DECEMBER 2009

tunnels & tunnelling INTERNATIONAL

FOCUS ON TBM

T&TI looks at the TBM recovery on Gilgel Gibe and deep boring in Peru

PRECAST SEGMENTAL LININGS

A review of moulding and reinforcement options for precast tunnel linings

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The McNally support system of steel slats bolted to the roof of the Olmas Trans-Andean deep bore tunnel in Peru is used to better contain the fractured rock (p23).

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Segments moulds by Ceresola for the second tube of the Kaiser-Wilhelm-Tunnel in the Mosel Valley, Germany

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Damage to the tunnel lining on the Gilgel Gibe headrace tunnel marks the start of Event 19 which delayed the job by two years

GUANGZHOU: SUBWAY CONSTRUCTION AT FULL SPEED FOR THE ASIAN GAMES.

The tunnel constructors in Guangzhou are forging ahead with a gigantic and innovative project. By 2010, they will have built around 145 kilometers of underground subway tunnels using Herrenknecht EPB Shields and Mixshields. The 16th Asian Games will be opened in the southern Chinese mega-city on November 11, 2010. By then, an efficient subway network must be available for up to 3.5 million passengers per day. Herrenknecht delivered a total of 41 EPB Shields and 6 Mixshields for the Guangzhou subway. 17 Herrenknecht TBMs are forging ahead with the new construction of Subway Line 5, and 19 machines are employed for the extension of Line 3. Here, the tunnelling teams are moving forward at rates of up to almost 50 meters per day (S-490 EPB Shield), setting the pace for Chinese metro tunnelling.

The speed of China's infrastructure construction projects is unprecedented – in particular when newly building and extending subway networks. Chinese construction companies are using a total of 112 Herrenknecht machines in eight multi-million mega cities to construct more than 300 kilometers of new tunnels.

GUANGZHOU | CHINA

PROJECT DATA

6x Mixshields, 41x EPB Shields
Diameter: 6,250mm
Cutterhead power:
40x 945kW, 6x 630kW, 1x 1,200kW
Tunnel length: around a total of 145km

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Firm belief

Below is a copy of a memo I recently sent to the Climate Change Summit in Copenhagen:

Dear World Leaders,
I write with urgency. Evidence has come to light that will radically alter the global approach to climate change.

Since August 15, 2009 I have taken readings from two thermometers on the outside west facing wall of my flat in North London. Readings were taken every four hours by two technicians and individually inputted in to two separate and secure databases. The readings have revealed a shocking truth. There has been an average temperature drop of 0.1oC per day since the records began.

If North London's inhabitants continue to be faced by this trend in one and a half years we will be living in the coldest outside temperatures on earth.

To increase our understanding of the current trend I reviewed Met Office data for temperatures in the rest of London and the UK and found they too were threatened by a return to the ice age. Further research revealed the entire northern hemisphere was seeing falling temperatures, some of them recording temperature drops of 0.2oC per day!

My next step was to gather data from weather stations spread across the southern hemisphere. The results were alarming. The weather stations recorded temperature increases of a rate equal to the falling temperatures in the northern hemisphere.

I embarked on an expedition to discover the causes of this trend and have found a clear correlation between the temperature changes and cultural habits.

Over the three months to November 15 outdoor barbeques in the northern hemisphere fell by 1.1% a day and grew by 1.4% a day in the southern hemisphere. Drastic action needs to be taken to counter the changing popularity of barbeques.

Yours faithfully,
Jon Young

Climate change is a science not a faith. And the recent reaction of climate change enthusiasts to the doubts spread by climate change sceptics was deplorable. UK Prime Minister Gordon Brown attacked climate change sceptics as "flat earth" thinkers for questioning data used in evidence for climate change. He, nor anyone else, should discourage debate and discussion.

Climate change is a young and little understood phenomenon. History has shown us that the weather is erratic and changeable and flawless predictions even a few hours ahead remain an aspiration.

Brown, and climate fundamentalists in both camps, is not the only one guilty of neglecting the debate. If you have ever asked, "Do you believe in climate change?" you should consider rephrasing.

Regardless of which side of the climate fence you sit on you should encourage further research and debate for there is no other way to increase your understanding of a problem and avoid drawing the wrong conclusions.

