SEPTEMBER 2008

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ROBBINS TBM ASSEMBLY AT LOS OLMOS

A 5.3 m Robbins TBM is standing up to the pressure in Los Olmos, Peru. The Main Beam machine is boring a 13.9 km (8.6 mi) long tunnel through the Andes Mountains, beneath up to 2,000 m (6,500 ft) of hard, potentially squeezing rock.

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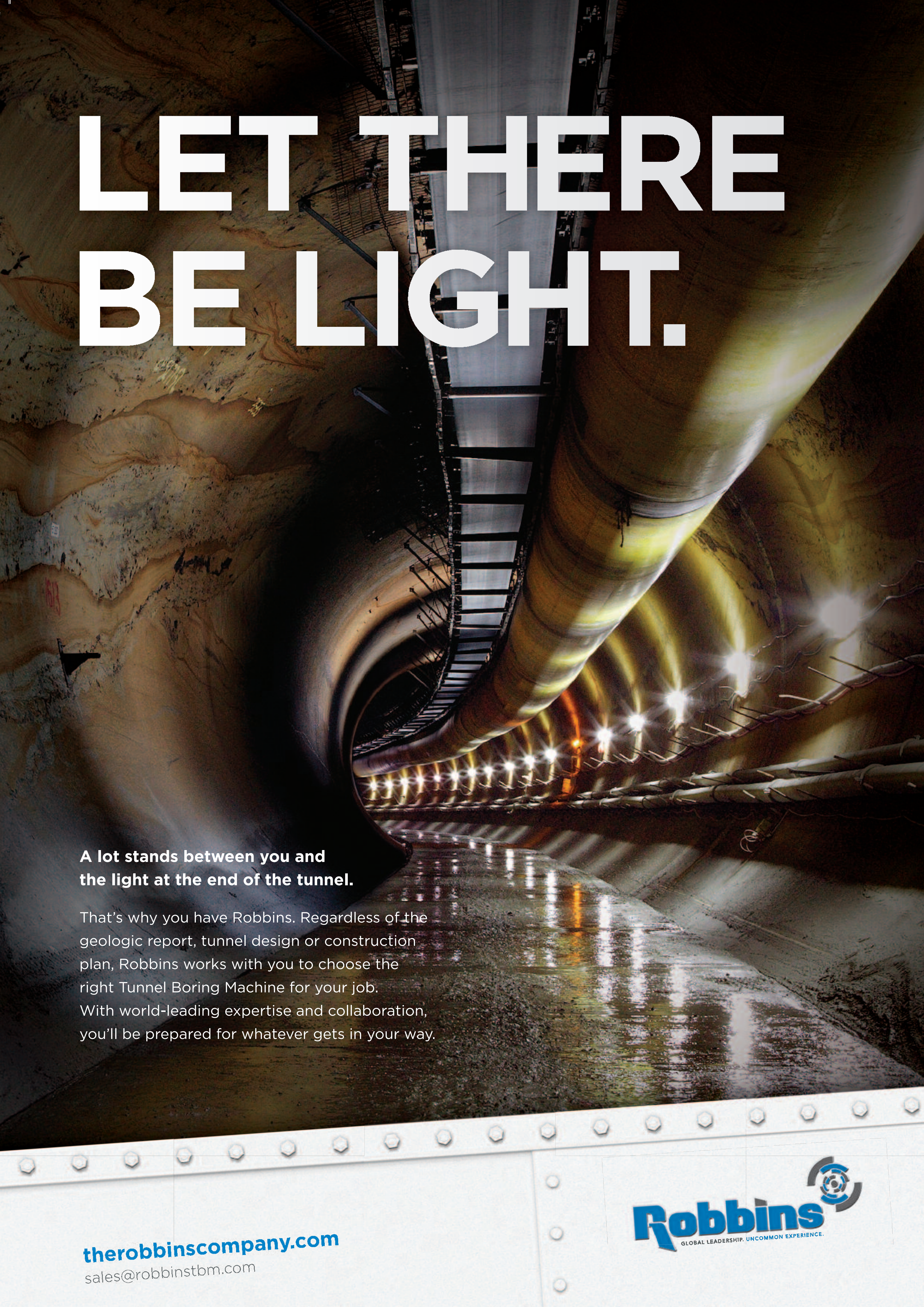
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SEPTEMBER 2008

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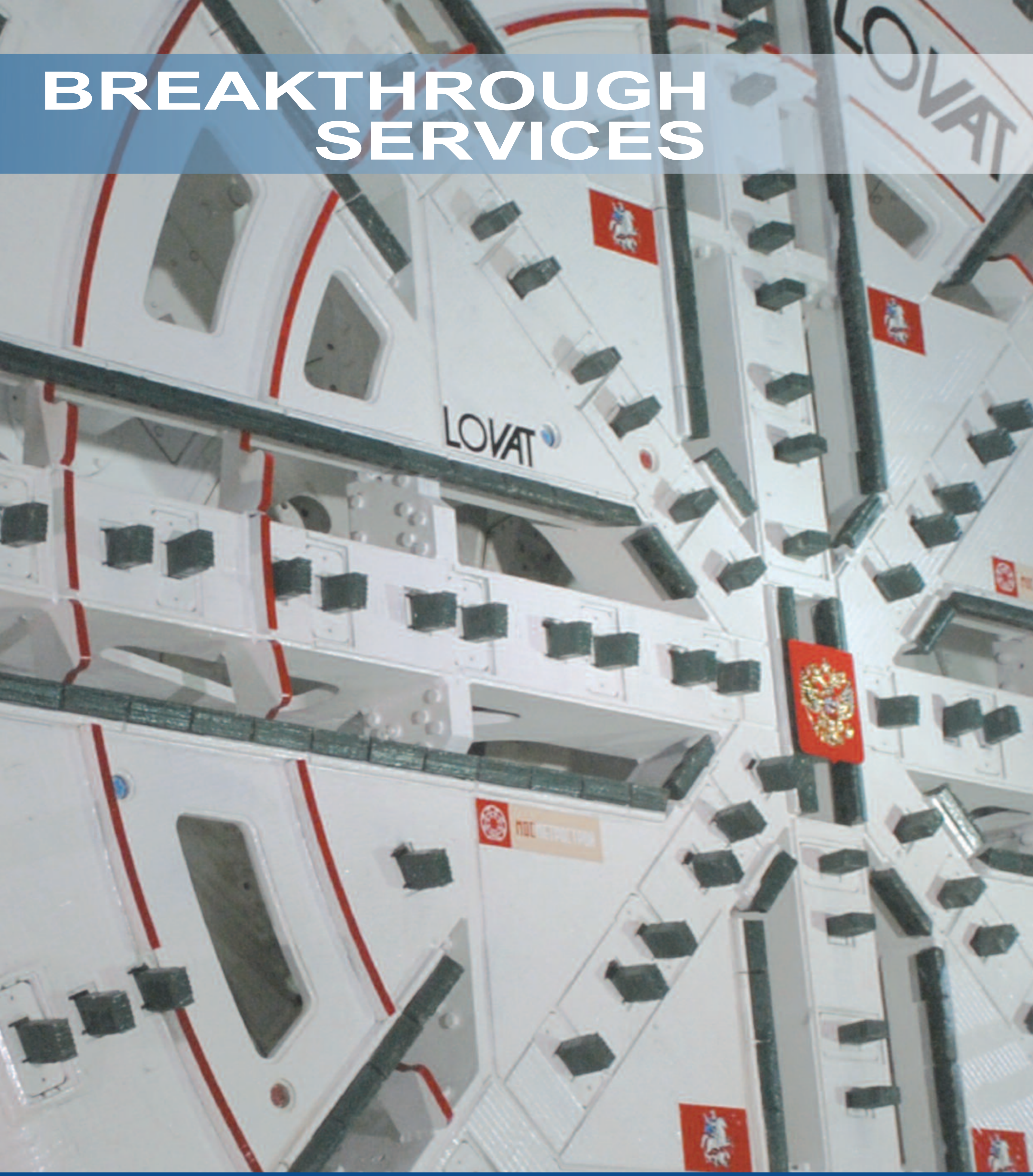
FOCUS ON AUSTRALASIA

A round up of the booming tunnelling scene in Australasia

GROUND STABILISATION

T&TI takes a look ground freezing and pre-excavation grouting

BREAKTHROUGH SERVICES



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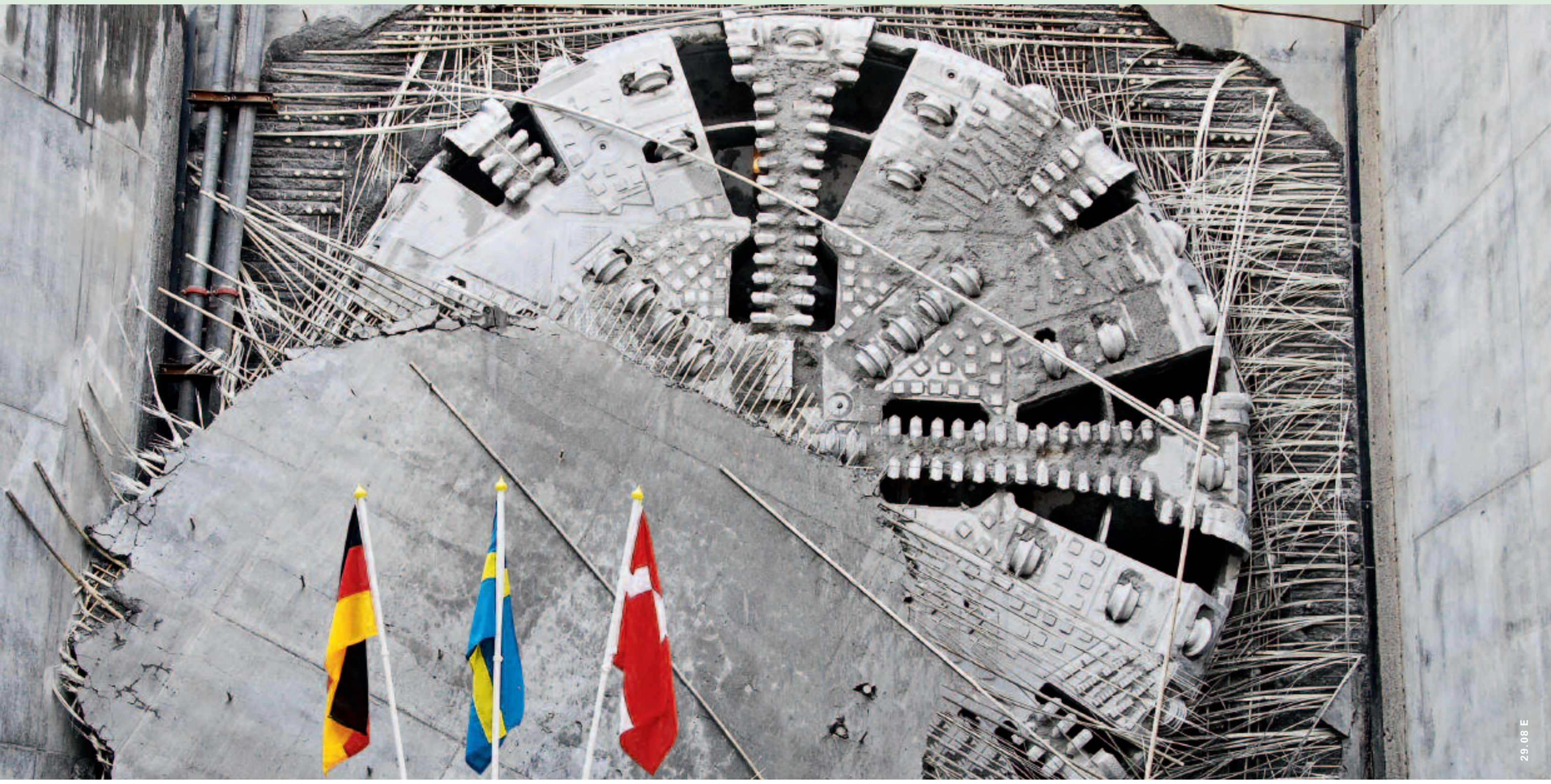
Sleeve pipe installation as part of a ground stabilisation scheme in the US



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MALMÖ: DIRECT CONNECTION TO THE ØRESUND.

The tunneling work at the City Tunnel in Malmö has been successfully completed. Two Herrenknecht EPB Shields achieved the breakthrough in March and April 2008 respectively. This means that the two tunnels can presumably be opened for rail traffic according to schedule in 2011. Together with a new aboveground stretch, they serve as link between the Main Station and the Øresund Bridge. This will reduce the journey time between Malmö and the Øresund considerably.

The EPB Shields called “Anna” and “Katrin” started in November 2006 and January 2007 respectively. The machines (∅ 8.89m) needed for the 4.3 and 4.6-kilometer-long stretches less than one and a half years, thanks to tunnelling performances of up to 239 meters per week. In addition to the project-specific adapted machine technology, the well organized logistics for the construction site contributed to the success. The Herrenknecht subsidiaries Herrenknecht Formwork and H+E Logistik participated in the project with the delivery of segment moulds and conveyor belt installations. An integrated Full Service Tunnelling system which leads to success quickly and safely. Also thanks to the uncomplicated communication with competent customers and project partners.

MALMÖ | SWEDEN

PROJECT DATA	CONTRACTOR
S-340, S-341, **2x EPB Shields** Diameter: 8,890mm Driving power: 2,400kW Tunnel lengths: 1x 4,289m, 1x 4,593m Geology: limestone	MCG Malmö Citytunnel Group: Bilfinger Berger AG, Per Aarsleff A/S, E. Pihl & Søn A.S.

Foto: Perry Nordeng

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We're all gonna die...

Eventually. But according to recent press reports, the world should already be a distant memory, swallowed up in a black hole created by a bunch of crazed scientists, bent on discovering the meaning of life at any cost, deep underground somewhere in Europe.

The event that generated this unbelievable frenzy of misguided nonsense was the turning on of the Large Hadron Collider at CERN in Switzerland. In the UK, column inches for such 'flicking of switches' are usually reserved for the likes of the Spice Girls turning on the Christmas Lights in London's Oxford Street. Not this time, finally an act of engineering got the spotlight, and was the coverage positive?

Unfortunately, it wasn't. Why? Because the perception was it was all about scary science that nobody really understands except nerds in lab-coats who can solve a Rubik's cube in the blink of an eye.

It's still amazing that such revolutionary acts of science can create such levels of wide-scale fear, generated almost entirely by sensationalist journalism which is often founded on a lack of knowledge. Complete naivety seems to be deeply routed in much of the world's population as to exactly what science does and the role it plays in bettering society.

One of the great ironies of the recent furore was to be found on the BBC website, which was inundated with users questioning scientist's ethics for tampering with the earth's natural balance (probably posted by people who think recycling means going twice as far on a bicycle).

It may have been opportune to point out to these web addicts that CERN is credited as the birthplace of the Internet. No science, no CERN, no Internet. Hopefully you get the picture.

You may ask what this has to do with tunnelling? Well, not much to be honest, apart from the fact that CERN has some magnificent underground engineering, including some of the largest weak-rock caverns in the world. But it has, once again, made me jump on my soapbox about the way the public perceives science and engineering.

In 1934, the UK's Queensway Tunnel, in Birkenhead, was opened by none other than King George V, in front of hundreds of thousands of people who turned up to witness the event.

We need to look at what has happened since then, and why engineers have somehow lost their crown. At least then we can attempt to climb back to the lofty heights of yesteryears.

Tris Thomas

COMPANIES IN THIS ISSUE

Fehmarn keeps alive immersed tunnel option

The tunnel option for the Fehmarn Belt crossing between Denmark and Germany may have been shunted into second place by the cheaper bridge concept but is to remain in the running until about 2011 as the developer - which has just prequalified consultants to bid for the design - awaits data from further survey work.

Tenders for the 18, 565m long road and rail tunnel option across the 19km long strait between the north European countries are due in December this year from three consortia:

- A JV of Cowi and Obermeyer Planen + Beraten with subconsultants Flint & Neill Partnership and Dissing + Weitling;
- A partnership of Grontmij/Carl Bro, Faber Maunsell, Bung, Grontmij/BGS and Capita Symonds; and,
- A JV of Ramboll Danmark, Ove Arup & Partners International and Tunnel Engineering Consultant with subconsultants WTM Engineers, HTG Ingenieurburo fur Bauwesen, Wilkinson Eyre Architects and Schonherr Landskab.

In early September, Denmark and Germany signed a Treaty to build the crossing.

The project developer – Femern Baelt A/S, which is publicly owned and under the authority of the Danish Ministry of Transport – plans for construction to start in 2012 and is aiming for the link to be opened in 2018. It is keeping the tunnel alternative alive as environmental pros and cons of the rival options are analysed over the next few years as the final, detailed geotechnical and environmental studies, launched in the middle of this year, and undertaken.

Fehmarn tunnel would be a road and rail crossing that has two cells for each service in the reinforced concrete immersed tube – two 10m wide road cell (each with two lands for traffic) and two 6.37m wide rail cells (each with single tracks). Near the mid-point of the strait the concept design proposes that a ventilation island be constructed. Ramps from the tunnel would be 805m and 1,085m long, respectively.

The latest survey will be done in a 2km-wide corridor between Rodby, Denmark, and Puttgarden, Germany, in water up to almost 30m deep. The work is being done under a US$56.5M contract by a JV of Ramboll Danmark and Ove Arup. An expert group of consultants has been assembled to review the data obtained from the survey, and they are: Bern Schuppener of Germany's Federal Institute for Waterway Engineering and Research; and, Ole Hededal and Niels Foged of Technical University Denmark.

The possibilities for a fixed crossing at Fehmarn Belt has been discussed for a number of decades, including when the planning was underway in the 1980s for Denmark's first major fixed link project, which joined the island to mainland.

Preliminary design and assessment work for the Fehmarn crossing was done by a JV of Cowi and Lahmeyer in 1999. More recent work, including managing the prequalification of consultants, has been under the control of Sund & Baelt A/S – which owns and operates both the Storebaelt and Øresund crossings, and of which Femern Baelt A/S is a subsidiary.

Drawing on construction experience since the preliminary work - including construction of an immersed tube tunnel for part of the Øresund link - the budget for the tunnel option was given as Euro5.5bn (US$7.35bn at 2007 rates) against Euro4.3bn (US$5.74bn) for the cable-stayed bridge. Both estimates are before detailed environmental costings. Funding for current work has come from the Danish Government with EU subsidises.

The Rafah run

Crossborder smuggling using tunnels continues in the Middle East with, here, Palestinians in the Rafah camp, in the south of Gaza Strip, receiving goods underground from Egypt

K HAMRA/AP/PA PHOTOS

Azerbaijan TBM first

A total of 5,740m of water transfer tunnels are to be excavated by TBM for irrigation and hydropower projects in Azerbaijan in the country's first use of the shields.

Robbins is to supply a 6.3m diameter mixed face EPBM, backup, tools, segment moulds and plant, rolling stock, ventilation, spares and operators to contractor Azerkorpu for the project in central Asia.

