - Intact rock	3700 MPa
Poisson's ratio	0.26
Bulk modulus - Intact rock	1700 MPa
Shear modulus - Intact rock	1300 MPa
Density - Shale bedrock	2.62 g/cm^3
Disturbance factor	0.0 (intact rock) 0.1 (damaged rock)
Unit weight - Overburden	21.0 kN/m^3
Tunnel field stress - Sigma 1 major horizontal stress	6.5 MPa
Tunnel field stress - Sigma 2 minor horizontal stress	1.5 MPa
Tunnel field stress - Sigma 3 vertical stress	1.3 MPa

Some geotechnical phases have remained active for many months beyond completion of major base scope deliverables. In all instances, remaining funds in the contingency and cash allowances have been used to complete necessary additional field work, laboratory testing, and reporting. The city prefers to use these remaining funds rather than issue additional RFQs to sub-consultants, as the administrative effort of issuing a new change order may delay the geotechnical program.

The city wishes to tender the Coxwell Bypass Tunnel construction Stage 1 this fall. Prior to tender, a variety of reports from all phases will be finalised and sealed by a professional engineer. This is a requirement for issuing a GBR and tendering detailed design drawings.

GEOTECHNICAL RISKS

Risk management of design and construction is one of the most important underlying aspects of the geotechnical program. For the DR&CW Project, a detailed risk register was created to track the following: hazards and their causes, potential consequences and their severity, the likelihood of occurrence, control measures, residual consequences, and mitigation measures. This is for the benefit of the design team, the City, and future contractors bidding on the work. Some specific risks, as discussed below, relate to the execution of the geotechnical program, the preliminary/detailed design development, and the construction contracts.

Protection of buried utilities and infrastructure

Protecting buried utilities and infrastructure from the effects of geotechnical field activities is a paramount concern of all stakeholders. Geotechnical sub-consultants are solely responsible for locating and identifying all buried utilities and services at proposed borehole and sampling locations. They are tasked with modifying borehole locations as necessary to minimise impacts on traffic and private property and to maintain adequate clearance from existing infrastructure. In some cases, after review of available information from city staff, shallow daylighting of utilities has been undertaken to satisfy clearance requirements.

A suggested procedure for locating Toronto Water assets is as follows:

1) Request locates from Ontario One Call (ON1Call).
2) Review drawings provided by the design team and City staff.
3) Review the comprehensive Digital Map Owners Group (DMOG) underground utility database.
4) Review the Toronto Water Asset Geodatabase (TWAG).
5) Compare the locates from ON1Call against the DMOG, TWAG, and drawings.
6) Consult Toronto Water if there is uncertainty in the locates.
7) If uncertainty persists, arrange for specialty locates (daylighting, sewer entry, etc.).
8) Perform a final walk-over of the site prior to drilling.

Buried bedrock valleys

Known buried bedrock valleys exist across the DR&CW Project. For example, between shafts LDS-3(B) and BB-1, a north–south valley runs somewhat parallel to Bayview Avenue while weaving back and forth across the road. Part of the proposed LD Tunnel alignment follows Bayview, so the LD and IHW Tunnels risk encountering this buried bedrock valley. To address this risk, borehole spacing has been tightened near all interpreted buried bedrock valleys to delineate the top of rock elevation close to the tunnel alignment. Refer to Figure 2 for the general location of this north–south running buried bedrock valley.

As a case study for buried valley mitigation, the preliminary design of the IHW Tunnel includes the crossing of a known 175m long buried bedrock valley north of the Keating Channel. This valley was previously encountered during the 1929 construction of the Cross Town Treated Water Tunnel. To mitigate construction risk, the design team has proposed the following options, which may be used separately or in combination:

1) Deepen the IHW Tunnel vertical alignment to increase the rock cover under the valley.
2) Use a convertible TBM (both rock and earth pressure balance) through the buried valley.
3) Conduct ground improvement in the valley with the preferred method of jet grouting.

From a cost, schedule, and risk mitigation perspective, the ground improvement option was determined to be preferred. Dewatering the buried valley to allow an open-face TBM to cross without risk of ground loss was not investigated, as the tunnel alignment is too deep for this option to be feasible. Furthermore, the dewatering option would also require significant water taking, to which conservation authorities are generally opposed.

Regardless of the risk mitigation option chosen during future detailed design of the IHW Tunnel, the geotechnical program includes a tight grid of 14 top of rock boreholes spaced at 50m within the interpreted buried bedrock valley. Data from these boreholes will be used to develop a detailed, three-dimensional subsurface model. Soil samples collected from the boreholes will be subjected to the standard suite of tests summarised in Tables 3 and 4.