Jon Young

COMPANIES IN THIS ISSUE

Repairs underway after Albania collapse

Permanent stabilisation of a collapsed section of the 5.5km dual bore Thirre tunnel in Albania is currently underway after a 50m length failed in early November.

The failure happened in the centre of the unlined section of the south tunnel where permanent works had not yet been completed. Modified NATM was originally used to excavate the 12.6m diameter tunnel and the area of the collapsed section has now been backfilled to half the tunnel depth to provide load and lateral restraint to the sidewalls.

Contractor, the Bechtel-Enka JV (BEJV) has now constructed shotcrete arches around the circumference of the tunnel to increase stability either side of the collapse. "We are now grouting the rock pile and will fill any void above the collapse," said a spokesperson for Bechtel. "The area will be re-mined through the use of a pipe roof in advance of the face of re-excavation."

The south tunnel has been under observation since October when initial ground movement forced client Albania Ministry of Public Works, Transport and Telecommunications, General Roads Directorate to close off the unstable section, halting the fit out activities.

"The tunnel must be closed in order to allow the constructor to pursue its work to stabilize a short segment where an unstable geological mass is exerting pressure on the wall. This is an unpredicted situation," said the Ministry in a statement in mid October. Three weeks later failure occurred with the client blaming "an unpredictable geological layer" for the collapse. It said that this layer has not affected the northern bore.

The tunnel is part of a new 171km highway that links the border with Kosovo to the Adriatic Sea. This contract is being carried out in three sections with BEJV having responsibility for the middle 60km stretch containing the tunnel.

This is the latest setback to the beleaguered project which is running a year behind schedule and has doubled in cost from €416bn (US$622bn) to €826bn (US$1.2bn). Final costs are expected to be over €1bn (US$1.5bn).

Opposition politicians from Albania's Socialist Party have called the scheme "a misuse of the Albanian people's money". MPs from the party have visited the site of the collapse demanding to know what caused the failure.

Following the tunnel collapse the General Roads Directorate retained engineering experts from Austria and Germany to analyze and address technical issues in the tunnel. The experts developed the plan to address permanent stabilisation of the area which is now being implemented by BEJV. "BEJV continues implementing a rigorous program to ensure safety of all personnel involved throughout tunnel construction," said the spokesperson.

Rowark appointed Crossrail head of procurement

Crossrail has appointed Martin Rowark to lead the CRL Procurement Division. As head of procurement, Rowark will ensure that the acquisition of works, services and supplies from the external supply market is efficiently and effectively managed in line with relevant procurement regulations, government policies and best industry practice. He is also tasked with achieving best value in the delivery of the procurement requirements of the Crossrail project to programme and budget.

Rowark joins CRL from the East London Line where he was advising Transport for London on the project which links Surrey Quays with Clapham Junction. It also links the underground section of the line into the overground rail network.

He will join Crossrail on 21 December 2009 and report directly to commercial director Martin Buck. Buck said: ""I am delighted that Martin Rowark will be joining us as Head of Procurement. He brings a wealth of experience to the project as he has contributed to key railway projects in the past. We look forward to having him on board and strengthening the team to help deliver Europe's largest construction project on time and to budget."

Rowark is also former deputy head of procurement for the London 2012 Olympics and partner at Davis Langdon.

New ticket hall opens at Kings Cross

Capacity at London Underground's Kings Cross Northern Ticket Hall has doubled to 8,000 square metres following an extensive construction programme completed last month.

The £810M project has seen 6,000 square metres added to the station along with and more than 300m of new tunnels linking the hall with the Northern, Piccadilly and Victoria lines. Tunneling contractor was Morgan Bemo JV. Principal contractor is Balfour Beatty, project manager is consultant is Atkins with Balfour Beatty Management, designer is Arup and the architect is Allies and Morrison.

The new ticket hall was funded by the Department for Transport (DfT) and delivered as part of Transport for London's (TfL) investment programme, which over the past year has seen new trains running on the Victoria line and London overground network, further extension of the Docklands Light Railway (DLR) and the go ahead for Crossrail.

Below: Capacity has been doubled in the new ticket hall

Shetland Isles tunnel plans

Shetland Islands Council (SIC) in the UK is pursuing plans to connect the Island of Bressay to Lerwick on the mainland with a 1.6km tunnel, between 10m and 11m diameter that will sit under 11m of water.

"We have made a commitment to fixed links and now we have got to start that journey," director of transport Michael Craigie told *T&TI*.