The TBM's shield will be manufactured in China due to proximity to Azerbaijan, where the entire machine will also be assembled and undergo tests in the factory, which are scheduled for March 2009.

The main parts of the EPBM – bearing, motors, gear boxes, cylinders, electric and hydraulic system will be made elsewhere – US, EU and Japan – and shipped to China.

Three tunnels are to be bored by the TBM with lengths of 3,000m, 1,380m and 1,360m, respectively. Launch is scheduled for May next year and excavation is expected to be completed in eight to nine months, said Robbins.

Geology comprises hard clay and silty sand, and there is no groundwater. The cutterhead will be fitted with discs and rippers. The tunnels are to be lined with 1.5m long, universal segmental rings (5+1) of 5.4m i.d. and 300mm thickness.

The contract for the TBM and accessories was awarded by Azerkorpu in March, and the contractor plans to use the EPBM on several other projects in the country.

Both tunnel and open canal construction is required for the Samur-Apsheron Irrigation Project, which is being developed by the government. The conduits will convey water from Samur river for irrigation purposes and also to help supply the new Takhtakerpu hydropower plant, which is scheduled to be operational in 2010.

Crossrail shortlists

The shortlists for the management and design support contracts on Crossrail have seen four firms invited to bid for programme partner, five for project delivery partner and 15 to tender for design framework agreements.

Construction of Crossrail in London will involve excavation of a total of 41.5km of 6m i.d. twin tube tunnel using seven TBMs, starting in 2011. Enabling works start next year. Trains are to run from 2017-18.

Cross London Rail Links (CLRL), the developer of the project, invited four parties to tender for the programme partner contract – Bechtel, Mouchel and two JVs: Parsons Brinckerhoff with Balfour Beatty Management (called Legacy 3); and, Aecom, CH2M Hill United Kingdom Unlimited and Nichols Group (called Transcend).

Five parties were shortlisted to bid for the project delivery partner contract. They are Bechtel, Laing O'Rourke Holdings and three JVs: Legacy 3; Capita Symonds with NNN; and, Fluor, Ove Arup and EC Harris (called Flare).

The 15 parties invited to tender for the design framework contracts are a single JV of Faber Maunsell with Gifford, and 14 companies: Aedas; Atkins; BDP; Capita Symonds; Halcrow; Hyder Consulting; Jacobs Engineering; Mott MacDonald; Mouchel; Ove Arup & Partners International; Parsons Brinckerhoff; Scott Brownrigg; Scott Wilson Railways; and, WSP.

Steve Rowsell, head of procurement, described the Crossrail team as having been "enormously impressed" by the quality and experience of the interested parties.

CLRL issued the invitations to bid last month, as planned. The US$28.1bn scheme to build a new main line rail link running East-West through the centre of London, and tying into existing networks, received legislative approval in July.

The shortlisting was described by Doug Oakervee, executive chairman of CLRL, as "another significant milestone" in the development of the project.

He added that as the construction project was Europe's largest "the appointment of our partners is critical to the success" of the scheme.

Separately, CLRL is to use Optimised Contractor Involvement (OCI) on Crossrail (*T&TI*, August, p11).

Finnetunnel 2nd launch prepared

The second Mixshield TBM on the Finnetunnel in Germany was being prepared last month for launch as its sister convertible shield made steady headway with a four month lead on the twin tube rail project.

A Wayss & Freytag-led JV is building the tunnels using a pair of 10.82m diameter Herrenknecht TBMs, and the second machine (S-420) is set to be launched shortly ahead of schedule. Originally, the programme anticipated the launch around December.

The first TBM (S-419) was launched ahead of schedule, in late April – ahead of the planned July start (*T&TI*, May, p7). By the end of last month the shield had excavated more than 600m, erecting 9.6m i.d. rings (6+1) that are 2m long.

Early geology, driving from the west portal, comprises weathered sandstone with clay/silt in the Finne fault zone, which in addition to high inflows prevents groundwater lowering by closed system dewatering.

The first TBM has advanced in slurry mode, which will be used for the initial approximately 1,500m long stretch of the tube.

However, slurry mode operation would be uneconomical to continue with due to high groundwater head (up to 6 Bar) in new red sandstone. The JV is, therefore, using the sandstone conditions to drawdown the groundwater using 80m deep boreholes. Along these approximately 3,100m long sections the TBMs will be operated in open mode.

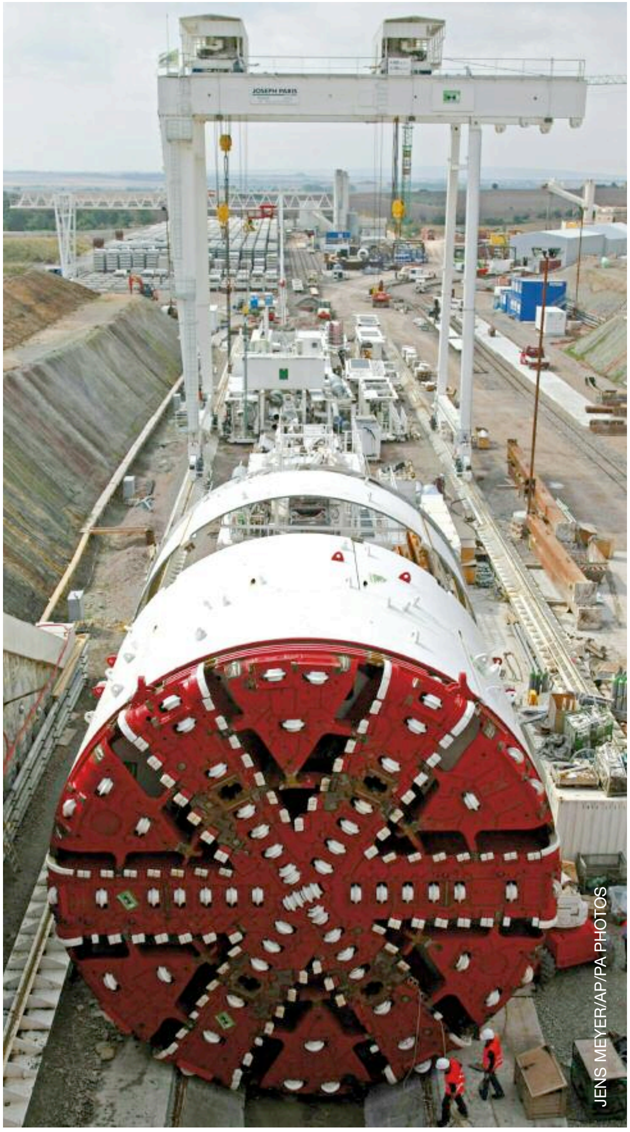
When the first TBM switches mode the slurry package is to be installed into the following shield.

The remainder of the Finnetunnel tubes are to be excavated by NATM mostly through dewatered red sandstone. Beyond this 1,350m long stretch, the NATM method will also be employed in a 850m long dry section. The tubes will be supported by a primary shotcrete lining and secondary (insitu) linings.

The JV – which includes Max Bogl and two units of Porr – was awarded the US$328M contract to build Finnetunnel by DB Netz at the end of 2006.

Finnetunnel is part of the 10.5km long Erfurt to Leipzig/Halle rail line. The 6.8km long twin tubes will have cross passages with airlocks built every 1000m, and the project is to be finished in 2011.

Right: Preparations for the launch to the 2nd Herrenknecht TBM to the Finnetunnel twin tubes, Germany


JENS MEYER/AP/PA PHOTOS

Ring works in Prague

Czech contractor Metrostav is driving twin tunnels in Prague for part of the inner ring road

Metrostav is using two Rocket Boomer L2 C rigs from Atlas Copco to drive almost two-thirds of the 3km long Spelc twin tube tunnel in Prague. The bores will pass below the Vltava river, driven north to south as part of the 6.4km long Blanka section of the city's inner ring road.

The faces are being advanced by heading (65m^2), bench (35m^2) and invert (25m^2) excavations. Primary support is 300mm thick SCL with lattice girders, mesh and expanded friction bolts.

By last month the north tube had advanced 1,180m, or almost three-quarters, and the south bore 870m, or nearly half way, respectively. The best advance was 147m in a month using a four-shift sequence.

Geology along the 'S'-shaped alignment was established by a pilot tunnel and comprises sandy shales, clayey shales and fine grained quartzite. Pressure grouting was undertaken along stretches from the pilot bore.

Cover to Spelc tunnel is up to 14.5m, though a 160m long section of thin cover overlain with water bearing gravels that required ground treatment by pressure and jet grouting.

The completed tunnel – to be opened in 2011 – will have an elliptical cross-section for two-lane stretches (123.7m^2) and three lanes (172.6m^2). A PE waterproofing membrane is being used for the 400mm thick final, PP fibre reinforced lining.

Beyond 'Big Bang'

While tunnellers note their major recent contribution to CERN's Large Hadron Collider (LHC) project that went live this month, the hunt for 'Big Bang' knowledge already has another, bigger excavation project in the pipeline – the International Linear Collider (ILC).

Last year, plans announced for ILC called for approximately 72km of new tunnels, including: twin 31km long, 4.5m diameter parallel tubes; a 7km long circular bore, 5m in diameter, between the main tubes; and, 13 access major shafts.

Three possible sites are: the CERN lab near Geneva, Switzerland; Japan; and the Fermi lab near Chicago. Geology at those 'deep' candidate sites is different – dolomite in the US, granite in Japan, and sedimentary rock/sandstone in Europe. However, a shallow site option exists for Germany or Russia (*T&TI*, February 2007, p12).

If sited at CERN, the ILC complex will add to an already massive underground complex, even before the major cavern works for the LHC research.

In Switzerland, the LHC excavations were an extension of the initial, 26.7km long by 3.8m diameter 'beam ring' and cavern complex built in the 1980s for the Large Electron Positron (LEP) machine. The ring was bored in molasse at depths of 45m-170m.

The main recent excavations for LHC focused on opposite sides of the 'ring' for the Atlas and CMS experimental zones, and began in earnest in 2000. The main excavations and associated tunnels were completed by 2003-4, and mainly employed NATM but also TBM methods.

The finished size of the principal (UX15) Atlas cavern is 30m wide by 35m high by 53m long, having been opened to 35.1m by 42.3m by 56.1m – therefore being one of the largest weak rock caverns. A second (USA15) cavern is 20m wide and was excavated to 23m. The finished CMS caverns are 26m wide by 53m long, and 18m wide by 85m long, respectively, and separated by 7m.

A procurement shift for LHC saw CERN split the packages on a geographical basis compared to the earlier approach, which caused friction during LEP construction, of keeping surface and underground works apart. As such, for LHC works the Atlas and CMS zones were handled as separate design and then construction packages.

Andes bore backed

Backing was given last month for a US$3bn rail tunnel project through the Andes between Argentina and Chile by the governments of both countries, and a feasibility study has been launched for private venture procurement.

The twin tunnel project is estimated to take eight to 10 years to construct. It is planned to run through a 23km stretch of the Cristo Redentor corridor in the mountains, between Puente del Inca, in Argentina, and Juncal, in Chile.

Both countries are looking for the rail scheme to be undertaken as a private venture. The procurement route would require private sponsorship of construction, operation and commissioning.

Earlier this year a new proposal was submitted to the governments for the private venture approach following their rejections of technical and economic concepts last year.

The new proposal for the tunnel, plus 200km of other rail rehabilitation and construction, came from a JV of two Argentinian industrial groups, Corporacion America and Tecnicagua.

In a statement, the Argentine Government said the scheme would help overcome the problems that freight transport faces from severe weather in the mountains with roads closed up to 60 days per year. By 2020 it will be carrying 20M tonne of rail freight between the stations of Los Andes, in Chile, and General Las Heras, in Argentina.

Fast forward

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Weinberg bore ready

Assembly is underway in Zurich of the 11.24m diameter Herrenknecht TBM that is to drive the Weinberg tunnel from Central Station in the 'Diameter Line' project to increase capacity at Switzerland's rail hub.

The Mixshield/shielded TBM (S-451) will be launched shortly from an assembly chamber and tunnel near Oerlikon station. It will drive a 4,863m tube to the receiving pit at Lowenstrasse station, which is being built below Central Station.

Geology along the alignment of the Weinberg tunnel comprises Upper Freshwater Molasse and moraine. Dewatering will be required locally at the Buchegg depression over which, for approximately 200m, cover is reduced as the route simultaneously passes from molasses into water-bearing strata.

Weinberg tunnel is being built by the Swiss rail authority, Schweizerische Bundesbahnen (SBB), as part of the 'Diameter Line' that will link Altstetten and Oerlikon stations via Central Station.

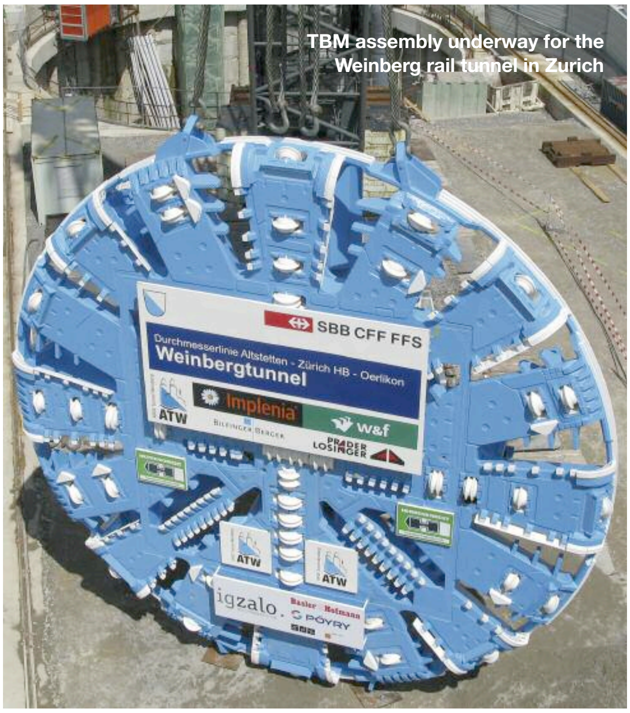
Underground works on Diameter Line involve construction of the Lowenstrasse Station, the Weinberg tunnel, and escape and rescue tunnels. Weinberg tunnel, which will be a single tube, double track rail link, has a pronounced bend and is almost 'S'-shaped in plan. It is being built as part of Phase 3 of the scheme, which has four phases in total and is due for total completion around 2013-15.

SBB's project designer and manager for Phase 3 is the 'igzalo' JV consisting of Basler & Hofmann, Pöyry Infra and SNZ.

All construction work is being undertaken by a JV of Implenia Bau, Wayss & Freytag, Bilfinger Berger and Prader Losinger, which won the two underground packages – Lowenstrasse and Weinberg tunnel – when they were tendered as separate contracts. The JV was awarded the contracts a year ago.

Local constraints in the launch area required the access shaft to be off-centre at the tunnel axis, which has resulted in more difficult assembly logistics. The JV contractor is having the TBM assembled in a chamber and also a NATM-driven tube, which will be 105m long to reach the portal before Oerlikon station.

However, there is not enough space for the full assembly of the backup and the shield is to be launched in two steps. Following an initial, short-mode advance of approximately 200m the backup will be completed. The TBM has a total thrust of 114,500kN, and cutterhead power and torque of 3,200kW and 23,700kNm, respectively. The NATM tube will be used for spoil removal.



TBM assembly underway for the Weinberg rail tunnel in Zurich

A total of 14,000 concrete segments for the primary lining are being manufactured by Swiss firm Ceresola TLS. It won the segment contract in February and worked with the JV to design and build the plant – using a carousel owned by the consortium – within six months.

Production started last month and will use a heat backflow process to reduce the number of precision moulds needed. The JV needs nine rings per day, each 2m long, 300mm thick (600mm at floor areas), having a 10.9m o.d. The final, insitu lining will also be 300mm thick and unreinforced except at escape tunnel junctions.

Arup's HS-2 plan sees major tunnelling

Proposals for the first stage of a second high-speed rail line (HS-2) for the UK could involve up to 48km of tunnel excavation in London, according to the feasibility study produced by consultant Arup and which is being discussed with the government and potential financial backers.

Arup said that the tunnels were envisaged to be continuous, twin 24km long tubes, which it said are feasible and deliverable. However, it declined to release further information, such as the breakdown of the expected tunnel layout and likely excavation methods, due to the negotiations underway with possible backers.

The general plan for HS-2 would see the rail link run from the existing terminus at King's Cross St Pancras station, in north London, to Heathrow airport – in effect making it a rail transport hub.

The tunnels are to be designed with a similar specification to the first high speed link (HS-1) to enable Eurostar-type trains to run between Heathrow and Continental Europe. HS-1 was designed with 7.15m i.d. segmental rings for the bore sections, which allowed additional space for fixed equipment and construction tolerance.

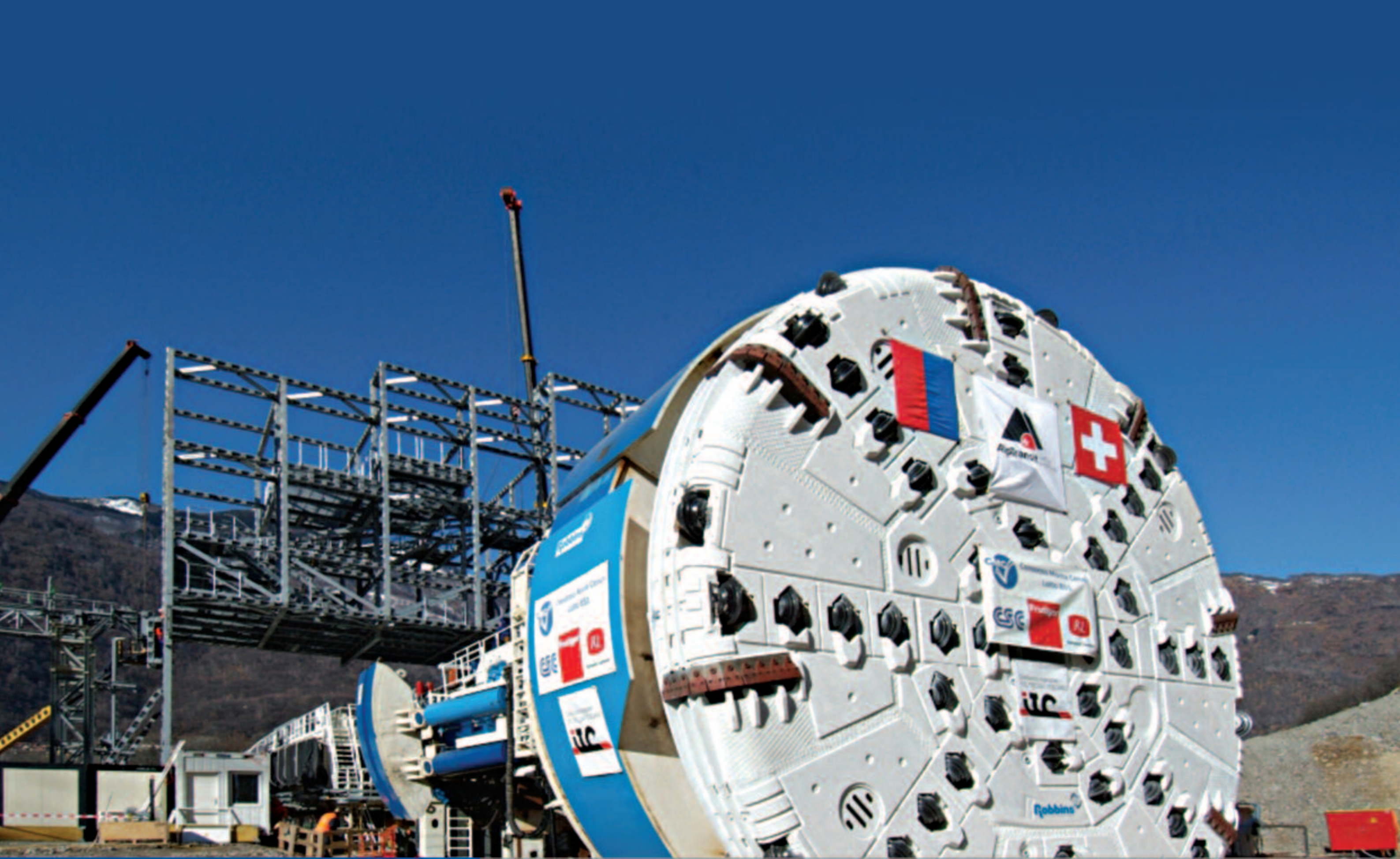
Arup said the capital cost of the first stage of HS-2, including a new station on the Great Western mainline but excluding infrastructure at the airport, is estimated at US$8bn to finish by 2019. The timeline appears to offer major tunnelling works to follow on from Crossrail and Tideway in London, but Arup would not comment on the workload or balance.