Rock support and tunnel lining

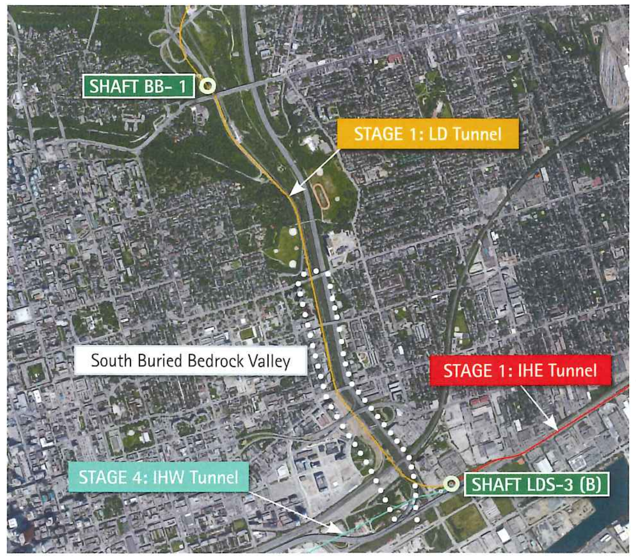
The type of temporary rock support required to stabilise the tunnel during construction and the type of final tunnel liner will depend on many different constructability and design considerations. One option, the two-pass method, is to install rock bolts and wire mesh at the tunnel crown immediately behind the TBM shield, followed by a cast-in-place concrete liner. Another option, the one-pass method, is to install a pre-cast concrete tunnel lining (PCTL) immediately behind the TBM shield and place a compressible material, such as cellular grout, between the outside of the PCTL and the rock interface.

Whichever rock support system is chosen for the Coxwell Bypass Tunnel, the geotechnical program will estimate the time-dependant deformation due to swelling, in-situ stresses, static rock load, rock displacement, and influence of the cellular grout. This gives the designers and contractors flexibility to consider alternate construction methods to mitigate risk and minimise cost.

The measured rock parameters calculated in the geotechnical programs, as summarised in Table 7 (Golder, March 2017 and July 2017), are reasonably consistent with local historic data. To date, no significant anomalies have been encountered. This suggests that typical local solutions for rock support and tunnel linings are viable for the rock tunnels in the DR&CW Project.

Geotechnical Baseline Report

As per the City's core deliverables, a comprehensive GBR is being developed for Stage 1. The GBR will be informed by industry standards for projects in the Greater Toronto Area and suggested guidelines from the American Society of Civil Engineers 2007 publication "Geotechnical Baseline Reports for Construction" by Randall Essex.



Right: ***Figure 2, Plan of buried bedrock valley along Bayview***

The GBR will establish a contractual understanding of the subsurface conditions. Its purpose is to set clear and realistic baseline statements for conditions anticipated to be encountered during subsurface construction. It will summarise ranges of possibilities instead of strictly high/low ends, as the design team cannot know the contractor's specific means and methods of construction. The GBR will refer to available factual information (the GDRs) from the geotechnical program. In the absence of factual data, baseline conditions may be based on previous tunnelling experience and engineering judgement. Any anomalies in the data will be addressed with clearly explained reasoning for necessary estimates and assumptions.

The GBR will provide all bidders with a single contractual interpretation on which to base their bids and to select/implement means and methods of construction. It will also assist in the administration of differing site conditions and provide guidance for monitoring performance during construction. Ultimately, the GBR will help appropriately allocate risk to the owner and the contractor.

CLOSING

As of mid-July, field work for Phases 1 to 5 of the geotechnical program are complete, and Phase 6 is under way. Of the approved preliminary and detailed design geotechnical budgets, roughly 80 per cent and 70 per cent respectively, have been spent. By effectively developing, implementing, managing, and using data from this geotechnical program, the design team will help bring the project to life.

As *Tunnels & Tunnelling* went to press, the City of Toronto has completed prequalification for the Coxwell Tunnel, and the project will be issued for tender in the fall with construction to start in Summer 2018.

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Essex, R. J. 2007. Geotechnical Baseline Reports for Construction, Suggested Guidelines, ASCE.

Golder Associates Ltd. March 2017. Coxwell Bypass Tunnel - Preliminary Geotechnical Design Report - DRAFT.

Golder Associates Ltd. July 2017. Tunnel & Shaft Lining Evaluation Study - DRAFT ver. 3.