The next step for the council is to obtain consents for the drill and blast project and determine a funding strategy. "It will be the first of its type to be done in the UK so there are no precedents. We have to determine how to obtain legal and technical approvals. We are looking at a base cost of £26M (US$23) but there is a further £8M (US$13) of risk that we have not yet mitigated out," he explained.

Craigie said that successful tunnelling projects in neighbouring Faroe Islands had influenced the decision to opt for a tunnel crossing and said that the Bressay project could be the first of several tunnels in the area. "Developments in technology demonstrated by our neighbours in Faroe have given us confidence that tunnels are technically and financially viable," he said.

The Faroe Islands in the North Atlantic are situated 322km northwest of Shetland between Iceland and Norway, and have successfully constructed three tunnels linking the various islands. A fourth, 27km crossing is now being investigated.

In the Shetland Islands three further tunnels are also being considered by the council but a decision to proceed on these will depend on the success of the Bressay scheme.

On the Isle of Whalsay a £111M (US$183), 6.5km tunnel to connect to the mainland is under consideration. An existing ferry service runs from the Shetland's capital Lerwick to Symbister but the Symbister terminal is considered to be severely under capacity. Proposals to build an alternative terminal or expand Symbister are also being considered.

Other crossings of 5.5km and 2.6km are also being considered between Yell and Unst over the Bluemull Sound.

However there is some local resistance to tunnel proposals due to the time it would take for a fixed link to become operational. "At Bressay we are looking at completion in 5 to 7 years. Planning consents will take two years and the tunnel will have roughly a 24 month construction programme," said Craigie.

The SIC originally proposed a £23M (US$38) bridge at Bressay but this was rejected in 2005 by the Lerwick Port Authority. It claims that the bridge would disrupt ferry operations and it is in favour of a tunnel link. Its objections to the bridge led to approval from the Scottish Executive being blocked. At the end of 2007 SIC reopened a consultation on the scheme. "Obtaining consents for a bridge were complex and there was tension between the various parties but since this process began there have been technical developments that make us more confident in tunnel technology," said Craigie.

LaserShell paper on the mark

A paper on evaluation of the LaserShell technique for sprayed concrete lining (SCL) has hit the mark with the Institution of Civil Engineers (ICE), which has given the Telford Premium Award to the author, Benoit Jones, an engineering manager with Morgan Est, which developed the system. The ICE praised the paper as an 'outstanding contribution to the civil engineering literature'. Jones said he hopes the paper 'helps advance the state-of-the-art method and provides useful data and improved understanding of how tunnels behave'. The LaserShell system has been used with SCL work on projects such as the Terminal 5 Tunnels at Heathrow Airport, and the upgrades of King's Cross and Shepherd's Bush stations.

Former Formula One and 500CC motorcycle world champion John Surtees has become the first person to drive through Eurotunnel as part of celebrations for its 15 year anniversary. The tunnel opened in 1994. Surtees was also taking part in the Burlington Beaujolias Run, where participants travel to France in the most environmentally friendly way possible. He drove a Ginetta G50 electric sports car along the service tunnel.

West Ham breakthrough

Thames Water's West Ham Sewer project achieved final breakthrough after a seven month drive. The Lovat EPBM operated by contractor Costain breakthrough in Newham, London on December 3.

The construction of the shafts began in summer 2008 and the TBM began its 2.8m diameter, 3.33km drive in May this year. The tunnel is lined with 19,770 precast trapezoidal concrete segments.

According to a Costain spokesperson the project went smoothly and without any abnormalities. The ground conditions were typical for the area. The tunnel passes through London Clay ground, specifically the basal layer of the Harwich Formation. This means that the ground contained a variety of materials such as sands and pebbles, occasionally some calcareous content such as shells and cemented sand, and some layers of volcanic ash. There was no water ingress as the tunnel remained above the water table.

Thames Water is investing £90M in West Ham to protect up to 800 homes and businesses from the risk of sewer flooding in the Forest Gate, West Ham and Stratford areas. The new tunnel will link with the existing sewer network by taking sewage flows directly to a new pumping station at Abbey Mills. Costain are also working with Thames Water to renovate a further 5km of sewers leading to the tunnel which will be enlarged and modernised under the scheme. The project is set for completion in Spring 2010.