The consultant said, though, that the project would be entirely privately financed – being "a new sort of PPP", as described by project director Mark Bostock, a director with Arup and who played a key role in realising HS-1. Arup sees the government contributing permissions and authorisations, the "champions' push".

Confirmation of the advanced stage of the study into HS-2 was given late last year when Arup was launching a book on HS-1, for which it had a catalytic role in making it happen. The feasibility study for HS-2 has been done at the consultant's own expense and it has invested more than three years' works with, at times, 40 staff working on the scheme.

Bostock said that HS-1 was able to get momentum because of significant political support championing the scheme. He believes such support will also be vital to realise HS-2.

Arup said its financial model includes raising revenue from the sale of capacity for train services, and introducing the new station and passenger facilities at Heathrow. Further stages of HS-2 would see the high-speed link extended north to the Midlands and beyond (*T&TI*, January, p12).



Hard-rock Robbins TBM
ø 9.7 m
Rowa back-up system

TBM for sale

Built 2003
Refurbished 2007

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Main technical data:

» boring diameter: 9.7 m
» power: 3'750 kW / 5'600 kW
» cutterhead power: 3'000 kW (10 x 300 kW)
» cutterhead speed: 0 - 8.3 rpm
» cutterhead thrust: 20'600 kN
» stroke length: 1.87 m
» hydraulic system: 150 kW (285, 345 bar)

Rock support: rock bolts, meshes, beams, shotcrete
Mucking system: continuous conveyor (800 t/h)

The complete technical documentation is available upon request.

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Prequal for HK's West Island Line

Contractor assessment is underway to prequalify to bid for metro tunnel construction on the West Island Line (WIL), between Sheung Wan (SHW) and Sai Ying Pun (SYP), in Hong Kong.

Submissions were due at the beginning of the month from firms seeking to prequalify to tender under a two-stage process for Contact 703, which is to be awarded on a Target Cost basis.

Bid documents are to be issued next month for submission in November, after which the second stage of the tender process will run over January-August 2009. The contract period is September 2009 to 2013-14.

The programme calls for the Eastbound and Westbound tunnels – approx. 770m and 490m long, respectively – to be driven concurrently. Ground conditions along the Eastbound drive comprise 410m of soft ground, 120 of mixed and 240m in hard rock.

Major ground treatment will be required for the works, both from the road surface and ahead of the excavation face. In addition, some prior backfilling would be needed where the alignment encroaches the existing overrun tunnel lining for 130m in soft ground. The client, MTR Corporation (MTRC) said building piles are also anticipated along the route of the new tunnels and will need to be removed from within the excavations.

MTRC says the major works will be approximately 6.4m diameter and done by closed face TBM and/or open faced "Greathead" shield with compressed air. The maximum operating pressure would be 3.5Bar, it added. There would also be a section - approximately – 365m long in good rock cover between the launch shaft and SYP station. Both tunnels will be bored from the launch/entrance shaft in the existing Sai Woo Lane Playground Area, excavated to a depth of 42m including 15m in rock.

Cavico sees more inflation uplift

Cost inflation in the construction sector in Vietnam has been a key factor in a second contract adjustment for Cavico, on the Bao Loc hydropower scheme, the company has reported.

Cavico said cost inflation plus additional works and responsibilities led to a negotiated cost adjustment of an extra US$2.8M – more than the initial value of the contract awarded in 2005 for tunnelling works.

The cost adjustment follows a month after the Vietnamese company received a negotiated uplift in contract rates on the A Luoi hydro scheme.

At Bao Loc, it was appointed by developer VGR Bao Loc to perform a range of tunnelling works under a US$2.1M contract. Cavico has built the headrace and penstock tunnels, the surge tank and adit bore for the project under the initial engagement.

The developer wanted additional works undertaken, including managing the concreting works. The bulk of the adjustment – US$2.2M – was for the extra work, but the significant balance of the total was to compensate for markedly higher fuel and materials costs that the contractor had to meet in executing the construction contract.

Cavico said it is in advanced stages of negotiations for cost adjustments on a number of other construction projects. Its workload includes a significant volume of tunnelling works in the country.

MTR shortlists for HK side of Express Link

Expressions of interest from consultant JVs have been invited by MTR Corporation (MTRC) for the detailed design of tunnelling and associated structures on part of the Express Rail Link (XRL) to be built between Hong Kong and mainland China.

Deadline for submissions is 18 September and appointments for the works – arranged in two major packages covering the section of twin tubes in Hong Kong territory – are due to be announced in early 2009.

XRL will be a 26km long railway running from West Kowloon, in Hong Kong, to Shenzhen and Guangzhou provinces, and be built mostly in tunnel. Combinations of excavation methods are expected to be required for the route, from TBM and drill and blast to cut and cover construction.

Two packages are being prepared for detailed design – C802 and C803. The former, "South" package is a stretch approximately 15km long from West Kowloon to Pat Heung Vent Building. The latter, "North" package runs on for approximately 10km to the boundary crossing, and includes an emergency station and sidings at Shek Kong.

MTRC said that there would be close liaison with mainland authorities to agree on arrangements for the tunnel section at the boundary crossing. The section on the mainland, from Guangzhou to Shenzhen, is scheduled to begin operating in 2010. It added that the cross boundary link would use a dedicated corridor in tunnel to ensure capacity is achieved and operational compatibility with the mainland and connect to the high-speed network.

The client took over the project after its merger with Kowloon-Canton Railway Corporation (KCRC) at the end of 2007.

HK's HAT sewer prequal: new deadline

The call for contractors to prequalify for two tunnel sewer contracts – DC/2007/23 and DC/2007/24 – in Hong Kong's Harbour Area Treatment (HAT) scheme has changed a few conditions and reset the deadline to 19 September, but the schedule remains for tenders to be invited around November/December this year.

Under the contracts, a total of 19.5km of sewer tunnels are to be bored through Hong Kong's granitic and volcanic rocks with excavated spans of 4m-5.5m plus various shafts. Bidders must have done pre-grouting as principle groundwater control under pressures of at least 7 bar.

The initial prequalification deadline was set for 27 June but was reset to this month – when, originally, bids were to be submitted. Hong Kong's Drainage Services Dept's construction schedule remains unchanged for 2009-13.

Changes in prequalification processes are to do with contractor experience, such as: the length of tunnel works previously undertaken (down from minimum 3km to 600m); minimum civils contract values (down from US$64.2M to US$38.5M); minimum drill and blast contract size (down from US$25.7M to US$5.1M); and, minimum period within which civils jobs were undertaken (up from five years to 10 years) while drill and blast timeframe remained at 10 years.

Contract DC/2007/23 calls for approximately 12km of sewer to be driven at depths of 140m-160m below sea level, plus eight shafts. The other contract will be shorter, shallower and smaller sewers over 7.5km long at depths of 70m-120m, plus seven shafts.

More work on Downtown Line

Shanghai Tunnel Engineering Co Ltd (STEC) has been awarded a contract to design and construct a station and tunnels on Phase 1 of the Downtown Line in Singapore.

The US$162.4M contract – C902 – involves construction of Promenade station and associated tunnel works, each 600m long. The new station will be built below the existing Circle Line station.

Work on site is due to commence in the last quarter of the year for completion in 2013. The tunnels are to be excavated using bored tunnelling from a launch shaft adjacent to Rochor Flyover.

Construction works on Phase 1 of Downtown Line started in February, and the prime tunnelling works on the 4.3km long line are on C905 which is being undertaken by Shimizu next to STEC's newly awarded contract (*T&TI*, March, p6).

Separate to the Downtown Line, STEC has been involved in bored tunnelling work on Circle Line 1, 3, 4 and 5 projects.

Other tunnel works on Phase 1 of Downtown Line, to be finished by 2013, include: C906 to Sembawang Engineers & Constructors; C907 by Taisei; C908 by a JV of Samsung and Soletanche Bachy; and, C909 by Gammon Construction.

Stations are being built at Bayfront, Landmark, Cross Street and Chinatown.

Earlier this year the Government in Singapore spoke of a number of plans for further metro extensions, such as for the North-South and the East-West lines. There will also be two new lines totalling 48km in length – the Thomson (TSL) and Eastern Region (ERL) lines, to be constructed by 2018 and 2020, respectively.

Vinci JV closes finance on Greece concession

The Vinci-led concession company building the Athens-Tsakona motorway, which involves a number of "major" tunnels, has closed the financing of the scheme.

A total of 19km of tunnels are to be constructed in the 30-year concession to finance, build and maintain 365km of road, almost 50% of which will be new construction over six years, it was announced.

T&TI was previously told that there would be at least 16km of major tunnels, classed as more than 500m long individual tubes. Seven tunnels are to be constructed some of which will be twin tubes. In total, 10 tubes are to be built.

The concession has been awarded to the Olympia Odos group, previously called Apion Kleos. Olympia Odos completed the financing for the scheme with a consortium of 19 banks. The debt financing totals US$2.32bn and includes US$290M from the European Investment Bank (EIB).

The balance of funds for the US$4bn scheme comes from equity investment by the concession partners plus a subsidy from the Government of Greece. The cost estimate for the project was given last year as US$2.8bn (mid-07 prices). The concession officially came into force last month.

The Olympia Odos group includes Hochtief PPP Solutions and three Greek firms – J&P-Avax, Athena and Aktor Concessions, a unit of Elliniki Technodmiki.

The actual works are to be undertaken by a JV led by Vinci Construction Grands Projets.

Mesta wins Orsta tunnel job

The Norwegian Public Roads Administration (NPRA) has awarded a contract to Mesta for construction of a tunnel in the town of Orsta.

Construction work on the US$16.3M contract is scheduled to start this month and be completed by the middle of 2010.

The tunnel will be 1,920m long and built on a peninsula in Storfjorden. The cross-section profile will be a standard T5.5 horseshoe shape.

Separately, the contractor has been given another contract by NPRA to install lighting in the Myrkdalen tunnel on Highway 13.

Atlas Copco, Minova sign pact

A marketing deal between Atlas Copco and Minova International has been agreed to widen the offering in excavation support to their clients.

Atlas Copco said the global agreement would give customers access to each company's rockbolts, including its Swellex inflatable bolts. In addition, Atlas Copco customers would also have access to Minova's resins, grouts and related equipment.

The deal is aimed at boosting the offerings in ground control and geotechnical engineering for the tunnelling, wider civil engineering and mining sectors. None of the product brands are affected by the marketing agreement.

Financial terms of the deal were not disclosed.

A spokesman for Atlas Copco said it wants to support growth in the rock reinforcement segment and make sales more efficient, and the companies expect to gain synergistic benefits from the pact.

Minova described the strategic agreement as a major step to providing a complete rock bolting solution, which underlines its plan to establish a total package through its own combined steel and resin business.

Minova is the ground control division of the Orica Group, having been acquired in 2006. Last year, Minova bought Czech company Geobolt and French firm Cocentall's assets and sales in moves to further boost its bolt capacity (*T&TI*, June 2007, p12).

Fitch exits ratings on Sydney's Lane Cove tunnel

Fitch has exited ratings on the Lane Cove toll tunnel in Sydney, Australia, which has been suffering from weak traffic volumes, due to too little information being provided.

The move late last month follows Moody's further downgrading its view on the schemes finances on the 3.6km long tunnel due to insufficient use by vehicles.

In June, Fitch had placed its BBB- rating on Lane Cove Tunnel Finance Pty Ltd's on Watch Negative status. Last month it said that due to non-provision of information it could no longer provide a rating.

In a statement, the credit ratings agency said it considers it unlikely that the project's debt would be able to retain investment grade characteristics if the proposed recapitalisation by Lane Cove Tunnel Finance was delayed or did not proceed.

Although it opened early, in March 2007, the privately financed project has suffered from below forecast traffic volumes for most of its operations.

The parent of Lane Cove Tunnel Finance – Connector Motorways Group (Connector) – is preparing the recapitalisation plan, and Moody's has noted that there is enough liquidity to meet cash calls to mid-2009, and longer if volumes do increase (*T&TI*, August, p12).

Bright future for Australasia

ATS journal editor, David Lees, gives an overview of the booming tunnelling workload mooted for Australasia in the coming years

Over the past few years tunnelling has really taken off in Australia although recently the focus has moved from Sydney to Brisbane. The recent 13th Tunnelling Conference held by the Australasian Tunnelling Society in Melbourne attracted over 350 attendees and papers were presented on a variety of tunnel projects planned and under construction. Tunnelling in New Zealand has begun to expand in recent years as well and the Australasian Tunnelling Society (previously known as the Australian Underground Construction and Tunnelling Association) changed its name to include New Zealand.

Queensland

Queensland has been dominated by infrastructure projects based on the Lord Mayor Campbell Newman's long term plan to improve travel in Brisbane, and recent completion of the Inner Northern Busway and the Tugun Bypass.

Brisbane NS Bypass

The big focus in Brisbane is currently the US$1.6bn plus North South Bypass Tunnel with a total length of 6.8km which includes 4.8km of dual twin lane tunnels.

RiverCity, consisting of ABN AMRO, Macqurie Bank, Leighton Contractors, Baulderstone Hornibrook and Bilfinger

Below: Segment erection on Brisbane's North - South Tunnel

Above: Canopy installation on Brisbane's Boggo Road Tunnel

Berger, was awarded the contract to build and operate Brisbane's North-South bypass tunnel under a public private partnership (PPP) contract with the Brisbane City Council with a 45 year concession.

There are two hard-rock, near 13m diameter TBMs on site, one commenced in December 2007, the second in April 2008. The double shielded machines commenced on the north side of the Brisbane River and are travelling south to finish at Woolloongabba by mid-2009

Boggo Road

Tunnelling at Boggo Road commenced in September 2007 and is being undertaken by an alliance between Queensland Transport, Thiess, SKM and United Group.

Tunnelling is proceeding with extreme care using a Voest Alpine AM105 roadheader beneath the heritage listed jail, built back in 1903, with canopy tubes and lattice girders being utilised to manage ground settlement as tunnel cover reduces to 5m.

When completed, the 430m long tunnel will connect the South East busway to the recently opened Eleanor Schonell Bridge.

Brisbane Airport Link

BrisConnections team of Thiess, John Holland and Macquarie has been named as the preferred consortium for the US$3.2bn plus Brisbane Airport Link - a 5km twin tube tunnel to the Airport, the 3km long Northern Busway road, half of which is in tunnel, and the Airport roundabout upgrade projects.

Work on the Airport link, including underground ramps, will total 11.8km and will be built using two TBMs and 11 roadheaders for completion in 2012.

The ground conditions consist of Brisbane Tuff, phylite and greywacke of the Neranleigh–Fernvale Formation and felspathic sandstone of the Aspley Formation with overlying alluvium.

Brisbane Northern Link

The Brisbane City Council's planned Northern Link tunnel will burrow under some of Brisbane's most expensive suburbs. The concept design plan for the 4.7km tunnel has been prepared by Sinclair Knight Merz and Connell Wagner.

A final design will not be done until the construction tender is announced late next year. The 5.5km road project is expected to open in 2014.

New South Wales

Following the financial problems of the Cross City Tunnel and Lane Cove Tunnel the construction of further road tunnels in Sydney such as the M4 East extension and the F3 to M2 connection has slowed.

However service tunnels and a huge Metro for Sydney continue to be developed.

City West Cable Tunnel

The City West Cable Tunnel passes below the Darling Harbour Exhibition Centre across Tumbalong Park to Sussex Street. It will carry 132kV electricity transmission feeder

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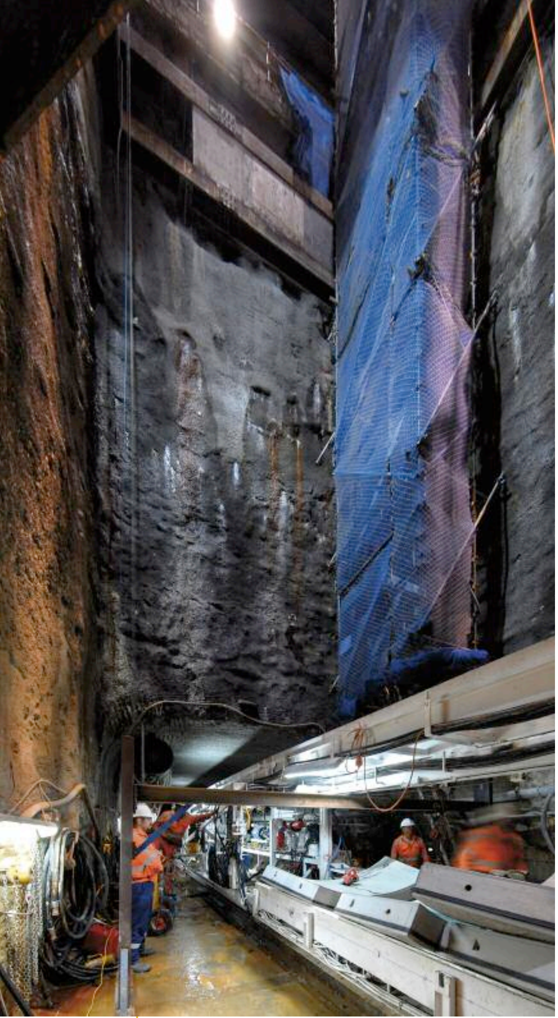


Above: View up the shaft on Sydney's City West Cable Tunnel

cables from Ultimo to the new City North Substation in the CBD. The tunnel being constructed by TBM is 1.6km in length, 3.75m in diameter and is located 20 to 45m below surface. Excavation will be primarily through Sydney Sandstone.