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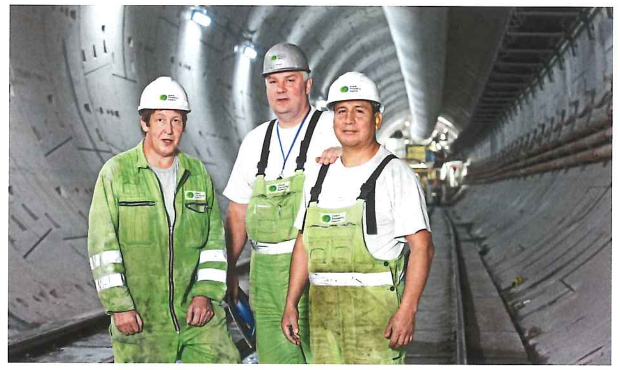

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What's on

2017

Aftes 2017
13-15 November 2017
Paris, France
The congress will highlight the latent value of underground space as a means of developing our living spaces, especially if urban planning harnesses it to establish a symbiosis between ground-level and underground.
www.aftes2017.com

TBM Digs
16-18 November 2017
Wuhan, China
Following the success of the first two TBM Digs events, the conference returns for the third time. This year it heads to the city of Wuhan in China's Hubei Province.
www.tbmdigs.org

British Tunnelling Society Underground Health and Safety Course
27-28 November 2017
London, UK
The British Tunnelling Society runs a two-day annual Underground Health and Safety Course. The course has been developed to focus exclusively on the underground environment. It aims to provide an introduction or enhance existing basic knowledge and develop an awareness of the particular health and safety challenges that working underground can pose. It is held at the Institution of Civil Engineers in London, booking is open.
www.britishtunnelling.org.uk

12th Iranian Tunnelling Conference: Tunnelling and Climate Change
27-29 November 2017
Tehran, Iran
The drop in total precipitation around the world, especially in the Middle East and Iran has resulted in rapid decline of water resources available to societies. The construction of water conveyance tunnels by transferring water form water-rich regions to arid regions can have a significant role in reducing consequences of this growing phenomenon. This event will focus on mitigating the effects of climate change.
www.itc2017.ir

Stuva Expo 2017
6-7 December 2017
Stuttgart, Germany
The premier tunnelling event in Germany returns to Stuttgart in December. The 2015 event's trade fair accompanying the Stuva conference exceeded all expectations. With 1,850 conference delegates and more than 550 trade visitors, around 2,400 visited in 2015 and the 2017 event is expected to build on this.
www.stuva-expo.com/en/

2018

IFCEE 2018
6-10 March 2018
Orlando, Florida
The world's leading foundations congress and equipment expo will be a broad-based geotechnical/ geoprofessional event with a focus on case histories, providing value to practitioners as well as to academia.
www.geoinstitute.org/event/2018-geo-congress/

2nd Annual International Tunnelling and Underground Space Conference
20-22 March 2018
Abuja FCT, Nigeria
The conference of the Tunnelling Association of Nigeria is themed as 'exploring the socioeconomic benefits of developing tunnelling and underground space infrastructure in Nigeria'. It is endorsed by both the International Tunnelling Association and the ITA Committee for Education and Training. The event will also see the launch of Think Depp Naija, an organisation that hopes to influence the thinking around infrastructure in the longer term.
www.tunnellingnigeria.org

NASTT No Dig 2018
25-29 March 2018
Palm Springs, USA
Since its launch in 2001, this show has nearly doubled in size, keeping pace with the rapid growth of our industry. Cutting-edge technologies are continually being developed and introduced, come see them on display at the largest trenchless technology show in North America.
www.nastt.org

World Tunnel Congress 2018
20-26 April 2018
Dubai, UAE
The World Tunnel Congress heads to the United Arab Emirastes in 2018, and demonstrates the rise of the Middle East to the centre stage of the global tunnelling market. The organisers invite you to experience true Arabian hospitality and enjoy Dubai, which claims to be the world's most cosmopolitan city.
www.uaesocietyofengineers.com

North American Tunnelling Conference
24-27 June 2018
Washington D.C., USA
The NAT is the premier biannual tunneling event for North America, bringing together the brightest minds in the tunneling industry.
www.natconference.com

11th International Conference on Geosynthetics
16-21 September 2018
Seoul, South Korea
The technical program will include a Giroud lecture, 5-6 plenary lectures (special lectures), 2-3 short courses and approximately 50 parallel sessions. It is expected to attract more than 1,000 experts from over 100 countries.
www.11icg-seoul.org