Abu Dhabi's Yas Island tunnel makes its debut in November

Tunneller tracker technology

Real Time Location Systems (RTLS) has announced that it has successfully implemented a solution to track workers in underground tunnel projects. The implementation is based on the Ekahau Wi-Fi RTLS solution that provides real-time location information on the whereabouts of people and assets anywhere within a site's Wi-Fi network coverage area, using the existing enterprise Wi-Fi network as the infrastructure platform. This new venture is in conjunction with its Spanish integration partner, Bautel Comunicaciones S.L.

The current implementation is operational in the Vigo, Galicia, construction project, where FCC - Acciona is excavating two tunnels both 8km long. The Wi-Fi network is installed in the tunnels using fiber optic cabling for data, voice and tracking purposes. As the workers enter the tunnel in the beginning of their shift, they check in their ID cards for an Ekahau wireless T301BD safety badge. In case of an emergency, management is immediately alerted with the last known location of each worker in the tunnel. The solution also enables workers to call for help by pulling the emergency switch on the badge itself. Once the switch is pulled, safety personnel and management receive the help request with the location information of the incident.

"This was the first deployment we have done using Ekahau's new T301BD badge," said Fernando Carnicero, Manager at Bautel Comunicaciones S.L... He added, "Ekahau is an ideal solution for this purpose, as it provides both the real-time location of the worker in case of an emergency, but also two-way communication with the workers in the tunnel, through the badge's text messaging capability. This has a very clear value to the construction company to increase the safety of its employees, as the construction site is operational 24/7 in 3 work shifts."

Pierson appointed chief executive officer of Parsons Brinckerhoff

Balfour Beatty announced that George Pierson has been appointed chief executive officer of Parsons Brinckerhoff. Pierson will retain his position as chief operating officer of PB's Americas division and Stuart Glenn will continue in his role as chief operating officer, international. Balfour Beatty acquired PB for US$626m in October 2009.

Pierson joined PB in 2006 and was appointed president and chief operating officer of PB's Americas operations in 2008. Keith Hawksworth, currently chief executive officer, is to become chairman, and succeeds Jim Lammie, who is retiring. Both appointments are effective from 1st January 2010.

In a statement, Ian Tyler, chief executive of Balfour Beatty, said: "I look forward to working with George as he leads the Parsons Brinckerhoff team within the Balfour Beatty Group to deliver the exciting opportunities which the combination of the two businesses creates."

Southampton rail tunnel expansion begins

Excavation work has begun on a £71m tunnel expansion project on a Victorian-era railway tunnel in Southampton, England. The Carillion managed project will increase the freight capacity of the tunnel and remove up to 50,000 lorries a year from the Southampton's roads.

By lowering the tunnel's invert by 50cm, freight trucks of 9' 6" (2.9m) or 'high-cube' containers will be able to be transported by rail from the Port of Southampton from 2011.

Richard O'Brien, Network Rail's route director for Wessex said: "Rail can provide a cheaper, greener and more practical way of transporting freight compared with road. This project aims to increase the amount of freight transported from Southampton by rail, which in turn will bring long-term benefits for city and the surrounding area."

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Glendoe bypass tunnel

A bypass tunnel is being considered to repair the top of the headrace tunnel which was blocked by rockfall a few months ago at the Glendoe hydropower project, in Scotland.

The client, Scottish & Southern Energy (SSE), said the work needed to repair the tunnel problem is so extensive that it now expects the power plant will not be operational until well into 2011.

While a number of options are being studied, the only one specifically mentioned was a bypass tunnel. However, all options would require significant programmes of work.

SSE said that it believes a significant proportion of the financial consequences of the problem will be covered by contractual arrangements and insurance. No further details were available.

The turnkey contractor on the Glendoe project is the Hochtief Glendoe JV, which includes Hochtief and Poyry. *T&TI* tried to contact Hochtief but there was no immediate response to the enquiry.

A rockfall blockage near the top of the 6.2km headrace tunnel was realised in August and subsequent investigations have revealed the amount of debris to be 'very substantial' but confined to a section near the top, said SSE.

The geology expected comprised interbedded quartzites and schists with little groundwater, and lining support varied depending on rock characteristics.

While both TBM and drill and blast were employed on the project, and mostly the 5.03m refurbished open gripper shield having been used for the headrace, it is not clear which method was used at the section that suffered the damage.

The headrace excavation was completed almost two years ago, and Glendoe was commissioned and became operational only a year ago.