The US$42.8M contract awarded to Thiess commenced in April 2007 and is due to be completed in April 2010.

NW Rail Link

The NSW Government has proposed a US$10bn metro system to provide public transport for the NW of Sydney. Featuring 17 new, easy access stations, the North West Metro will run in 5.5m diameter TBM constructed twin tube tunnels for some 32km from Rouse Hill via Epping to the CBD. The first stage from Epping to the Hills Centre will be completed by 2015, with the entire line from Rouse Hill to the CBD to be completed by 2017. The metro project replaces the government's 10-year-old plans for the north-west rail link, which was to make use of the existing heavy rail system.

Sydney Desalination Plant

Blue Water, a joint venture of John Holland and Veolia Water, has been contracted by Sydney Water to design, construct, operate and maintain the Sydney desalination plant for a price of some US$761M.

Water from the desalination plant at Kurnell will be pumped into Sydney's water distribution system through a pipeline from Kurnell, across Botany Bay to Kyeemagh. Seawater will be pumped into the plant through a tunnel from the Tasman Sea. The water will be distributed to up to 1.5M people south of Sydney Harbour, to supplement their water supply.

The land portion of the pipeline will be laid using a number of methods, including open trench and trenchless construction. Microtunnelling will mainly be used in residential areas and to cross rivers, railways and major roads. The project start up was in mid 2007 for commissioning in 2010.

Victoria

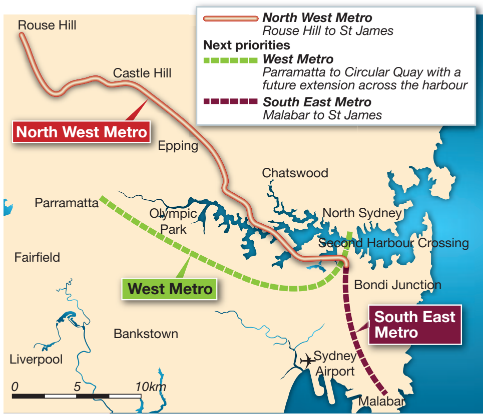
Accidents in the Melbourne City Link tunnels have caused Vic Roads to develop new rules for road tunnels in Victoria just in time for the opening of the EastLink freeway. But this has not stopped planning for further road tunnelling projects to ease transport across Melbourne. The other two main projects currently underway in Victoria are the Bogong Hydro Plant and the North West Sewer Project. Both these projects are continuation of historic works. The Bogong Power Station was originally intended to be part of the overall hydroelectric development of the Kiewa Valley in Victoria, however, it was never built. The Northern Sewer Project is an extension of Melbourne's North West Sewer commissioned in 1998.

Northern Sewer Project

John Holland was initially awarded the US$238M contract to build the first stage the Northern Sewer Project and then awarded the US$135.6M Stage 2 contract in September 2007. The project is to finish by mid 2012. Connell Wagner and design joint venture SKMJacobs are the Project Managers.

Stage 1 is a major 8km long deep tunnelled sewer connecting the existing system near Merri Creek to the northwestern sewer in Essendon and commenced in early August 2007. Geology is typically siltstone, with intrusions of basalt and alluvial soil deposits. Tunnelling is by two Herrenknecht EPBMs with eight shafts with maximum depth of 65m and 13m in diameter.

Stage 2 is a 4.5km long, deep tunnelled sewer joining the Stage 1 works at Coburg which commenced in late 2007. The sewer will have a cut diameter of 3m and a finished diameter of 1.8m and includes four major access shafts of up to 39m in depth and 10m in diameter. The tunnel alignment goes through high strength abrasive basalt to be excavated by hard rock shielded Robbins TBM, a section of Brighton group and alluvium is anticipated and a Herrenknecht



Right: Fig 1 - Plan map of the ambitious $12.5bn North West Metro for Sydney, 32km of which will be in twin tube tunnel

Below: Breakthrough on Perth's Metro Rail Project

EPBM will be used for this section.

The Robbins TBM will bore through basalt rock ranging from low strength to 270MPa. Muck cars will be hoisted up the shaft and dumped into a spoils bin for removal by rubber-tired vehicles. Launch of the TBM was scheduled as *T&TI* went to press.

Bogong Hydro Power Project

McConnell Dowell Constructors have been awarded a design and construction contract for the Bogong Hydro Power Project by AGL Southern Hydro in Victoria, in the largest hydropower project to be constructed in Australia in 25 years.

The scope of work consists of approximately 6km of 5m diameter headrace tunnel, two vertical shafts, a 1km steel-lined high pressure tunnel, a power station to house twin 70MW generators and a tailrace outfall into neighbouring Lake Guy

Bogong is scheduled to be fully commissioned by October 2009 and will generate 94,000MWh of emission free new renewable electricity each year thereby abating 122,000 tonnes of greenhouse gas emissions.

North Central City Corridor

The centerpieces of Sir Rod Eddington's US$14bn blueprint for Melbourne's transport are two new mega tunnels under Melbourne.

Sir Rod has called for construction of a road tunnel starting in the west, via one of two yet-to-be-selected routes, and finishing in Clifton Hill at the Eastern Freeway with no exit points to the CBD. His proposal for a new 17km rail tunnel would run from Footscray to Caulfield, with new stops at Parkville, the city, along St Kilda Road, and finishing in Caulfield.

Western Australia

Perth has just seen the completion of the Perth Metro Rail Project this year, the biggest tunnelling project ever in Western Australia with 700m of twin 7m diameter bored tunnel. However sewer tunnel projects continue with the Alkimos Wastewater Project.

Alkimos

The Alkimos Wastewater Scheme is a US$285.4M project to provide essential wastewater infrastructure for the northern suburbs of Perth. The Alliance contract was awarded to the Alkimos Water Alliance comprising Multiplex Engineering, Macmahon Contractors, Züblin (Australia) and the Water Corporation in early 2007.

The project includes a wastewater treatment plant built in an open cut of approx. 3M cubic metres volume and 5km of 2m diameter main sewers. The Quinns Main Sewer is being constructed using open cut and pipe jacking with 13 shafts up to 20m deep. The project also includes a 3.7km ocean outfall and a 1km tunnelled connection to the treatment plant using a Herrenknecht Dual Mode TBM. T&T

New Zealand

There are a good number of projects underway in New Zealand. The Johnstone's Hill road tunnels just north of Auckland, are progressing well and other infrastructure tunnels are planned for Auckland. A number of major outfall projects are underway including the Rosedale Outfall and Hobson Bay projects. There are also plans for extension of the Waitaki Hydro Scheme

Johnstone's Hill Tunnels

The Northern Gateway Alliance is constructing New Zealands largest tunnel project. The parallel Johnstone's Hill Tunnels are each 340m long and form a major part of the largest infrastructure project under way in New Zealand, the Alpurt B2 Bypass. Initial plans for the route proposed the traversing of Johnstone's Hill via a deep cut in the Hill but this gave way to the more environmentally sensitive tunnel project.

Johnstone's Hill Twin Tunnels are 15m apart, each tunnel is concrete lined and carry two lanes, a hard shoulder and a footpath, although initially, only one lane will be marked on the northbound road surface.

The tunnels are fully lit and include fire suppression equipment, traffic control systems, and ventilation fans.

The northern portals of the tunnels have been constructed by cut and cover techniques allowing the natural contours of the hill to be reinstated following construction. The portals on the southern slope of Johnstone's Hill are located in an environmentally sensitive area. To minimise the environmental footprint, both tunnels were dug from the north until access became available to develop the southern portal area, dramatically reducing the impact on the southern slope.

Vic Park Tunnel

As part of the project to improve Auckland's central motorway system Transit is planning to build a northbound tunnel beneath Victoria Park while retaining the existing viaduct for southbound traffic.

The 440m long Vic Park Tunnel will reduce congestion between the Central Motorway Junction and the Harbour Bridge by easing a bottleneck created by the Victoria Park viaduct.

Construction is scheduled to start in 2009 and be completed in 2014, at an estimated cost of US$210.5M.

Auckland Loop Tunnel

Auckland Regional Transport Authority has begun planning for a US$658M central Auckland "loop" tunnel considered the key to ending growing congestion on tracks into the Britomart station. The plan is for a 3.5km tunnel beneath Albert St and including underground stations near Wellesley St and Karangahape Road.

Hobson Bay Sewer

The 90-year-old sewer, which cuts across Hobson Bay, will be demolished as part of the US$78M project let by Watercare Services. Joint-venture contractors Fletcher Construction and McConnell Dowell hope to finish in 2010.

Replacing the sewer main with a larger capacity tunnel for carrying and storing wastewater meets projected growth in the area, helping the marine environment by practically eliminating wastewater overflows into Hobson Bay and opens up the bay for recreational purposes and improves views of the area

Rosedale Outfall

Planning is well advanced for North Shore City Council's new Rosedale Wastewater Treatment Plant outfall, which will discharge high quality treated effluent from the treatment plant, 2.8km out to sea into the Rangitoto Channel. It needs to be completed by the end of 2010. The proposed onshore section of the new outfall is planned to be totally built by underground tunnelling, much of it deep underground. The tunnel will be bored from the treatment plant to a point offshore, where it will rise to join a section of pipe buried in the seabed, minimising disruption at Mairangi Bay beach.

Waitaki Hydro

Meridian Energy's proposed North Bank tunnel hydro scheme could generate enough electricity to power Christchurch, but it might not be commissioned until 2016.

Meridian's plan is to take water from Lake Waitaki and discharge it back into the Waitaki River 34km downstream at Stonewall. This tunnel concept would provide 128m of head. The existing Waitaki power station provides 21.5m of head. The total output from the Waitaki station and North Bank schemes when complete would be about 1900GW hours a year.

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Bribane's quiet achiever nears end

Tunnelling successfully under a heritage-listed jail was one of several interesting challenges for Brisbane's Boggo Road Busway Alliance (BRBA). Gavin Bradford, project manager for Stage Two of the Alliance, describes the project to date

South East Queensland is Australia's fastest-growing region, with an estimated 1000 new residents arriving every week to enjoy the benefits of the 'sunshine state'. The Queensland government has invested heavily in infrastructure to meet the demands placed on the region's water, housing and transport. While large-scale tunnel projects seem all the fashion around town, there is a 'quiet achiever', which deserves its own share of the limelight - the Boggo Road busway tunnel. Dedicated busways are a very important component of Brisbane's public transport initiatives.

The Queensland government-funded Boggo Road Busway Alliance (BRBA) is a partnership between Queensland Transport, Thiess Pty Ltd and Sinclair Knight Merz. The alliance is responsible for the delivery of 1.7km of dedicated busway linking the M1 South East Freeway to the University of Queensland via the existing Eleanor Schonell Bridge which opened in December 2006. The busway takes its name from the iconic heritage-listed jail under which a different sort of tunnel has been excavated.

The busway's termination at the state's largest university is warranted. The University of Queensland is the third largest traffic generator in Brisbane after the central business district and the airport.

The busway will open in mid 2009.

Tunnelling

Stage Two of BRBA is a 640m long tunnel, of which 430m is true shallow-cover driven tunnel. The excavated tunnel cross section is a typical busway horseshoe shape, 14m wide and 7m high, with an average excavated cross-sectional area of 105m^2. Total spoil to be removed is approximately 50,000bcm over a 57 week period from August 2007 to early October 2008.

The driven tunnel is being excavated with a refurbished ATM105 roadheader. This roadheader had a previous life on the Eastlink road tunnels in Melbourne. Advance is achieved with a 5.5m high top heading followed by a 1.2m high benching activity.

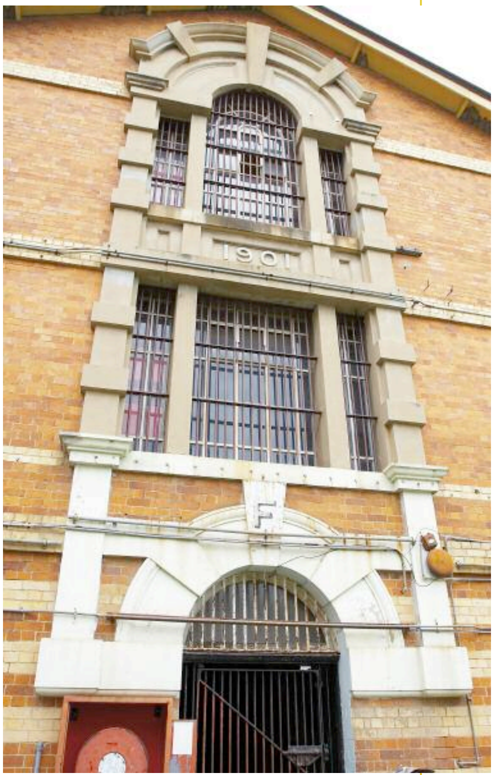
Geological conditions are extremely variable within the driven tunnel section of the works, although an added benefit is the lack of groundwater ingress to the works. The geological profile is generally divided into three distinct sections.

- Initial 150m in weathered Brisbane Tuff material – typically in UCS range 20-120MPa
- 150m in the Tingalpa formation (siltstones and sandstones) – typically in UCS range 10-40MPa
- 130m back in the stronger Brisbane Tuff

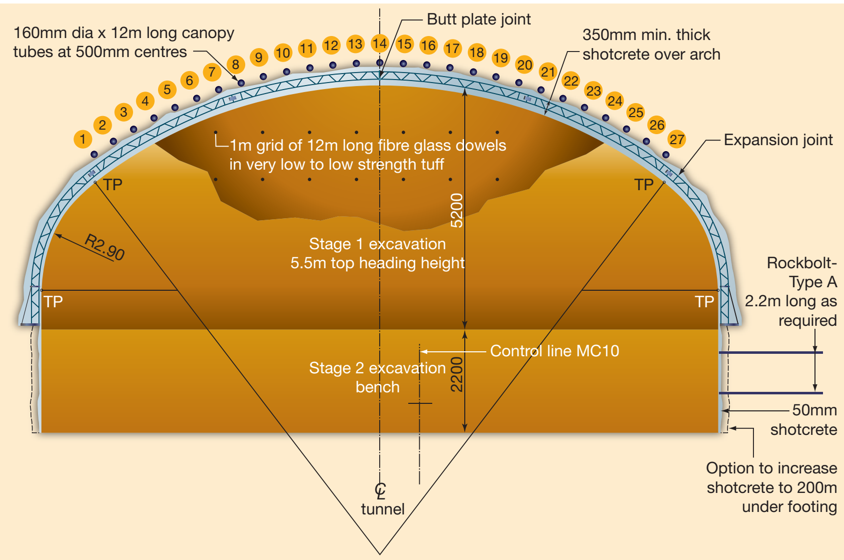
Within each of these formations are several small faults, conglomerates, breccias and claystones.

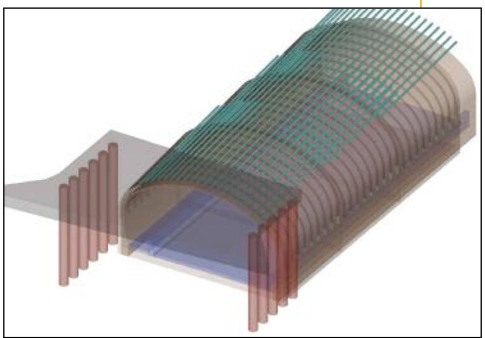
Three distinct temporary ground support types are used during the roadheader top heading excavation.

- The 117m of tunnel beneath heritage-listed Boggo Road Jail utilises 12m long horizontal fibreglass face nails, 12m long canopy tubes and lattice girders at 1000mm centres encased with 300mm of plain shotcrete. Each canopy tube array consists of 27 No. tubes at 500mm centres. Face nail numbers varied typically



Above: The heritage listed Boggo Jail





Left: Cross section through the tunnel
Below: 3D of the system of advance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from 20-30 each array. Canopy tubes were supplied by Alwag, a subsidiary of DSI. The average advance rate for this ground support type was in the order of 7 lineal metres/week for an 11 shift week

- Lattice girders at 1200mm or 1500 centres encased with 300mm or 250mm thick plain shotcrete respectively for average advance rate 10-11m/week. In what we believe to be a first in Australia, self-drilling friction stabiliser rockbolts supplied by DSI have been used to pin the lattice girders to the crown in these areas where there are no canopy tubes, and this has allowed for all persons in the work area to remain separate to the support installation and not work close to unsupported ground
- 3600mm long resin encapsulated rockbolts on 1200mm or 1500mm grid laterally and longitudinally for average advance rates 16-20m/week. All resin and bolts are installed remotely with a Tamrock Minimatic two boom jumbo drill.

The geological model

Rather than go into detail about what can sometimes be mundane descriptions of “how we sprayed shotcrete” or “how we installed rockbolts”, the project has some interesting innovations and has incorporated some “lessons learnt” from recent Australian tunnelling projects and put them into practice quite effectively. Discussion around the geological model is the first item of note.

The tunnel, except for the old jail, has the unique advantage of not passing under any other buildings or significant structures along its 430m alignment. This attribute enabled the tunnelling team in the early conceptual stages, to drill 10 boreholes on or very close to the tunnel centreline, some within the jail perimeter. This provided in-situ core information at an average of less than 40m centres. From this information a very detailed and accurate geological model was developed. This in turn allowed the tunnel designers to accurately forecast ground support design.

Design and construction interfaces

The project has several success stories, but the one that stands out is the excellent relationship between the design team and the construction team. The unique alliance framework, now popular in Australia for the delivery of major infrastructure projects, facilitates the two disciplines to work closely together and two distinct advantages became apparent on this project:

During the project estimate and approval stage, the geological model was available and tunnel designers and constructors were able to analyse the information and make critical decisions on the ground support types and methods of excavation.

Above: **Alwag canopy tube installation using the Tamrock Boomer**

At the same time, the construction team was also able to work closely with the tunnel estimators, in the same office environment, to take the design and the work method statements and price the job accordingly.

Two fundamental decisions emerged from this process. One was the decision to install lighter-weight lattice girders underneath the canopy tube arrays through the jail area instead of traditional steel sets and use 300mm plain shotcrete as the primary stiff support. Secondly, the idea to use resin encapsulated rockbolts in lieu of shell anchored or grouted bolts because of the variability of the ground in the tunnel crown.

The Permit to Excavate process

The driven tunnel section of the Boggo Road busway is also unique for another reason - the shallow cover. The minimum ground cover beneath old Boggo Road Jail is 6m, the maximum cover along the alignment is 15.5m and the overall average cover to the crown of the excavation is less than 11m. Not much, considering the tunnel excavation is over 14m wide.