PIARC International Conference on Road Tunnel Operations and Safety
3-5 October 2018
Lyon, France
This World Road Association endorsed event comes amidst increasing interest in the emergence of new types of vehicles in the driving environment, and how tunnels will keep pace with continuing technological advances.
www.piarc.org

10th Asian Rock Mechanics Symposium
29 October-3 November 2018
Singapore
Asia is witnessing the greatest growth and demand in the world for infrastructure and resource development. According to Asian Development Bank, approximately US$8 trillion needs to be invested in overall national infrastructure before 2020, 68% of which is for new capacity. Certainly, rock mechanics and rock engineering will have a critical role to play in many of these infrastructure and resource development projects. The theme for ARMS 10 is "Rock Mechanics in Infrastructure and Resource Development".
www.arms10.org

2019

Bauma
8-14 April 2019
Munich, Germany
The largest construction trade show in the world returns to its traditional venue in Munich. Last held in 2016, a lot can be learned about the health of the construction industry from the mood at this enormous event.
www.bauma.de

World Tunnel Congress 2019
3-9 May 2019
Naples, Italy
The one tunneling event that is unrivaled in its international reach. The World Tunnel Congress is coming to Italy and tunnellers representing owners, contractors, engineers and suppliers will be exhibiting. The event is expected to attact as many as 600 technical papers, 250 exhibitors and up to 3,000 attendees.
www.facebook.com/events/1753343481565751/

ECSMGE 2019
3-9 May 2019
Reykjavik, Iceland
The Icelandic Geotechnical Society are pleased to welcome you to the XVII European Conference on Soil Mechanics and Geotechnical Engineering, held in the Icelandic capital. The theme of the conference is "Geotechnical Engineering, foundation of the future" and will embrace all aspects of geotechnics.
www.ecsmge-2019.com

World Road Congress
6-10 October 2019
Abu Dhabi, UAE
The World Road Congress will cover a number of areas, including Road policies, Environment, Economics, financing, Governance of authorities, Planning, Risk management and many more.
www.piarcabudhabi2019.org

British Tunnelling Society evening meetings

The BTS has a membership of over 814 individual and 266 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. Regular BTS monthly meetings are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month. In recent years, the BTS Young Members (BTSYM) group has also begun hosting its own events.

Finsbury Park Squareworks
16 November 2017
A presentation on the Finsbury Park Station step-free access scheme for London Underground. This will include information on squareworks tunnelling, shaft sinking and undertrack crossings, all carried out from within a live London Underground station.
Speakers: Farid Achha, London Underground; John Elliott, Alan Auld Engineering; Menelaos Lydakis, C Spencer Group

Waterview Tunnel, New Zealand
14 December 2017
A Memorial Lecture in commemoration of the late Chris Parker (formerly Balfour Beatty International director and general manager, with responsibilities for both UK and International tunneling projects), and will include a brief tribute to Chris, by Mike McConnell. The Lecture will be given by Tom Parker (Chris's son) and colleagues, on the Waterview Connection in Auckland, which is the largest and most complex Road Project ever undertaken in NZ. The project includes twin tunnels, each three lanes wide, with an outside diameter of 14.41m, excavated under residential development, the Great North Road, and Auckland's western rail corridor.Tom will also provide a flavour of some of New Zealand's future major infrastructure projects.
Speakers: Tom Parker (Project Director) and Iain Simmons (Tunnelling Manager)

Tunnel Design Life of 120 years - Definition, Assessment and Improvement
18 January 2018
The first meeting of 2018 will focus on design life requirements of tunnels and how these are assessed by designers; and improvements and cost savings that can be made on projects when the concrete mixes are tested early on in the design stage.
Speakers: Charles Allen, Phil Bamforth, Jon Knights

Joint BTS/Minsouth Meeting: The North Yorkshire Polyhalite Project
8 February 2018
Details to be confirmed, but the project to be presented is the York Potash scheme. The client, Sirius Minerals intends to develop the world's largest known high grade polyhalite deposit. Construction includes a new mine to extract the ore, a 37km tunnel hosting an underground mineral transportation system (MTS), a granulation facility in Teesside, and an export quay on the River Tees. The highlight is the 37km MTS through the Redcar Mudstone, with planning consent given for a bore up to 6m. The tunnel will be excavated by a number of hard rock tunnel boring machines.
Attendees are reminded that this meeting takes place on the second Thursday of the month.
Speakers: Simon Carter, Sirius Minerals

If you have a topic or project you feel would be suitable for a BTS evening presentation, please contact:

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