Through at Terrassa

The JV contractor driving the twin tubes of the Terrassa rail project, in Spain, has holed through last month with a Lovat mixed face TBM to complete the first section of one tunnel.

There are two 6.9m diameter Lovat shields being used on the job by the JV of FCC Construccion, Copisa and Obrascon Huarte Lain (OHL) to bore 3.7km long tunnels at Terrassa for an extension of the FGC network at the edge of Barcelona.

The first section was 2,042m long, and was completed when the first TBM broke through at Val Paradis station. The TBM advanced 830m in the final four weeks.

Geology along the alignment is mainly sedimentary deposits, and includes argillaceous, granular and cemented materials. There are also some isolated layers of conglomerate and cemented deposits. The entire drives are below groundwater level, and the head over the tunnel invert ranges 5m-24m.

The JV ordered both machines in 2007 for the project, which is being developed by Ferrocarrils de la Generalitat de Catalunya (FGC), the rail company of the autonomous Government of Catalonia.

The TBMs can produce 9,000kNm of torque, thrust is 65,000kN and they are designed to advance at an average rate of 10m/day. Lovat is also supplying assistance and parts (*T&TI*, February, p8)

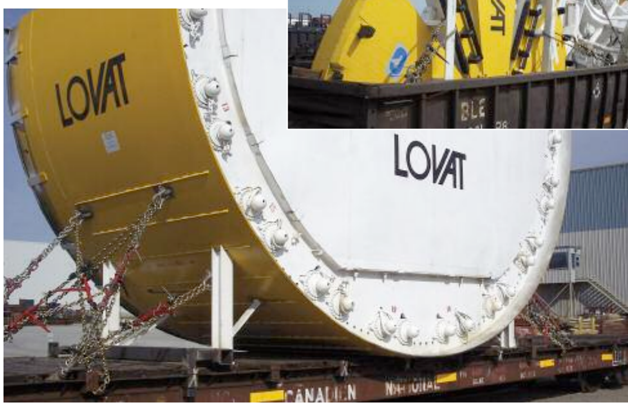
Buenos Aires flood relief tunnel receives TBM

A Lovat ME310SE Series 24500 TBM plus back up system has arrived in Argentina ready for employment in the construction of the Arroyo Maldonado Flood Relief Tunnel in Buenos Aires.

The 7.8m diameter soft ground EPBM was delivered by UK firm Abnormal Load Services (International). The shipment comprised of 13 break bulk items with a maximum unit weight of 86,000kgs and maximum width 5.02m, plus a total of 40 x 40ft (12.19m x 12.19m) open-top container loads.

Canadian regulations restricted the road haulage of the heavy and oversize break bulk items from Lovat's factory only to the nearest railhead, some 19km from the factory. The break bulk loads were then transferred to flatbed railcars and carried by rail through to the port of Halifax NS.

ALS employed a chartered heavy lift vessel to deliver the break bulk loads, totalling 533 tonnes/1,003m3, from Halifax to Buenos Aires.



Above and right: The 7.8m diameter TBM was shipped in parts to Argentina

First Buttenberg breakthrough

First breakthrough by TBM was achieved late last month on the Buttenberg road tunnel, which is being constructed as part of the A5 bypass at Biel-Bienne, in the Canton of Berne, Switzerland.

The 12.6m diameter Herrenknecht EPBM holed through on the 1,230m long drive on 20 November. Geology along the alignment comprised mainly sandstone, occasionally weak, and some soft marl.

Contractor on the project is a JV of Walo, Porr and Specogna. The engineer on the Buttenberg works is Emch + Berger.

Following the southbound drive, the TBM is being transported overground to the south west along the line of the new road to where it will be relaunched early next year to drive the first, 2480m long tube of the Langholz tunnel.

Both of the tunnels have 12.24m i.d segmental concrete lining. The twin tubes of each will be linked by cross passages every 300m.

While about 1400m of the Langholz tunnel is expected to be through similar rock to that of Buttenberg, approx. 900m of the alignment is through more difficult conditions of loose rock and more groundwater. Like the Buttenberg drive, though, the planned advance rate is 14m per day and the drive is due for completion by the third quarter of 2010.

The TBM is to bore the second tube of the Buttenberg tunnel starting late 2010. Boring on the twin tube of the Langholz tunnel is to commence in mid 2011 for completion by about the second quarter of 2012.