Being aware of this fact, the alliance tunnel team modified a process used recently on several Australian tunnelling projects, called the “Permit to Excavate”, and used it successfully to assist safe and efficient excavation. The core of its success lies in the fact that this process requires a member of the geological team, the design team and the construction team to sit together every day and analyse face mapping, the actual geological conditions versus predicted, general progress, quality, settlement results, tunnel convergence and water inflows, so that the conditions of advancement are agreed and signed off upon. This information is then passed to the tunnel supervision and excavation continues for another 24 hours under the new permit.

Boggo Road Jail and settlement

The initial 117m of the driven tunnel beneath the 107 year old Boggo Road Jail was the most challenging for a number of reasons and a steep learning curve through this section was experienced. But this was anticipated and the program adjusted accordingly. Drilling 12m long, 55mm diameter face nail holes and the same length 140mm diameter canopy tube holes in variable ground, with a new team and new equipment, at the start of a project, was always expected to present difficulties. It should be noted that the major obstacles were not related to ground conditions or design; they were linked to work crews developing safe, repetitive methods over time and modifications required to the jumbo drill to overlap with these methods as they developed. Despite a slower than expected start up, the canopy tube section was completed on budget and time. Rates of 10 No. 12m long tubes drilled and installed per 10 hour working shift were achieved towards the end of this operation. Canopy tubes were installed with a Tamrock Minimatic two boom jumbo drill. Each tube consists of 4 No. 3m long elements. The initial 3m element has a sacrificial drill bit and excellent

Above: **Measuring possible settlement at the Jail**

alignment accuracy is achieved if the first section is drilled on line and grade. This accuracy allows neat excavation underneath the tubes, easy installation of lattice girders and reduces shotcrete wastage.

Each canopy tube array had a 9m effective length due to the 3m overlap between arrays. The use of lattice girders in lieu of traditional steel sets proved a good decision because although extra time is taken up spraying the thicker shotcrete, time and cost savings are achieved via the quick erection of the light weight girders and the fact that once the shotcrete is sprayed, no further secondary spraying at a later date is required. This surface is then ready for waterproofing. To our knowledge this is the longest section of canopy tube support in Australia and the first time that the lattice girder and shotcrete support under canopy tubes has been used in Australia.

Forecast settlement under the jail was 10mm and this was not exceeded. Surface settlement was some 7-10mm with no damage to the heritage structures recorded.

Above: **The Meyco Suprema preparing to spray a lattice girder**

Plant and equipment

Boggo Road Busway Alliance was fortunate in starting tunnelling in August 2007 as the the Mitcham to Frankston tunnelling project in Melbourne, constructed by Thiess Holland JV, was disposing of equipment. Excellent quality equipment was sourced including an ATM105 roadheader, Meyco Suprema robotic shotcrete rig and Caterpillar 25 tonne moxy trucks. The quality of this equipment and of the refurbishment works, especially to the roadheader by Sandvik Mining & Construction at Tomago near Newcastle, in New South Wales, have been key to the success of the excavation.

Another successful innovation in the area of plant has been the installation of two concrete drop pipes from the surface linking the underground works. Two off-road concrete agitators have been purchased for the tunnel fleet, which allows concrete to be efficiently transferred to the underground works at any time of night or day in any weather and means subcontractor trucks with all their associated issues are not required to enter the tunnel.

People, production and safety

Demand for quality people in the Australian construction sector is at an all-time high. At the start of the project the recruitment of the tunnel workforce focussed on drawing on the workforce finishing in Melbourne and the relationships with the supervision also sourced from that project. Recruitment also targeted the mining sector and drawing on the existing unskilled surface workforce on other parts of BRBA. This three pronged attack proved very successful in building a quality excavation team of 31 people.

Tunnel engineering resources are even more difficult to find. Whilst key leadership roles in management and supervision roles were in place early, BRBA spent considerable time in attempting to recruit other site and project engineer roles with tunnelling experience. This proved unachievable and a different strategy was adopted. Quality engineers with no tunnel experience were identified as a solution to the issue. The Australian experience is that generally engineers specialise in areas of expertise and this is split between underground or surface environments. The key is to get them exposed to the underground environment and then provide strong leadership to bring them up to speed. One particular point of note is that the tunnel site engineers have spent dedicated periods working on shift with the tunnel crews, similar to the practice used in the Australian underground hard rock mining industry.

The quality of the people on the project is directly related to the safety performance. To date, the tunnelling works have exceeded 365 days Lost Time Injury Free.

BRBA has adopted a great program around work and lifestyle. Production for the week commences at 8pm on a Sunday night and finishes at 6am on a Saturday morning; a total of 11 No. 10 hour production shifts. Saturdays are dedicated maintenance and housekeeping. Production windows from 4pm to 8pm daily are covered by an overlapping afternoon shift which allows production to continue and negates the need for 12 hour shifts. All staff work a 5 day week on average and this is managed rigorously to achieve a work lifestyle balance and a safe tunnelling operation. T&T

WHAT ELSE BESIDES EXCAVATION?

Crack control requirements stipulated by the owner, the Queensland Government, require that the final concrete lining be reinforced, not a common requirement in Australian road tunnels. The following are all subsequent post excavation activities:

- Installation of in-floor drainage, working floor blinding and 200mm high concrete kicker curb pour - all prior to arch formwork for the concrete lining. The key decision was made to install drainage early to take pressure off subsequent civil, and M&E works
- Installation of a geofabric and PE waterproofing membrane from a custom gantry
- Steel fibre reinforced shotcrete final lining to 4 No. 20m long raised fan niches equally spaced along the tunnel alignment
- Final arch lining reinforcement installation – a unique method proposed whereby self supporting lattice girders are installed at 1800mm centres prior to 12mm and 16mm straight bar installation. This method negates the requirement to penetrate the waterproofing membrane to hold the reinforcement in place
- Form and pour 300mm (minimum) thick reinforced concrete lining. Arch formwork is currently being constructed in Malaysia by CAD2000 and due on site late September 2008. Formwork has been designed at a 9m length to match the sawtooth sections in the canopy tube excavation where the thickest concrete sections exceed 1000mm and to keep pour volumes around 100 cubes so that formwork can be turned around in a 24 hour period to achieve 5 pours per week
- Mechanical and electrical fitout by United Group working as a sub-Alliance including a 6mm/minute deluge system for fire control

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Beating the clock - on-site first time assembly

With increasing TBM diameter sizes becoming more common, onsite first time assembly can save both time and money. Desiree Wills of The Robbins Company explains the principles

When the world's largest hard rock TBM was launched in September 2006, it met a tight schedule date nearly five months ahead of that previously planned. The Robbins 14.4m diameter machine was built for the Niagara Tunnel. Project in Ontario, Canada (*T&TNA*, p9). "It was quite unheard of," explains Ernst Gschnitzer, project manager for Niagara contractor Strabag. "The time between when we signed the contract and when the machine was launched spanned less than 12 months. That included the time to manufacture, ship, and assemble all of the components for both TBM and back-up."

The Niagara build served as the first instance of a new TBM construction method called Onsite First Time Assembly (OFTA). OFTA allows TBMs to be initially assembled onsite, rather than in a manufacturing facility. The process eliminates all pre-assembly and disassembly in workshops and requires fewer total man hours as a result. The reductions in man-power and shipping of large components generally add up to significant cost savings as well.

"We first developed OFTA for the Niagara TBM as a way to build a large diameter machine in a relatively small amount of time. We analysed the risks and benefits ahead of time and determined that this method would be the most successful given the schedule," says Doug Harding, Robbins Vice President.

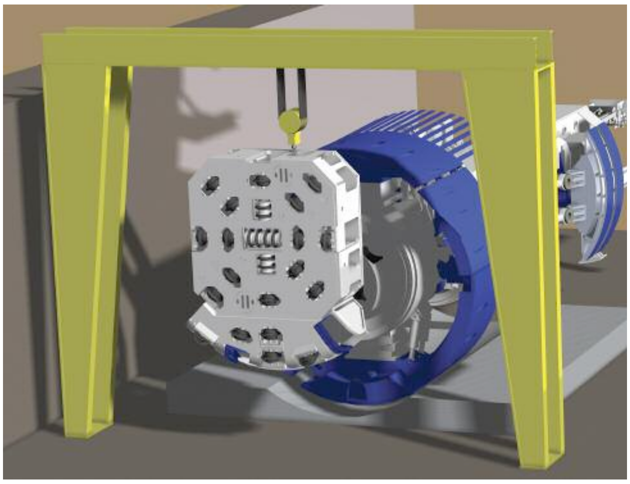
Since its inception at Niagara, OFTA has been used on several machines including a 10m diameter Robbins Double Shield machine for India's AMR Project, and a 12.4m diameter Main Beam TBM for the Jinping-II Hydroelectric Project, in China.

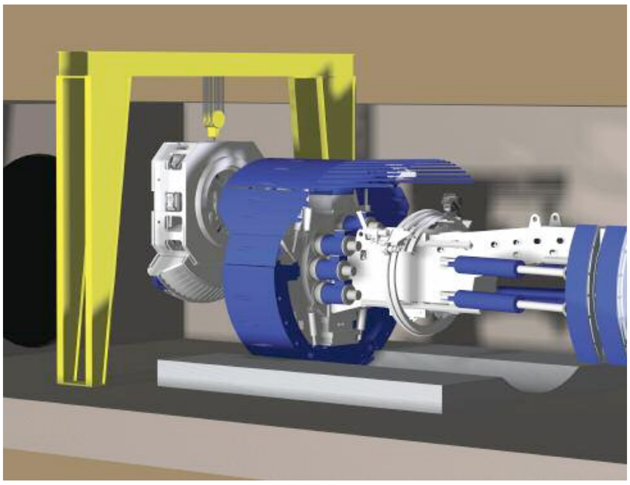
Below: **The 14.4 m diameter Robbins machine for the Niagara tunnel project served as the first instance of onsite assembly**

Analysis of time savings

When comparing Niagara to conventionally-assembled large diameter TBMs, the time savings are significant. For example, a 10m diameter Main Beam machine typically requires four months of assembly in a manufacturing facility, with an additional one and a half months to disassemble various components for shipping. The shipping process itself can take up to one month, and an additional month is sometimes needed for final assembly at the jobsite.

During the OFTA process, complete assembly may range from three to four months, with an additional month often required because of the inefficiencies of working at site and unforeseen interface problems. However, the disassembly and shipping phase is entirely eliminated, saving several months in the overall schedule. In the case of the 14.4m diameter Niagara Project the assembly process began in late April 2006 and was launched during the first week of September.





Above: **Robbins' OFTA method utilises a concrete cradle and gantry cranes to initially assemble a TBM on-site. The OFTA method eliminates assembly and disassembly in workshops, resulting in cost savings due to decreased man hours**

"Assembly was, however, just the first step of the process," says Gschnitzer. "After the launch ceremony we spent some extra time optimising and commissioning the equipment, though this was not unexpected. The large diameter machine was somewhat of a prototype with a complex back-up system as well - but that's tunnelling. It's something we take as part of the process." The machine has now advanced approximately 3000m on its 10.6km long hydroelectric tunnel drive beneath Niagara Falls, most of it under challenging ground conditions.

OFTA in Detail

The process of onsite assembly will be specific to the project requirements. Pre-planning is generally done months in advance to ensure that adequate personnel, cranes, and other lifting devices are available at the site. A typical project requires that Robbins engineers develop a complete set of procedures for the assembly. Key personnel are then provided to oversee the assembly, including mechanics, electrical engineers, welders, fitters, and field service supervisors.

Multiple quality control measures are in place to make sure the OFTA process runs as efficiently as possible. "We currently send inspectors to all sub-suppliers, and build templates to ensure critical TBM components fit up," says Robbins president, Lok Home. Increased quality control ensures the correct components are sent to the jobsite, and that the components themselves are high quality.

Sub-assembly and testing of critical systems, such as the electrical and ventilation systems, is also done in facilities before they are shipped to the site. "The increased quality control does cost more, though it is still offset by the overall savings in terms of reduced assembly labour," says Home.

Components are shipped to site to build the machine from the inside out, starting at core components such as the main beam, working out towards components such as the outer cutterhead pieces and gripper shoes. The machine is constructed in a launch chamber, shaft, or pit and typically rests in a concrete "cradle" while gantry cranes lower components into place. Once the machine has been fully assembled it can then crawl forward to the tunnel face.

For shielded machines the process is much the same. In May 2008 for example, the first of two 10m Double Shield TBMs was assembled onsite at India's Alimineti Madhava Reddy (AMR) Project in Andhra Pradesh state. Crews utilised gantry cranes capable of lifting up to 170 tonnes to hoist components into the launch pit. The cutterhead, gripper system, forward shield, and telescopic shield were assembled in the concrete cradle. The finished TBM then crawled forward by reacting against invert segment pieces installed progressively up to the tunnel entrance.

Overall, the process took about the same amount of time as a similarly sized open-type machine. "The assembly went quite smoothly, with some minor mismatch problems that were worked out. Even with that, the assembly at site resulted in cost savings in terms of transportation," says Mr Anil Kamat, project manager for Jaiprakash Associates Ltd (AMR contractor). Initial onsite assembly of a second 10m machine is scheduled to begin in late 2008.

Below: **Onsite assembly was used for a Double Shield Machine for India's AMR Project, in Andhra Pradesh state, this May**

The future of onsite assembly

Robbins is now proving OFTA's versatility on a variety of different machines and locations worldwide. The method can be used on any TBM type, from open to shielded to soft ground machines. OFTA can also be used on any diameter TBM, though its greatest use to date has been on large diameter machines. "We think the OFTA process will become a standard in the industry, particularly because larger TBM sizes are also becoming more prevalent," said Home.

Currently underway is the assembly of the 12.4m diameter Main Beam TBM for the Jinping-II Hydroelectric Project. The jobsite, located in a remote area of China's Sichuan Province, requires that most components be shipped via barge on the nearby Yalong River (a tributary of the Yangtze). The swift assembly, due to finish in August 2008, has allowed for decreased shipping costs and shipping risks since the low water season on the Yangtze has been largely avoided. Low water conditions can be risky for barge shipping and generally result in alternative, more costly means of transport such as rubber-tired vehicles.

In addition to the AMR and Jinping-II machines, Robbins has plans for several future machines to utilise OFTA. The Pula Subbaiah Veligonda Tunnel No. 2, also in India's Andhra Pradesh state, will involve a 10m diameter Robbins Double Shield TBM identical to those at AMR. Its onsite assembly for the HCC/Coastal Projects Pvt Ltd JV is planned in 2009.

Most recently, Robbins has signed two additional contracts for projects involving OFTA. The first, a complete contract with Coastal Projects Pvt Ltd, is for the 12km long Sleemanabad Carrier Canal in Madhya Pradesh, India. The project will utilise a 10m diameter hybrid-type EPBM, which can be converted in-tunnel from a screw conveyor to rubber belt conveyor depending on the ground conditions. The full length of the tunnel is located in variable ground ranging from clay to gravel to full-face hard rock. OFTA of the hybrid machine is expected to be much the same as that for Double Shield machines. The assembly is planned for late 2009 and will last approximately three and a half months.

A second project will involve the initial onsite assembly of a 9.59m diameter EPBM. The contract was signed with the ICA consortium (made up of Empresas ICA, Cicsa, and Alstom SA) on July 29th, 2008 for the machine, back-up system, and cutting tools. The machine will bore a 6.2km long tunnel for the Mexico City Metro's Line 12, connecting the southern areas of Mexicaltzingo and Mixcoac. T&T

Above: **Dave Sethman, Robbins TBM assembly supervisor, oversees the onsite assembly of the 10m diameter Double Shield TBM at AMR**

Fire engineered solutions for road tunnels

Tim Healey, director of civil engineering for Capita Symonds, Les Fielding, of London Bridge Associates, and John Celentano, of Mouchel, described state-of-the-art fire solutions for road tunnels at the British Tunnelling Society meeting this June

Tim Healey opened the June BTS lecture, explaining that fires in tunnels could have disastrous results, the worst scenario being loss of life. Fires can damage the structure of a tunnel as well as severely damage tunnel equipment and this can render the tunnel inoperable for a considerable time costing local, and further reaching, economies substantial sums of money.

Fires can start from combustion within a vehicle such as binding brakes or simply as a result of a collision and the fire can even be brought into the tunnel by a vehicle that is on fire before entering the portal.

Over the last 10 years there have been nine serious and well documented incidents in European road tunnels as a result of fires, which have led to a total of 82 people losing their lives, with at least twice as many injured through smoke inhalation.

The worst of these was Mont Blanc where a total of 39 people lost their lives and the tunnel was out of use for over a year with a cost to the local economy somewhere in the region of 700M Euros.

The issues for civil engineers and tunnel operators are:

- How do we prevent in-tunnel collisions?
- How do we deal with the immediate aftermath of an incident?
- How do we protect the tunnel structure?

To deal with the first two issues there is now an EU directive that requires all tunnels longer than 500m to be unidirectional where the traffic level is greater than 10,000 vehicles per day/lane and to be of a maximum grade of 5% with advisory vehicle spacing of 2 seconds for cars and 4 seconds for HGV.

In addition, there is a requirement for traffic control such that vehicles can be managed and the tunnel evacuated in the event there is a fire as well as a requirement for emergency walkways, escapes/refuges and emergency vehicle cross passages to be spaced every 1500m.

Application of the advisory vehicle spacing of the EU directive implies a reduction in capacity of around 25%, which may not be viable for many urban tunnels. It is important therefore to have properly signposted means of escape and refuge together with the ability to stop traffic entering the tunnel once an emergency occurs. To minimise risk in urban tunnels it is advisable to avoid having junctions immediately on exit from a tunnel.

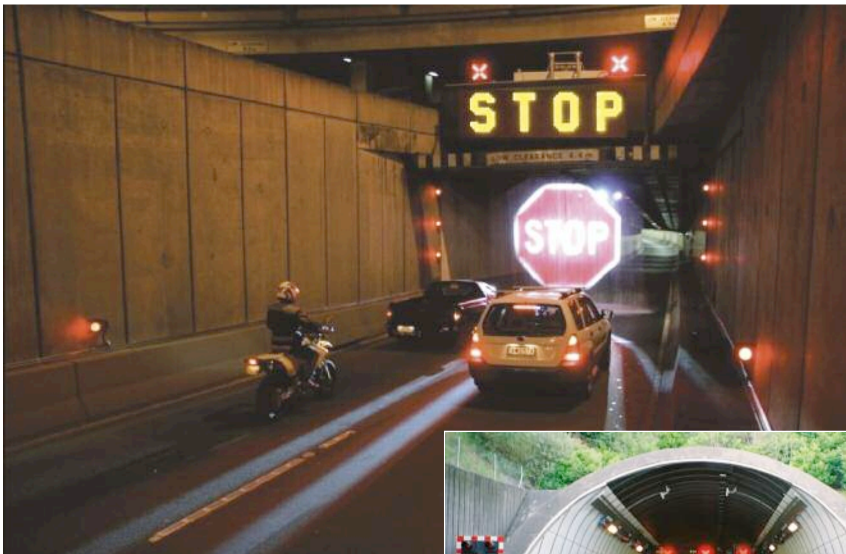
The spacing of cross passages is often driven by construction methods. If the tunnel is being driven with a TBM then construction of cross passages is expensive and time consuming, whereas in tunnels driven by drill and blast or sequental excavation techniques, construction of cross passages can be integrated into the tunnel advance. At present, various European tunnels are being constructed with spacings varying from 100m to 500m.

The third issue of protecting the structure in the event of a fire is essential to reduce the risk of long-term damage. Serious damage can delay the return of the tunnel to use and can have a dramatic effect on the local economy. The major areas that suffer in the event of a fire are the tunnel structure and the M&E equipment within the zone of the fire.

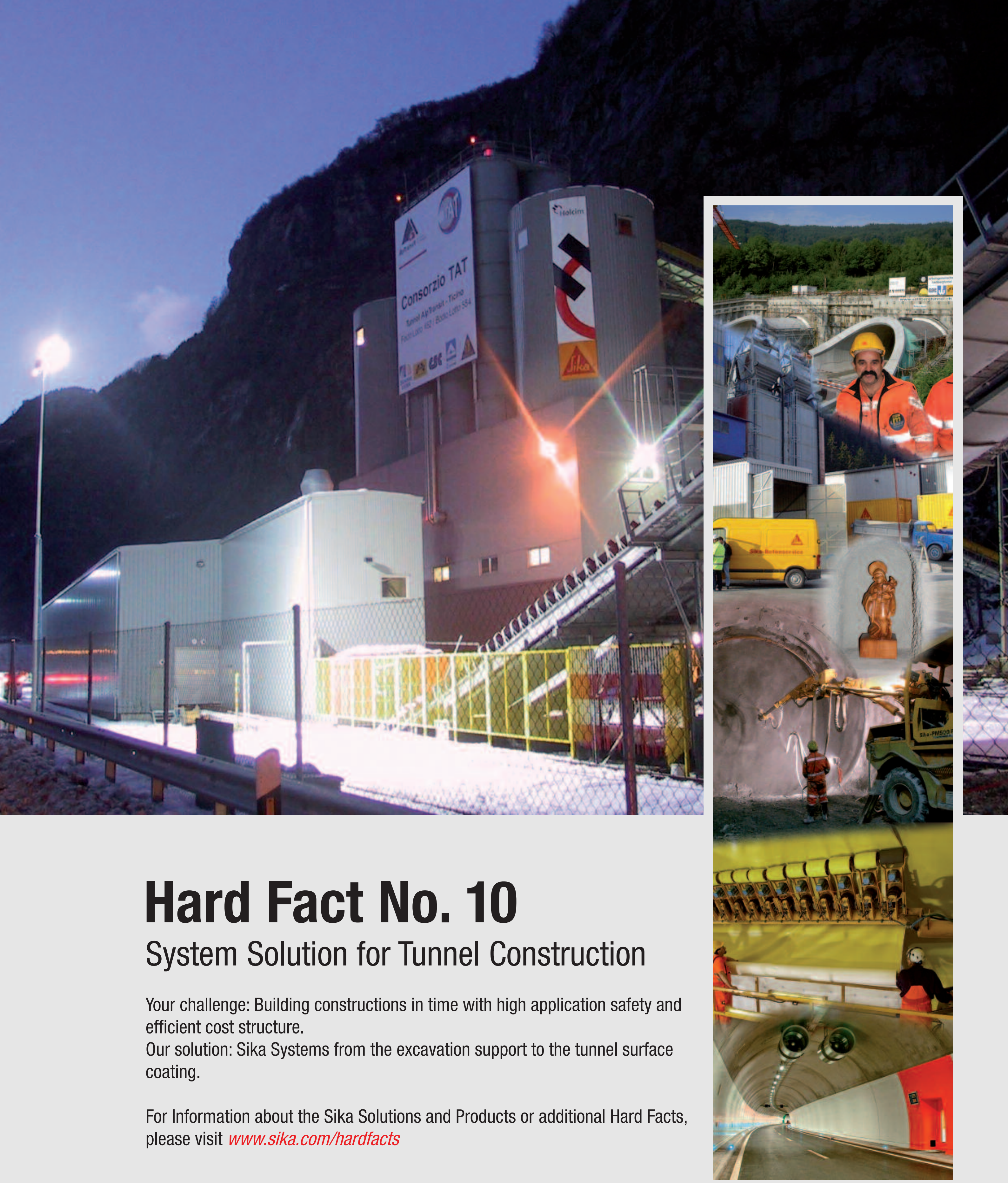
Modern use of polypropylene fibres in concrete can radically reduce spalling of the concrete and fireproof coatings and/or secondary linings can reduce the fire load on the structural concrete thereby reducing the damage and allowing the tunnel to be

Table 1: Serious European Road Tunnel Fires in last 10 Years (involving loss of life)

Date	Tunnel	Fatalities
March 1999	Mt Blanc –France	39
May 1999	Tauern – Austria	12
July 2000	Rotsethhorn – Norway	2
October 2001	Gleinalm –Austria	5
October 2001	St Gothard – Switzerland	11
November 2003	Floyfjell – Norway	1
April 2004	Baregg – Switzerland	1
June 2005	Frejus – Italy	2
September 2006	Viamala - Switzerland	9



Above: Sydney Harbour Tunnel's Laservision 'Softstop' virtual barrier
Right: Saltash's Wig Wag lights



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brought back into use in as short a time period as possible.

On the recent refurbishment of the UK's Holmesdale tunnels on the M25 motorway it was essential to protect the existing roof beams, which if subject to excessive fire load could deform and possibly collapse. In this instance a fireproofing coating was used.

Dealing with combustion

Les Fielding explained the fundamental requirements for combustion to exist, namely oxygen, heat and fuel. Using a video of a nightclub fire, Les clearly demonstrated how quickly a fire can take hold and how quickly noxious gases are produced that give rise to considerable problems for humans trying to escape. In a recent incident in London's Limehouse tunnel a bus that entered the tunnel on fire created dense smoke within the tunnel in just six minutes.

Methods of controlling fire seek to remove one of the three requirements for combustion by either starving the fire of fuel, smothering the fire and thereby removing the oxygen, or cooling the fire thereby removing the heat.

Traffic control can reduce the amount of fuel by restricting the vehicles that are involved in the fire and ventilation can help to dissipate the fumes and flammable gases that may be created.

Smothering can be achieved using water based foam suppression systems (WBFSS) for flammable hydrocarbon fires (figure 1), Tunnel Plugs or reduced Oxygen Systems (FirePass, Oxyreduct).

Cooling can be achieved using water based suppression systems, water mist systems or compressed air foam systems but all of these are expensive and need a full risk analysis to determine the cost benefit value compared with simpler protection systems.

Considerable large scale testing has been undertaken in Europe using WBFSS and these have shown that the use of WBFSS has many advantages as follows:

- Dramatically reduces heat output
- Provides thermal management in the tunnel
- Prevents fire spread
- Enhanced life safety/extended escape time
- Reduced risk to emergency responders
- Reduced closure time after the fire

Up to date Guidance has been published in the last 2 years by the National Fire Protection Association (NFPA), the World Road Association (PIARC) and the ITA project for upgrading methods of Fire safety in existing tunnels (UPTUN) on the use of fixed fire fighting systems in road tunnels.

A comparison can be made between two tunnel fires in 2007, where in Melbourne the fire was controlled reducing damage and injury, whereas in California the fire was uncontrolled and considerable damage ensued.

Design considerations

Dr John Celentano took over from Les Fielding to talk about design considerations and the need to balance risks against the final design to ensure an integrated approach.

As a result of the recent spate of fires in tunnels, fire safety has undergone a radical review with a plethora of new legislation being issued particularly in the fields of

- Life and operational safety
- Fire design requirements
- Network resilience
- Introduction of new systems

As a result designers have become confused particularly as most of the new legislation is prescriptive and often contradicts both current standards and best practise.

A number of research projects have increased the confusion with varying recommendations occasionally influenced by political needs or financial implications.

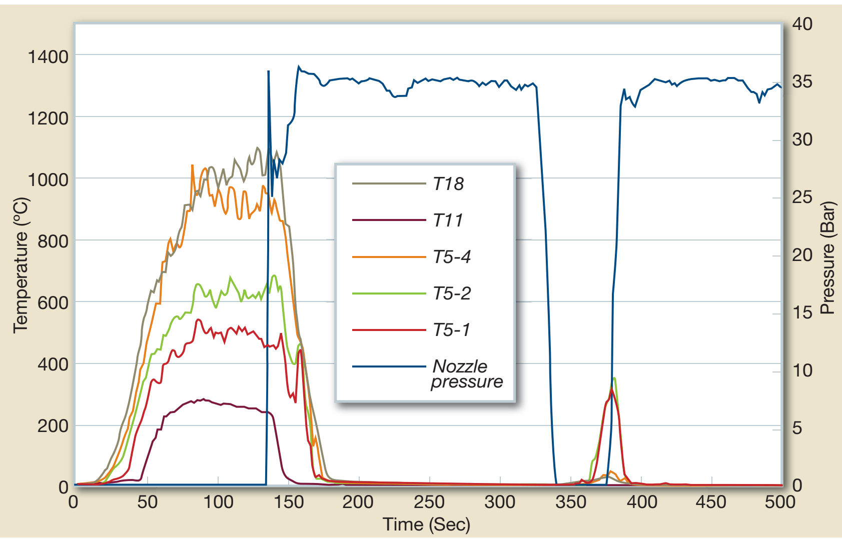
In essence there are two approaches to design of fire safety in tunnels:

- Prescriptive - where the tunnel is considered to be safe if designed to existing standards
- Risk Based - where the tunnel is safe if it meets the predefined risk criteria.

The most sensible approach is the risk based approach as this allows a structured, harmonised and transparent assessment of risk for an individual tunnel to be assessed resulting in the installation of appropriate measures to reduce and mitigate the consequences of the identified risks.

Feasibility Studies normally begin with an assessment of risk. Risk analysis can utilise simple elementary methods such as those set out in BD78/99 right up to the sophisticated systems such as Monte Carlo, in principle as the complexity increases so the subjectivity of the results

Below: Fig 1 - WBFSS – AFFF additive test Jan 2008, for a 200MW liquid fire test



Above: Holmesdale fire protection

Below: Tunnel plugs

Above: **Uncontrollable fire in the Santa Clarita Tunnel, on California's I-5**

decrease and so it is extremely important to ensure that the analysis is kept as subjective as possible.

The first requirement for designing for fire safety is to assess the actual fire size likely to occur and this is where some problems in assessment can occur. Different models have the potential to produce different results.

At the Holmesdale Tunnel, four models were considered and they all gave widely varying answers. At the moment the UK does not have a set methodology and existing design fire size charts provided by various authorities such as NFPA, PIARC and the British standard only add to the confusion by providing varying sizes.

To eliminate the design confusion in the UK there is a need for a standardised approach using standardised risk assessment models and standard design fire size curves based on recent research and studies.

At the moment there are no standard fire curves in the UK and it is necessary for designers to take an integrated approach for the system design taking into account ventilation, fire suppression, structure protection and life safety systems.

The Design can be approached from:

- Current Design Practice - where the design allows for the greatest fire size and therefore generally results in a more costly and less effective and resilient design, or
- An Integrated Design Approach - where integration of the various systems such as ventilation, structural protection and fire suppression ensures a lower fire size thereby reducing the cost and improving the efficiency and resilience of the design

Ventilation as an element of the integrated approach provides a means to dilute fire gases and direct smoke away from users. The advantages are that ventilation can prevent back-layering of heat and smoke and control of the fire as a life safety device, however it should always be remembered that a disadvantage is that uncontrolled ventilation can provide fresh oxygen thereby increasing the fire size.

Recent research by Heriot Watt University concluded that active ventilation systems were the way forward.

Structural protection as an element of the integrated design approach has considerable advantages with regard to protecting the structure of the tunnel and passive systems, which offer limited life safety protection but protect escaping people and fire fighters from explosive spalling are gaining favour.

The one drawback is that any existing standards and regulations make little reference to the subject and this needs to be swiftly rectified to allow the whole industry to move forward.

Finally, suppression systems and, in particular, water suppression have advantages in that they suppress fire growth whilst providing site safety systems, but they have the disadvantage that they need early operation to maximise their benefit, they are costly and system choice needs to be right.

Together with the above elements, it is essential to harmonise the life safety systems regarding time related criteria of detection, evacuation and operation of systems. This needs to be integrated with design decisions regarding:

- Spacing of cross passages
- Video incident detection systems
- Public announcement
- Evacuation signage
- Traffic signalling

In conclusion, design of fire safety in Tunnels needs to be standardised on the following basis:

- A UK standard design approach (Design Integration)
- Design approach should be risk based
- Design approach should integrate life and fire safety systems
- Standardised risk assessment model
- Standard UK HRR/design fire curves
- Integrated approach on the use of active ventilation, structural protection and water suppression with a view to lowering design fire sizes from the current thinking of 250MW down to 50MW.

T&T

QUESTIONS FROM THE FLOOR

Donald Lamont, from the UK's Health & Safety Executive, noted that separating the traffic in the Mont Blanc Tunnel worked effectively, whereas the same solution would not work in say the Mersey Tunnel. He also felt that inflatable pods had drawbacks particularly in rail tunnels, where it would be difficult to seal around the catenary. It was Donald's view that the first 2-3 minutes of a fire were critical and that suppression should be considered for safety. In conclusion, he asked what consideration had been given to Network Rail tunnels, where generally no escape systems were present.

Tim Healey Agreed that separation would reduce capacity. Authorities need to consider the monitoring and emergency management arrangements for the tunnel and if reduced capacity would lead to unacceptable traffic congestion on the local network. Historically, people's natural reaction is to stay with their car until told to evacuate and it was therefore necessary to improve operator response time. Les Fielding agreed that there were problems and issues with the use of inflatable pods and it would be necessary to ensure that special areas were identified for pods to be sited where fixtures and fittings did not interfere.

With regard to rail tunnels there is generally a lower risk of fire and the fire size is well known and, except for long tunnels, the safest solution is for the train to continue out of the tunnel.

Mike McConnell, retired, asked how do we achieve integrated guidelines?

Les Fielding responded that in his view we need to provide a solution to reduce the fire size by a combination of suppression, ventilation and minimal thermal protection and he confirmed that Tunnel Operators were looking at fire size

David Hindle, OTB Engineering, was very sceptical of the position taken by the speakers, in his view the slide detailing deaths was misleading and statistics would clearly indicate that tunnels are inherently safe with the major causes of accidents being weather or dangerous driving.

David's view was, that by taking the approach outlined, the industry was in danger of pricing itself out of business. Designers should take a responsible view of risk assessment by providing signage and methods of escape rather than implementing very expensive fire control/suppression systems that might never be used.

David was unaware of any deaths from fire in tunnels in the UK.

John Celentano disagreed totally with David's viewpoint, but felt that David's comments showed the need for a standardised approach to be agreed that reflected every viewpoint.

Rapporteur: David Court

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Ground freezing - principles, applications and practices

Michael Schultz and Michael Gilbert, of CDM Inc, Cambridge, MA, USA, and Helmut Hass, of CDM Consult GmbH, Bochum, Germany, describe the intricacies involved in ground freezing

Ground freezing, an innovative ground stabilisation technology, was actually developed and used in Germany as early as 1883 for shaft sinking in water-bearing soils for coal mining. It is perhaps the only technology that can create both a watertight seal and provide load carrying capability.

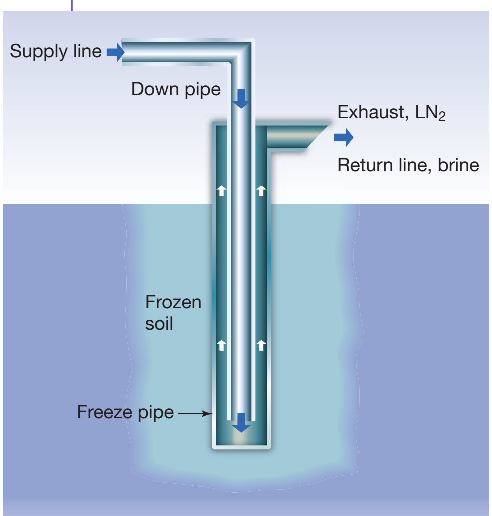
The use of ground freezing for civil underground construction projects has become common in the last 20 years. Recent technological advances, such as computational analysis, drilling technologies, mobile freeze units and the recognition that it is "environmentally friendly" have increased the number and types of applications.

Freezing principles

Ground freezing is based on withdrawing heat from the soil. The method is very safe but it must be designed in detail. The process converts in-situ pore water into ice. Like the cement paste in concrete, the ice binds the soil particles imparting strength and impermeability to the frozen soil mass.

For the creation of a frozen soil body either a row of vertical, horizontal or inclined freeze pipes have to be drilled. An open-ended inner pipe, sometimes referred to as the down-pipe, is inserted into the centre of the closed-end freeze pipe (figure 1). The down pipe is used for the supply of a cooling medium, usually brine or liquid nitrogen. The inner pipe is connected to the supply line and the outer pipe to the return line (when brine is used) or the exhaust line (when liquid nitrogen is used). The coolant flows through the inner pipe. On its way back through the annulus the coolant picks up heat and is warmed. The frost penetrates the soil and a ring of frozen soil grows around the pipes. The freeze pipes can be arranged to achieve all shapes of frozen soil walls (bodies).

Below: Fig 1 – Ground freezing principle



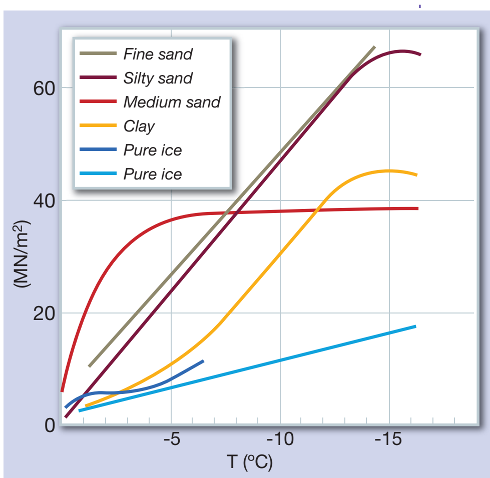
Brine freezing requires a closed circulation system and the use of refrigeration plants. The brine (usually calcium chloride $CaCl_2$) flows back through a manifold system before returning to the freeze plant. The brine supply temperature T generally ranges from T = -20°C to -37°C.

Liquid nitrogen freezing is a process by which heat is extracted from the soil through direct vaporization of a cryogenic fluid (LN2) in the freeze pipes. From an on-site storage tank or directly from a tank truck, the LN2 is fed through surface manifold system into the inner pipes. The LN2 starts to vaporize at a temperature of T = -196°C in the annulus between freeze and inner pipe, picking up heat on its way up. The cold nitrogen gas is directly vented into the atmosphere. Freezing with LN2 is fast. A frozen soil body can be formed within a few days, whereas it takes weeks for the brine system.