The A5 bypass at Biel-Bienne has been in planning for about 30 years and work finally began in late 2007. It has two branches, and both the Buttenberg and Langholz tunnels form most of the eastern arm – Ostast – of the new road links. The majority of the bypass will be completed by 2016.

Crossrail tunnels tender list

Crossrail has issued the tender list for two tunnel contracts – Western Running Tunnel (Contract C300) and Eastern Running Tunnels (C305). The deadline for Expressions of Interest (EoI) for the two more central London station tunnels is also this month.

The five JVs on the tender list to bid for the two main running tunnel contracts, accounting for a total of 36km of almost 42km of 6.2m i.d. twin bores and to be excavated by TBM, are:

- Balfour Beatty, Morgan Est, Vinci and Beton und Monierbau
- BAM Nuttall, Ferrovial Agroman and Keir
- Costain, Skanska and Bilfinger Berger
- Dragados and John Sisk
- Laing O'Rourke and Bouygues

Crossrail is to issue information packs and tender documents during the next two months. Contracts are due to be awarded in mid-2010. Excavation is due to commence in late 2011.

The C300 running tunnel package comprises a 6.2km long stretch in west London from Royal Oak portal through the centre to Farringdon station, and includes a crossover.

Package C305 is longer and consists of three sections in east London – 8.3km, 2.7km and 0.9km, respectively. The longest and shortest stretches both run from the portal at Limmo Peninsula to Farringdon station and Victoria Dock portal, respectively. The other section is from a TBM launch chamber at Stepney green to the portal at Pudding Mill Lane.

The call for Expressions of Interest (EoI) to bid for the two main running tunnel packages was issued in August.

A call for EoIs for the station tunnels at Liverpool St (Contract 500) and Whitechapel (Contract 510) was issued last month and the submission deadline is 15 December.

The EoIs for the station tunnels at Bond St (Contract 410) and Tottenham Court Road (Contract 420) were received at the beginning of last month and are being evaluated.

Contracts 500 and 510 were estimated to take 47 months and 37 months, respectively, to complete. Their procurement involves negotiated procedures.

Preconstruction period will include reviewing client's designs to improve buildability and mitigate risks. Both contracts involve excavation of access shafts and tunnels constructed using sprayed concrete lining. The TBMs boring the main running tunnels are to be pulled through during the build. Job can be split into one or more lots.

Contracts 410 and 420 were estimated to take 43 months and 48 months, respectively, to complete. They have similar tasks and performance requirements as the other central London stations tunnels, such as for TBM pull-through.

Skanska jobs

Skanska has been awarded contracts to build the Strindheim and Kvivs tunnels in Norway by the national roads authority, Statens Vegvesen (NPRA).

NPRA awarded Skanska Norway a NOK730M (US$130M) contract at the end of last month to build the Strindheim tunnel on the E6 road in the central region, between Trondheim and Stjordal.

The 2.1km long twin-tube tunnel will be mostly excavated through rock but there will also be some concrete construction. In addition, the job involves construction of two access tunnels with combined length of 740m.

Work starts on site next month, with tunnelling not expected to commence until around May 2010. The contract is due for completion by the end of 2013 and the tunnel is to be open for traffic early the following year.

A separate contract was awarded to Skanska by NPRA for the Kvivs tunnel, which is to be built on the E39 road in More and Romsdal region. The tunnel is part of the Kvivsbegan project.

The value of the Kvivs tunnel contract is NOK338M (US$60M), and also involves road and bridge construction. The project extends over 8.1km and 6.5km of the distance is tunnel.

Swedish tunnel under budget

The Citytunneln project in Malmö, Sweden is set to come in under budget according to the latest cost projection. The prognosis found that the project will cost SEK8,565bn (US$1,229bn) instead of the budgeted SEK9,450bn (US$1,357bn).

The figure was reached after costs from all the major contractors were summarised and because the cost of the remaining work can be estimated more accurately. "We took plenty of time and we were very thorough with the tender documentation. We also managed to create a good climate of cooperation between ourselves and the" said Citytunneln project manager, Örjan Larsson.

Tube Lines arbiter begins interim review

Negotiations with the PPP Arbiter Chris Bolt to help settle contractual disagreements between Tube Lines and London Underground over upgrade of the Northern, Jubilee and Piccadilly lines began last month. The negotiations follow on from LU's decision to refer a dispute over costs to the arbiter and come ahead of a formal performance review scheduled to begin in July 2010.

Formal review of the PPP contract takes place every 7.5 years, but over the past year discussions between the contractor and the client have been ongoing after LU issued re-stated contract terms and set an affordability limit, this then led to Tube Lines submitted revised pricing.

As a result the two organisations are disputing the value of upgrade work to be carried out between 2010 and 2017. Tube Lines formal submission to LU in June proposed a cost of £6.8bn (US$11.1) but said this could be cut to £5bn (US$8.2bn) by implementing cost saving measures. LU said it could afford £4.1bn (US$6.7).

Representations were made to the PPP Arbiter shortly after Tube Lines issued its latest quarterly report. In this it reported that it had achieved a milestone in the refurbishment work by completing its 75th station upgrade, and had work getting underway on a further three stations – London Bridge, Bermondsey and North Greenwich on the Jubilee line.

The company – a consortium of Amey (majority owner) and Bechtel – now has 13 stations undergoing refurbishment and plans to begin work on a further eight stations over the next few months. It is contracted to complete 96 station upgrades on the Jubilee, Northern and Piccadilly lines by June next year – just before the formal review of the PPP contract.

In its latest performance report, Tube Lines had capital expenditure of £88.9M (US$147.7M) against plan of £86.8M (US$144.2M) over the three months to 30 September. It beat availability targets on all lines, improved the number of 'zero delay' days to 32 from 27 in the comparable period last year. However, recordable incidents were slightly up.


Expanding Horizons

Last call for XRL prequals

MTR Corp has issued a call for contractors to prequalify for the final tunnelling package and underground works package on the Hong Kong section of the Express Rail Link (XRL) to Guangzhou and Shenzhen.

Expressions of interest are wanted for Contract 824 (Ngau Tam Mei to Tai Kong Po tunnels) and Contract 823B (Shek Kong Stabling Sidings [SSS] and Emergency Rescue Siding [ERS]).

The client expects to issue tenders in the first quarter of 2010 for submissions in Q2 and proposes the awards will be made in Q3. The contracts are to be completed by Q1of 2015.

Contract 824 involves excavation of a 2.6km long single bore, twin-track tunnel as well as a 400m long bifurcation cavern and stub tunnels.

There is also a 90m deep ventilation shaft, enlarged at the base, and a 40m deep emergency access shaft, cross passages and pump sumps.

Geology comprises volcanic rocks with recognised fault zones. High rates of water ingress are expected and pre-grouting along with temporary support will be needed to limit inflows. The alignment passes near a water tunnel.

The tunnel is to be excavated by drill and blast, and the shafts sunk using either secant bored piles or diaphragm walls.

Contract 823B calls for construction of a 650m long by 20m deep and 28m wide box structure for the ERS facilities.

XRL is being built to tie Hong Kong into China's high-speed rail network, and is being constructed in two parts. It is being built in two parts, the first in mainland China and a second 26km long section running from the border to Hong Kong. The full XRL link is to be completed by 2015. Recently, the Hong Kong Government approved construction of its section, and its project representative is Jacobs.

A wide mix of tunnelling methods are to be used on the project, ranging from TBM bores to drill and blast excavation and cut and cover boxes.

Eight other contract packages are in more advanced stages of procurement and the first award is expected to be before the end of this year.

Alpine JV bags Bosruck 2nd tube

A JV led by Alpine Bau has won a contract to build a second tube for the Bosruck road tunnel in Austria.

The contract to build the 5.5km long motorway tube at Bosruck was awarded to the JV of Alpine and its wholly-owned subsidiary Beton und Monierbau (Bemo) by the roads authority Asfinag.

Net value of the contract is Euro129.6M (US$195M), excluding VAT. Three rival bids were received by Asfinag for the contract.