Frozen soil behaviour

The behaviour of frozen soil under load differs significantly from that of unfrozen soil due to the presence of ice and unfrozen water films. Freezing increases the soil's strength and stiffness. Frozen soils are subject to creep and relaxation effects and behaviour is much affected by temperature changes. The viscoelastic behaviour of ice is dependent on many factors, such as salinity, pressure, strain rate, crystal orientation, and density. A decrease of strength and stiffness from 40-60% of the initial values of frozen soil has to be thought to account for creep.

The uniaxial compressive strength (qf) of frozen soil is an important value for the structural design as well as the Young's modulus of elasticity (E). These parameters are not only time dependent but are also strongly dependent on temperature. The uniaxial strength versus temperature at full saturation is shown in Figure 2 for soil types and for pure ice. In the temperature range of interest, the strength behaviour of frozen soil is almost linear.



Above: Fig 2 - Frozen soil strength vs temperature

Groundwater flow can have a major impact on the freezing operation. Flowing water provides a continuous source of heat, and can delay the freeze-up time or (in a worst-case) a state of thermal equilibrium can be reached in which the soils stop freezing and closure (merging of the frozen soil from adjacent freeze pipes) of the freeze wall cannot be achieved. As a rule of thumb, effective flow velocities (seepage velocity) of less than 2m/day for brine freezing and 4 to 6m/day for LN2 freezing has little or no effect on the freeze wall development. Incase existing flow velocities are higher, additional measures, based on the particular project conditions, can be taken to ensure timely formation of the freeze wall.

Investigation and lab testing

As discussed, groundwater flow can have a major impact on freezing. The hydraulic conductivity (k) and gradient on the site must be determined in order to evaluate existing and potential groundwater flow conditions. Attention must be paid to possibly increased flow velocities in localized zones of coarse-

grained layers including dewatering measures that may influence the groundwater flow and result in high groundwater velocities.

When the ground freezing method is used additional subsurface investigations are required. Soil conditions should be investigated using continuous undisturbed sampling to get a soil profile with depth.

A programme is required to verify the estimated soil parameter values or to determine the range of soil parameters for frozen and thawed conditions. The test programme should be conducted by experienced personnel in a special laboratory for frozen samples and include index properties; frost heave tests; and geotechnical soil properties for unfrozen, frozen, and thawed samples.

Design of ground freeze systems

Sufficient thermal and structural calculations are required for the design of a ground freezing project. The thermal design determines the time to form the freeze wall, freeze plant capacity, freeze plant operation during maintenance freezing, and temperature development as well as temperature distribution in the soils. The structural design provides the dimensions of the freeze wall and the required average freeze wall temperature.

The thermal design can be based on rough calculations for the freeze wall growth and the heat flux using analytical methods during pre-design. In most final designs thermal calculations using the Finite Element Method (FEM) are required to verify results of the pre-design and to optimize the freeze pipe spacing and arrangement, freeze plant capacity, and the whole freeze system layout. With this method the actual conditions (freeze pipe spacing and location, interrelation of adjacent freeze pipes, dependencies of freeze wall growth between different layers, etc.) can best be considered.

Structural design is required when the frozen soil body serves as a structural element. For many practical applications, it is sufficient to check the stress in the structural design of the freeze walls. The required structural design data for the allowable stress, Young's modulus, and shear parameters will be determined using the estimated frozen soil stand-up time. The basis for a sound structural design of a load-bearing frozen soil is knowledge of the time and temperature dependent strength and deformation properties of the material.

Monitoring and quality control

During construction, the development of the frozen soil has to be monitored. To check and control the freezing process, the operation of the freezing system must be monitored. Temperature measurements in the soil are strongly recommended. Thermocouples in temperature monitoring holes should be placed at expected critical areas. Figure 3 presents an example of the time dependent development of the frozen soil thickness based on temperature monitoring data compared with results based on thermal FE-calculations.

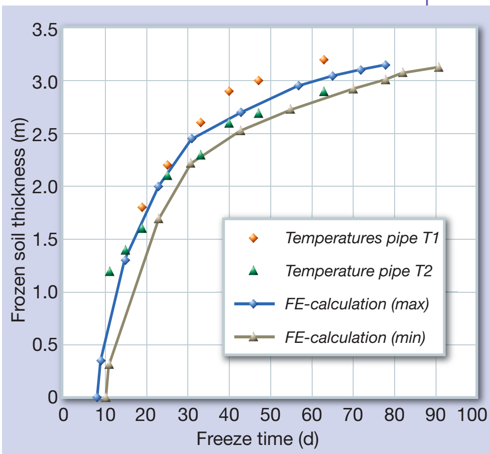
The location and deviation of each freeze pipe and temperature monitoring pipe should be determined by survey. Based on the survey data of all pipes the actual location of the pipes can be evaluated to asses if the freeze pipe spacing is sufficient at all locations. If required, additional pipes can be installed before freezing operations start. The actual location of the freeze pipes and the thermocouples can be incorporated in the thermal finite element model and the time dependent temperatures can be used for direct comparison with the related thermocouple readings during freezing. Also, a monitoring programme for deformation measurements should be provided.

Contracting practices

Contracting practices for ground freezing vary between the United States and Europe. These differences influence the uses of the technology, particularly in the US. Traditional Design-Bid-Build (DBB) in the US and the interpretation and separation of design vs contractor means and methods often work against the innovative use of ground freezing. In addition, the small number and size of contractors specialising in ground freezing in the US, as compared to Europe, and the lack of innovation and adaptation of technological advances limits the use, especially in horizontal applications.

Ground freezing is generally considered a stabilisation technology that competes with other ground water and structural stabilisation techniques. As such it is considered part of the contractor's mean and methods. Unfortunately, the use of ground freezing, as stated earlier, must be considered during the design in order to effectively be used. Whereas grouting technologies can typically use the geotechnical parameters developed from a "normal" geotechnical study, ground freezing must consider the specific data collection and testing discussed earlier that are typically beyond most geotechnical studies.

The current state of the practice in the tunnelling and underground construction projects, at least in the US, has accepted the use of the Geotechnical Baseline Report (GBR) as a contract document. This development has contributed to the ability of the designer to effectively assess the use of all stabilisation technologies and has created a further need to develop the parameters



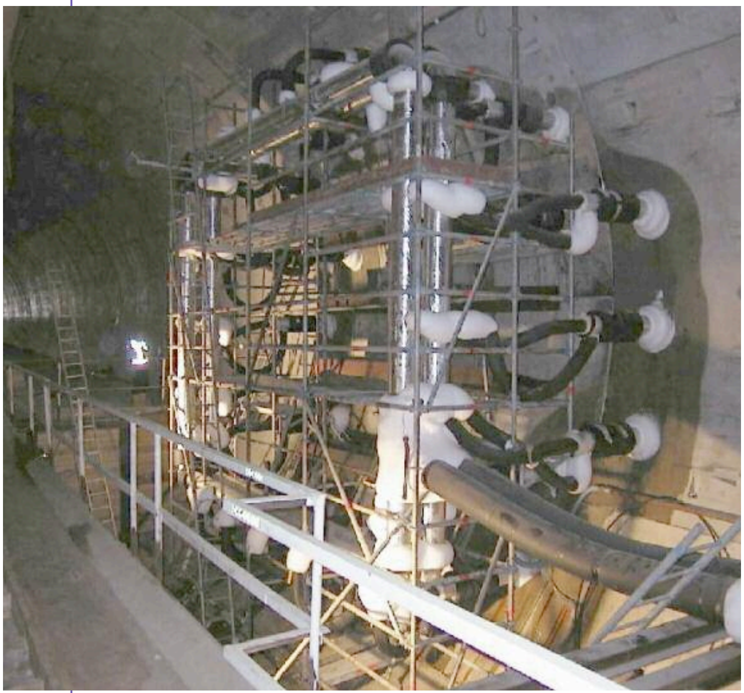
Above: **Fig 3 – Comparison of temperature monitoring and FE-calculation results**

and conceptual designs for ground freezing during the design stage.

To demonstrate the differences in technological advances as well as contracting practices, case studies from both the United States and Europe should be referenced. The Brightwater Conveyance Project, in Seattle, is a prime example of the vertical ground freezing practice used in the US. The Ballinger Way Portal for the Brightwater Central Tunnel Contract consists of a 7.3m i.d. shaft with a bottom slab at a depth of 67.3m. Two methods of support for this excavation were presented in the contract documents: slurry wall or ground freezing. The ground freezing alternative provided the bidders with strength data of frozen soil in the GBR. Baseline values of each soil unit for the short term and time dependent frozen soil parameters were provided in the GBR.

The design submittals had to address: thermal calculations for initial and maintenance phases; coolant plant and pump requirements and estimates of time to attain closure. The freeze time calculations were required for both the planned location

Below: **The frozen Brightwater shaft at a depth of 35m**



Above: Ground freezing equipment in use at Westerscheldetunnel

Above: Access shaft of the tunnel track in Düsseldorf

of freeze elements as well as for the actual installed locations.

To date, the excavation has successfully reached final depth with the contractor installing the final portal wall lining.

In contrast, the Westerscheldetunnel, located in the western part of the Netherlands, demonstrates the use of horizontal freezing using advanced equipment designed for the project. The tunnel project consisted of two tubes each with two road lanes. The 11.33m diameter, 6.6km long tunnel tubes were driven under sea using two TBMs with a lowest elevation of approx. 60m below MSL.

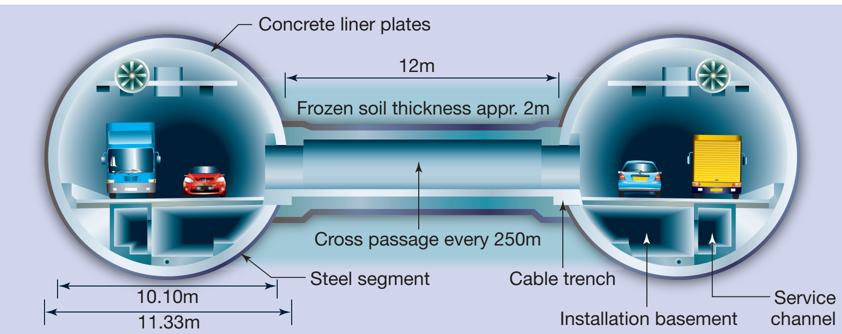
Each cross-passage freeze zone consists of 22 freeze pipes and two temperature monitoring pipes (figure 4). A major construction problem encountered with the installation of the freeze pipes was the extremely high water pressure. To fit these installations, a special sleeve was designed. The borings were drilled from the eastern tunnel tube to the western tube, using a specially enhanced lost bit drilling technique.

The Düsseldorf mass transit subway system expansion, in Germany, is another good example of European practices. Four 40m long tunnels were excavated directly below buildings and a major roadway. All four tunnels were advanced using the Sequential Excavation Method (SEM) formerly called New Austrian Tunnelling Method (NATM). In each case, there was very little space between the roof of the tunnel and the bottom of overlying building foundations. As a result, any ground loss or other causes of settlement due to tunneling, would have lead to direct and adverse movement to the building foundations.

For the driving of three of the tunnels, the gravel and sands were stabilised and the groundwater was controlled by ground freezing using a brine coolant. For the ground freezing operation of the three tunnels a freeze plant of two units with an operating brine temperature of T = -35°C and a capacity of 330kW each were used. The freeze plant was installed in an isolated hall because of the urban residential area.

The access shaft was located in the backyard of two residential buildings in very tight highly-demanding urban conditions. All of the tunnels were driven without incident and with only negligible subsidence to the buildings and the main road directly above the tunnels. T&T

Below: Figure 4 – Section in the area of a cross-passage



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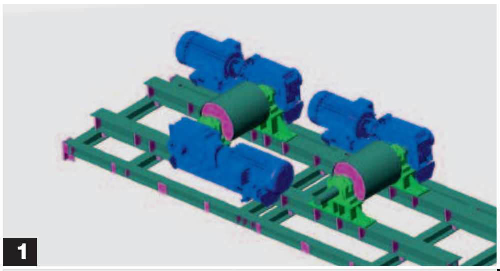

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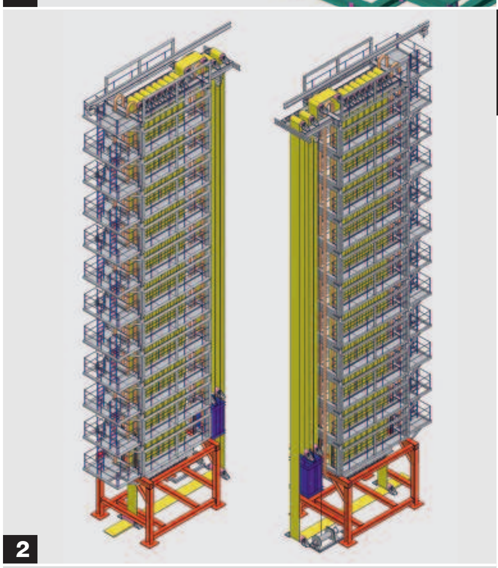

2

1 Computer rendering of a two-drum driving station

2 Computer rendering of the conveyor belt storage for Crevola Toce III hydropower tunnel, Italy

Marti Technik 3D designed belt conveyors

The growing mechanisation and the increased advance rates have brought Marti Technik to develop high-performance logistics systems. According to geology, the tunnelling method, the power and muck removal concept as well as the final dump site, Marti Technik designs an environment-friendly, tailored-made concept. The goal is to maximise the advance rate.

State-of-the-art techniques allow conveyor belt installations in tunnels up to 11,000 m of length (between axes), powered by a head station at the portal. Complex applications demand belt conveying systems able to cope with curves, slopes or lack of space, especially in urban areas.

Marti Technik perfects constantly its calculation methods thanks to the implementation of various projects and verifies them in the practice. That allows a computer-aided calculation of the conveyor system in a few hours. All the essential parameters of the system are defined, such as the belt tension, the stationary or not stationary driving power, the behaviour in curves (inclined position), the fill rate, and the friction coefficients. 3D computer models are developed and integrated into the tunnelling method concept.

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Pre-excavation grouting in soil or rock

Alex Naudts, of ECO Grouting Specialists Ltd, takes an indepth look at pre-excavation grouting and offers advice for successful applications

Quite often, prior to or during tunnelling, there is a need to stabilise the ground and (or) to reduce the permeability of the formation. Typically, pre-excavation grouting (PEG) is used to achieve this. PEG can be used both in rock and soil formations.

In soils, PEG is a predictable and reliable technique performed to prevent or minimise settlement. It protects the infrastructure above the tunnel alignment. Cement based suspension grouts (regular and microfine) and sodium silicate based grouts are typically injected to consolidate and strengthen the formation and create a reinforced canopy above the tunnel trajectory. Incase of low to medium flow conditions, water-reactive polyurethane grout is often used. For extreme flow conditions, hot bitumen grouting produces results in a reliable and predictable manner.

Grouting in soils is typically performed through permeation and permeation in conjunction with hydro-fracturing. Multiple injection passes through steel sleeve pipes are ideal, since they also create an effective forespiling system to facilitate tunnelling without causing unacceptable settlement, even with minimal overburden thickness.

For PEG in rock grouting, typically, a reduction of water inflow is the main objective. There are, however, situations (faults, badly fissured rock, karsts, etc.) where grouting is mainly required to strengthen the rock formation. Far too often, designers fail to realise that, in order for a grouted rock envelope to create a reduction of inflow into an unlined opening underground, the hydraulic conductivity has to be reduced to a very low number.

As a result, more often than not, the inflow into the tunnel is still aperture limited and the grouting operation does not impact on the inflow. Hutchinson[1] invented the WIRF theory and Naudts[2] developed the GFP theory to correlate the residual hydraulic conductivity in the grouted rock envelope with the tunnel inflows.

PEG in soil formations

In order to protect structures and minimise or prevent settlement, grouting the soils prior to tunnelling has been a classic and proven concept for more than five decades.

Above: **Sleeve pipe installation (five rows) above a future tunnel trajectory in Columbus, Ohio, in 2008**
Right: **Horizontal sleeve pipe used to create a grouted arch below a railway in Newport, Minnesota, in 2006**

The following pro-active grouting techniques and systems are typically used:

- Permeation grouting single pass
- Permeation grouting multiple passes and more than one type of grout
- Hydro-fracture grouting
- Permeation grouting in conjunction with hydro-fracturing
- Jet-grouting

A commonly used reactive grouting system to attempt and achieve the same, is compensation grouting. The latter can be used in conjunction with some of the pro-active techniques, for soils that cannot be adequately treated prior to tunnelling.

Permeation grouting ("pure" or in conjunction with hydro-fracturing), provided

the soils have a hydraulic conductivity (permeability value) greater than 0.0005cm/s - remains the least intrusive, clean, predictable grouting system to treat the soils prior to tunnelling. To be successful, it is absolutely necessary to use sleeve pipes and to perform multiple grout passes, via the same sleeve pipes with reasonably durable grouts.

Sleeve pipes can be installed vertically or (preferably and where possible) horizontally to create an arch of grouted soil covering at least the upper half of the future tunnel. The advantage of horizontal sleeve pipes (whether steel or plastic) is, that they can be transformed into a grouted forespiling system, a continuous, reinforced grouted earth, whereby only a short span at the time is unsupported during tunnelling.

The grouts selected for permeation grouting must be suitable for the encountered soils.

In general, properly formulated, stable cement based suspension grouts are only suitable for the grouting of soils with a k-value (permeability value) in excess of 0.08cm/s. Stable, microfine cement based grouts are typically suitable to permeate soils with a k-value greater than 0.001cm/s, provided the silt content is less than 13%. Both these 2 types of grouts however can be used for "permeation grouting in conjunction with hydro-fracturing" even when the soils have a k-value which is lower.

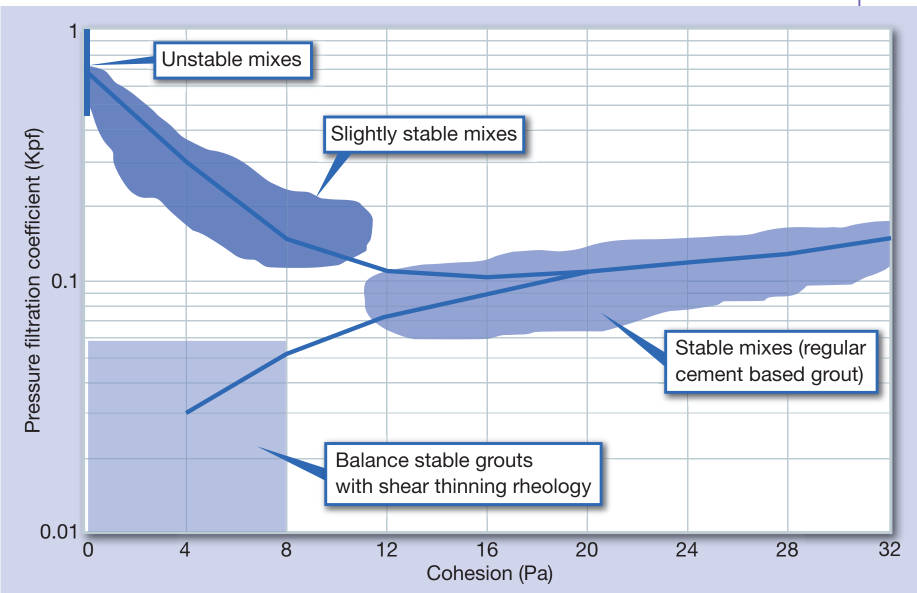
Solution grouts can typically be used for permeation grouting as long as k is greater than 0.0005cm/s. The layer thickness and the silt percentage also play an important role in the injectability of the soils and the permeability limits are therefore only indicative.

It is a proven concept to utilise several grout passes, alternating between solution grout (typically sodium silicate based grout) and cement based grout, to create grout cylinders with a predictable diameter and mechanical characteristics.

Because of the high pH of cement based grouts, sodium silicate based solution grouts tend to be considerably more durable than if only sodium silicate based grouts are used.

During the first grouting pass, grout will predominantly permeate the most pervious layers in the pressurised grout zones. Once the first grouting pass is finished, solution grout might sag, under gravity. The soil dissipates the heat (from the exothermic reaction) and hence it will take considerably longer for the grout to gel (in-situ) than the pot-life indicates. As a result there could be grout migration after the grouting pass is finished, in pervious soils. During the second grout pass, the layers that were originally the most pervious are now the least pervious; hence grout will permeate more readily into these layers during the second grout pass.

By alternating solution grouts with suspension grouts, the suspension grouts will hydrofracture through the untreated or partly treated soil layers. From the grout "wings" grout will permeate a nominal



Above: **Fig 1 – Pressure filtration v's cohesion for PEG**

distance into the soil on both sides of the induced fractures.

By executing 3-4 grout passes, the formation gets treated more uniformly and grout cylinders with a predictable size are formed. The grout spread that can be obtained with the equation of Cambefort-Naudts[3].

Especially when grouting below the groundwater table, classic sodium silicate based grouts are quickly deteriorating, even when neutralised more than 60%. If a higher degree of neutralisation is used, the set time of these evolutive solution grouts are too short to obtain adequate permeation. For the longest time, the only alternative to the "unstable" sodium silicate based grouts were water-reactive polyurethane grouts and acrylamide grouts. The latter are non-evolutive solution grouts and have a viscosity equal to water. Some formidable soil grouting projects have been performed with both polyurethane and acrylamide grouts.

Nowadays, there are however durable, inexpensive, non-evolutive sodium silicate grouts, even when injected below the water table but they are not yet widely used.

Jet grouting has been used for the treatment of a large variety of soils. Whilst it is technically feasible to use jet-grouting in soils that can be treated with permeation grouting, preferably, jet-grouting should only be used in soils with low hydraulic conductivity. Because of its perceived simplicity and in spite of the mess (spoils) that is created, it remains the technique of choice for some grouting contractors. Heaving and settlement of the structures to be protected has been a problem. Executing a horizontal jet grout curtain remains a major challenge with this technique.

PEG in rock with cement based grouts

PEG in rock is almost exclusively permeation grouting. One of the key issues is that the grout must be substantially amenable to the formation. This means, in case of suspension grouts, the particles must be able to pass through the fissures. This automatically results in a change from regular to microfine cement based grouts if the amenability coefficient is too low and a change from microfine cement to solution grout for the same reason.

The starter mix should be "in the box" (figure 1), comparable to the strike zone in baseball; the suspension grout should have cohesion less than 8 pascal and a Kpf less than 50 x 10^{-3} $min^{-1/2}$ for optimum penetrability.

The three ground rules for professional rock grouting are:

- The grout must be "in the box"
- The grout mixes have to be amenable to the formation
- The grout mixes must be adjusted during the grouting operation based on the evolution of the apparent permeability

If these three rules are followed, a highly effective rock grouting operation will be executed[4].

The Grouting Intensity Number (GIN)[5] theory was only a first step towards an engineered approach in rock grouting. This theory, however, only has merit if a grout formulation is highly amenable to the formation, and the grout does not washout. For this reason, this author

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developed the Apparent Lugeon Theory[4] which invariably leads to successful rock grouting projects. It is the mathematical model for several computerised real time monitoring and assessment systems used world-wide.

The state-of-the-art in engineering and directing a professional rock grouting is to change the sequence of mixes as follows:

1. Utilise a stable balanced suspension grout as a starter mix. Make the appropriate changes (use of finer suspension grouts) to obtain adequate amenability.
2. If the apparent Lugeon value does not decrease, gradually increase the solids of the mix, keeping the formation "inside the strike zone".
3. Circumstances permitting, gradually increase the solids content until the Lugeon value starts to decrease slowly.
4. Only when it becomes apparent that a very viscous and thixotropic grout is needed, (i.e. the apparent Lugeon value only decreases slowly or not at all) should one go outside the "strike zone" and increase the cohesion of the grout to values exceeding 8 Pascal. The maximum cohesion that should be used is 80 Pascal, in order to prevent plugging the grout lines.

Neat cement grouts contain two products that are not very compatible: water and cement. Stokes' Law governs the sedimentation of the particles; the finer they are, the slower the process. Segregation causes bleed paths to form unless a low water/cement ratio is used. The resistance against pressure filtration of these grouts is poor, compared to balanced, stable suspension grouts. In rock and structural grouting, this lack of grout stability causes bleed water migration through the gelling grout. This creates pathways and bleed-pockets in the upper part of the cracks and crevices in which erosion and chemical attack can take place.

To obtain durable suspension grouts, the calcium hydroxide formed between the chemically resistant, hard ettringite in the cured cement paste, needs to be tied up and also turned into (secondary) ettringite. The ability to modify viscosity, cohesion, bleed, gel-time, resistance against pressure filtration, and strength of cement-based grouts is essential to ensure a high quality end product.

The amenability concept

The amenability theory was developed by Naudts in 1994[6]. The amenability coefficient (Ac) is determined by dividing the apparent Lugeon value of the formation (Lugr) determined by using grout as the test fluid; by the initial Lugeon value of the formation determined during water testing (Luwa). For field applications in rock grouting, the following equation is used to calculate the apparent Lugeon value:

$$Lu_{gr} = \frac{flow\ (l/\text{min}) \times 1m \times 143\ psi \times V_{marsh\ gr}\ (\text{sec})}{1l/\text{min} \times L_{zone}\ (m) \times P_{effective}\ (psi) \times 28\ \text{sec}}$$

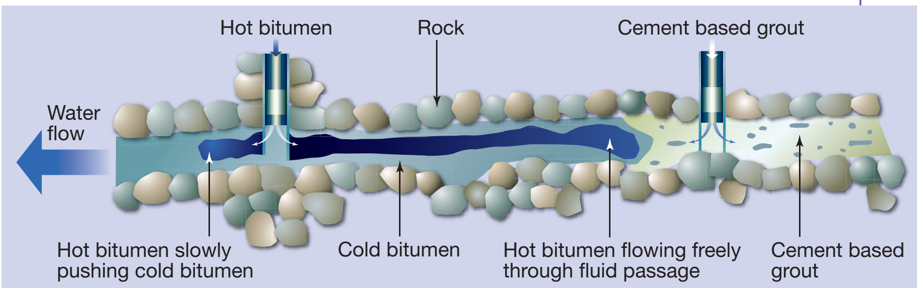
Amenability is a measure of the suitability for a given suspension grout to permeate fissures and apertures, accessible to water, in the grout-zone. Since Luwa is directly related to the aperture size of the fissures and open pores intersected by a borehole, it is clear that not all of these apertures are accessible to a selected grout. Only the fissures or pore channels that are wide enough will accept the grout. Hence the permeability coefficient established with grout is directly related to the aperture width of the fissures intersected by the borehole that can accept grout. By dividing Lugrout by Luwa the percentage of open apertures intersected by a borehole accessible to grout is given. Hence, Ac = Lugr/Luwa

The amenability coefficient (Ac) will immediately signal if the selected formulation is suitable, somewhat suitable or not suitable at all. The amenability coefficient indicates where, or if, regular cement-based grout is no longer suitable and one has to resort to a formulation with finer particles. Expensive and useless grouting operations can be avoided if the amenability of the formation is recognised to be too low.

The amenability coefficient is calculated early in the operation. The apparent Lugeon value, however, is calculated on a continuous basis as the grouting operation progresses. The apparent Lugeon value combines flow and pressure; the main grouting data. In a properly executed grouting operation, the apparent Lugeon value will decrease with time. If the apparent Lugeon value remains constant or increases, it means that gouge or drill cuttings are being displaced or that the grout is sagging or is being washed out.

If on the other hand, the apparent Lugeon value is decreasing quickly, it means that "particle pick-up" is taking place or that the solids content is too high or that a grout with a lower pressure filtration coefficient is needed. The role of additives and admixtures is to optimise the effectiveness of formulations in relation to the hydro geological conditions encountered in the formation.

Since 1996, the real time monitoring and recording of the apparent Lugeon value has been computerized (CAGES)[6].



Above: **Fig 2 – Hot bitumen penetration**

Solution grouts for rock grouting

Classic sodium silicate grouts are not recommended for rock grouting because of durability issues and syneresis (resulting in unacceptable residual permeability). Only the more advanced, durable, non evolutive sodium silicate grout should be considered.

When using water reactive polyurethane grouts, only the hydrophobic, rigid or semi-rigid, MDI types should be considered. The hydrophilic polyurethane are not suitable because of durability and other issues. Only the second and third generation of water reactive polyurethane should be used since some do not react, even under moderate pressure.

Acrylamide grout is a grout with the viscosity of water. It can be safely used if the proper protocol is followed. The set time of this non-evolutive solution grout can be varied from a few seconds to nine hours. It is possible to reduce the permeability of a rock formation to less than 0.1 Lu.

Acrylate grouts have a similar cross linking system as acrylamide grouts. There are sodium, magnesium and calcium acrylates. Some of these grouts have durability problems and excessive water absorption after gelation.

Rock grouting with hot bitumen

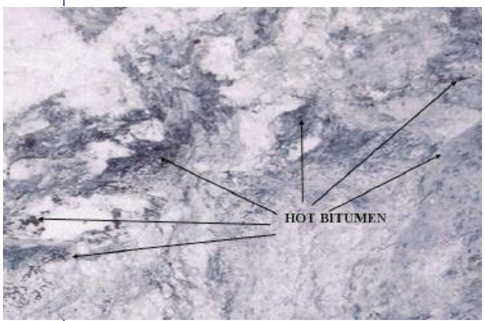
The nature of most bitumen grouting projects typically involves situations in which very serious water inflow problems needed to be solved.

When hot bitumen is injected into a

medium with running water, it cools quickly at the interface with water. Steam is created at that point, decreasing the viscosity of the bitumen. The steam acts as an "air lift" drawing the bitumen into its pathway through small and large fissures or pore channels. The centre of the bitumen mass remains hot, and, as a result of the grouting pressure, continuously breaks through (re-melting) the skin formed at the interface of the water. The faster the water flows, the faster the bitumen cools off. The skin prevents wash-out, while the "sheltered" hot bitumen behind the skin behaves as a Newtonian fluid, penetrating in a similar fashion as solution grouts. Hot bitumen permeates fissures as narrow as 5 micron.

When hot bitumen cools it is subject to significant thermal shrinkage. This phenomenon is partially overcome in smaller fractures if pressure continues to be applied and warmer bitumen pushes the cooling bitumen into the shrinkage gaps. Cement based suspension grout is often injected in conjunction with hot bitumen to compensate for the thermal shrinkage of the bitumen; to make the bitumen less susceptible to creep; and to increase the mechanical strength of the end product. Pre-excavation grouting at the New Yung Chung Tunnel was successfully performed with hot bitumen (flow: 4,000-6000l/s under a hydrostatic head of 50 bar). T&T

Below: View of tunnel face - hot bitumen penetrating large and fine fissures in Marble formation in the Yung Chung Tunnel, Taiwan in 2002



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WEBSITE DIRECTORY

Dates & Events

22-27 SEPTEMBER
2008 ITA World Tunnel Congress
Agra, India
The 34th ITA General Assembly and Congress will be held at the Hotel Jaypee Palace, in Agra. In view of the large scale tunnelling works in India, there is much scope for agencies to demonstrate their capabilities and network. Contact: CBIP; email: sunil@cpib.org; web: www.wtc2008.org

23-26 SEPTEMBER
InnoTrans 2008
Berlin, Germany
This international convention and trade fair for transport technology, including railway infrastructure, interiors, public transport and tunnel construction. The conference has become an increasingly popular addition to the event calendar. Contact: Messe Berlin; Web: www.innotrans.com

6-8 OCTOBER
International Congress 'Building Underground for the future,' Monaco
Organised by the Association Francais des Tunnels et de l'Espace Souterrain (AFTES), the three day event will consider the future use of the underground space with papers presented from all walks of the tunnelling spectrum. Contact: AFTES: email: aftes@snc.fr; web; www.aftes.asso.fr

8-10 OCTOBER
6th Austrian Tunnel Day 2008
Salzburg, Austria
Organised by the Austrian Society for Geomechanics (OEGG), topics for the 6th Austrian Tunnel Day include: Tunnelling in the past and present; Special challenges on large current projects; and a panel discussion entitled "Fair construction execution - economic construction". Contact: OEGG: email: salzburg@oegg.at; web: www.oegg.at

16 OCTOBER
Tunnelling 2008
London, United Kingdom
This one day conference, supported by the British Tunnelling Society, includes project updates on the Crossrail and Thames Tideway projects, as well as National Grid's cable tunnel projects. Contact: Melanie Putzki; Tel: +44 20 7728 5232; web: www.tunnelling2008.co.uk

22-24 OCTOBER
Underground Infrastructure of Urban Areas, Wroclaw, Poland
The conference is organised by the Urban Engineering division of the Institute of Civil Engineering, Wroclaw University of Technology, in association with the ITA, ISTT and EFUC (European Forum on Underground Construction). Contact: tel: +48 71 320 2914; email: andrzej.kolonko@pwr.wroc.pl; web: www.bliw.wroc.pl/uiua/2008

27-28 OCTOBER
20th National Conference, Tunnelling Technology & The Environment Niagara, Ontario, Canada
Organised by TAC, the Tunnelling Association of Canada, this year's conference focuses on Tunnelling Technology and The Environment. Contact: +1 604 629 1736; email: info@tunnelcanada.ca; web: www.tunnelcanada.ca

10-12 NOVEMBER
ICDE 2008, Challenges and Risk Management of Underground Construction, Singapore
The International Conference on Deep Excavations (ICDE) is an ITA sponsored event organised by TUCSS. It aims to be a forum for contractors, engineers and owners to share and discuss experience. Contact: TUCSS; email: info@tucss.org.sg

10-13 NOVEMBER
CityBuill, 5th Underground City 2008, Moscow, Russia
An annual event to demonstrate experience in the development of the underground space for the creation of city infrastructure and increase the attractiveness of investing in multipurpose underground structures. Contact: Tel: +7 (495)9802186; email: irb@global-expo.ru; web: www.city-build.ru

MAY 2009
Tunnels & Underground Spaces for Transportation & Urban Development Tehran, Iran
The 8th Iranian conference on tunnelling and underground spaces is designed to act as a platform for national and international companies to demonstrate their capabilities, in view of the large number of tunnelling projects being planned in this country. Contact: Iranian Tunneling Association; Tel: 98 21 8863 0495; email: info@irta.ir; web: www.irta.ir

23-28 MAY
2009 ITA World Tunnel Congress
Budapest, Hungary
The 35th ITA General Assembly and Congress will be held in Budapest. With a large amount of tunnelling underway and in planning, the organisers are confident it will be a successful event. Contact: Diamond Congress; email: secretariat@ wtc2009.org; web: ww.wtc2009.org

14-17 JUNE
RETC 2009
Las Vegas, Nevada, USA
RETC is recognised as a leading international tunnelling event for contractors and engineers. Last year, conference attendance exceeded 1500 professionals from more than 30 countries and the exhibition sold out in record time. With a venue of Las Vegas, 2009 is sure to be even more of a success. Contact: SME; web: www.retc.org

22-25 JUNE
5th Symposium of Strait Crossings
Trondheim, Norway
Organised by SINTEF and the Norwegian University of Science and Technology, this major symposium aims to act as a forum for the exchange of information, research, new technology and recent experience. The event will also include an exhibition. Contact: NTNU; email: sc09@adm.ntnu.no; web: www.straitcrossings.com

09-11 SEPTEMBER
EURO:TUN 2009
Bochum, Germany
The 2nd International Conference on Computational Methods in Tunnelling. Organised by the Institute for Structural Mechanics. Contact: Conference Secretariat: Tel: +49 234 32 29051; web: www.eurotun.rub.de

BRITISH TUNNELLING SOCIETY

16 OCTOBER: **Dubai Metro Tunnels**
Design and construction of the red and green lines in challenging ground conditions. Note, this meeting will take place at Earls Court Conference Centre following the Tunnelling 2008 Conference.

12 NOVEMBER: **2nd Avenue Subway**
Joint meeting with BGA on the Geotechnical Design and Construction of New York's mega project. 5.30pm for 6pm, at the ICE, Westminster, London.

09-11 SEPTEMBER
EURO:TUN 2009
Bochum, Germany
The 2nd International Conference on Computational Methods in Tunnelling. Organised by the Institute for Structural Mechanics. Contact: Conference Secretariat: Tel: +49 234 32 29051; web: www.eurotun.rub.de

02-04 MARCH 2010
International Conference on Tunnelling, Kuala Lumpar, Malaysia
Organised by IEM - Tunnelling and Underground Space Division, The Institute of Engineers Malaysia. Contact: Tel: +60 3 79 68 40 01; web: www.iem.org.my/ external/ tunnel/index.htm

14-20 MAY
2010 ITA World Tunnel Congress, Vancouver, Canada
Prior to the 2010 Winter Olympics, ITA visits Vancouver for its yearly conference and exhibition. Contact: web: www.wtc2010.org

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition that is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site: Tris Thomas, 'Tunnels & Tunnelling International', Progressive House, 2 Maidstone Road, Sidcup, Kent DA14 5HZ, United Kingdom.
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REPRO/PRINT

Tunnels & Tunnelling International is printed at Broglia Press, Poole, Dorset, United Kingdom

Tunnels & Tunnelling International ISSN number 0041-414X is published monthly for US$226 a year by Progressive Media Markets Ltd, Progressive House, 2 Maidstone Road, Sidcup DA14 5HZ, UK. Periodicals postage paid at Rahway, NJ.

POSTMASTER: send address corrections to Tunnels & Tunnelling International c/o BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001. US agent: BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001.

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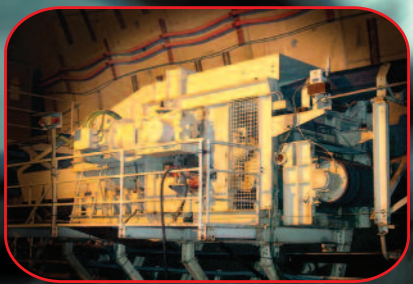

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