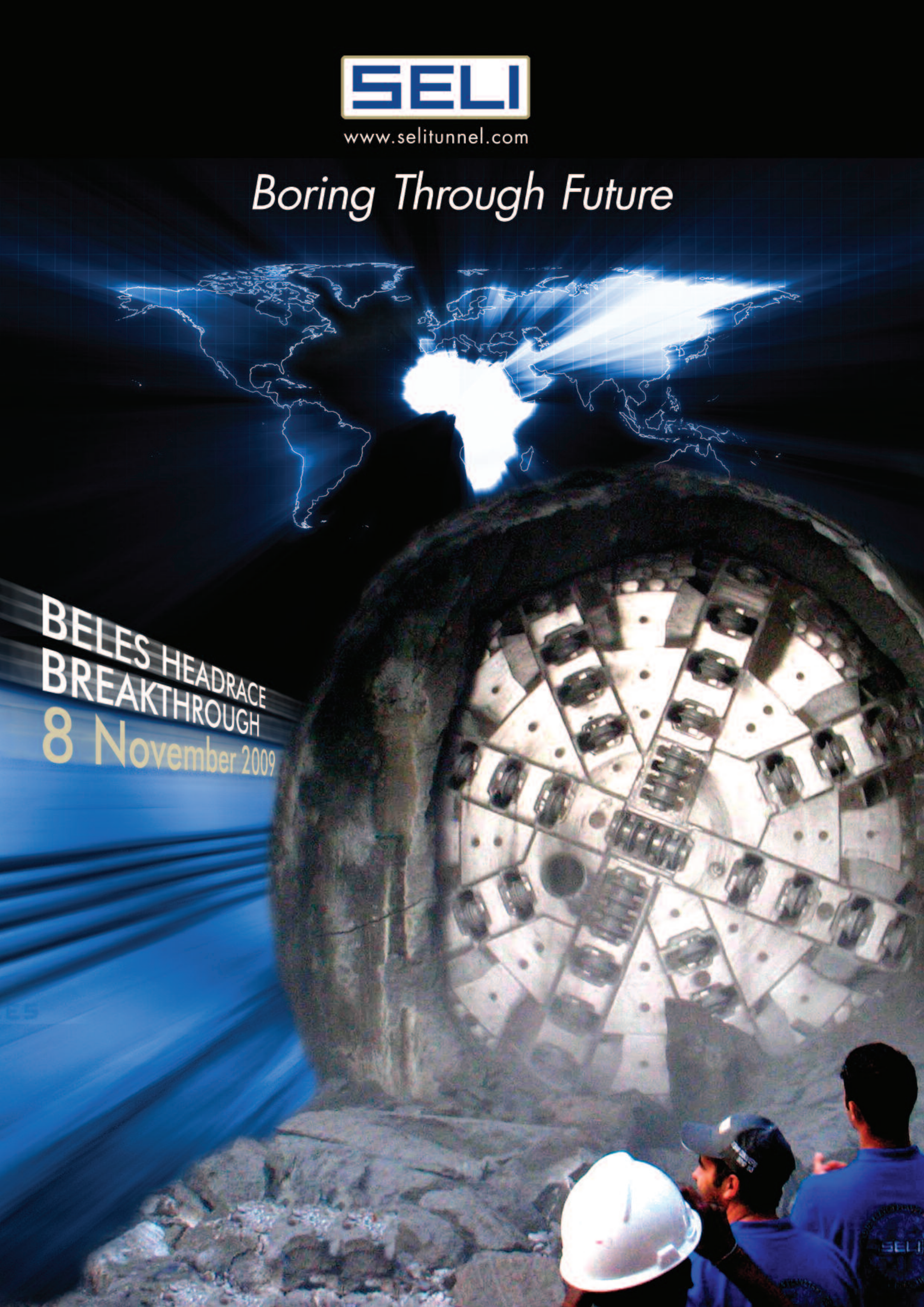
The new, two-lane west tube is to be excavated by drill and blast as well as mechanical excavation, and has an internal width of approx 7.5m. The new tube will have five emergency bays and 11 cross-passages will link the twin tubes.

"Construction of the western tube is a special challenge from a tunnel engineering point of view. We expect extreme water ingress during construction due to the snowmelt. At the same time we expect to encounter difficult geological conditions during excavation due to soaking, water-soluble material such as plaster, salt and clay," said Alpine managing director Roman Esterbauer.

Construction work starts on site next month and the job is to be completed in 2013. Traffic will then switch to the new tube while the existing tunnel is refurbished by 2015.

The second tube is being added because Bosruck tunnel has become a bottleneck on the A9 Phyrn motorway linking the states of Styria and Upper Austria. Asfinag is doubling capacity at Bosruck as part of its tunnel safety investment programme.

Bemo joined Alpine – itself a part of Spain's FCC group – in February 2009.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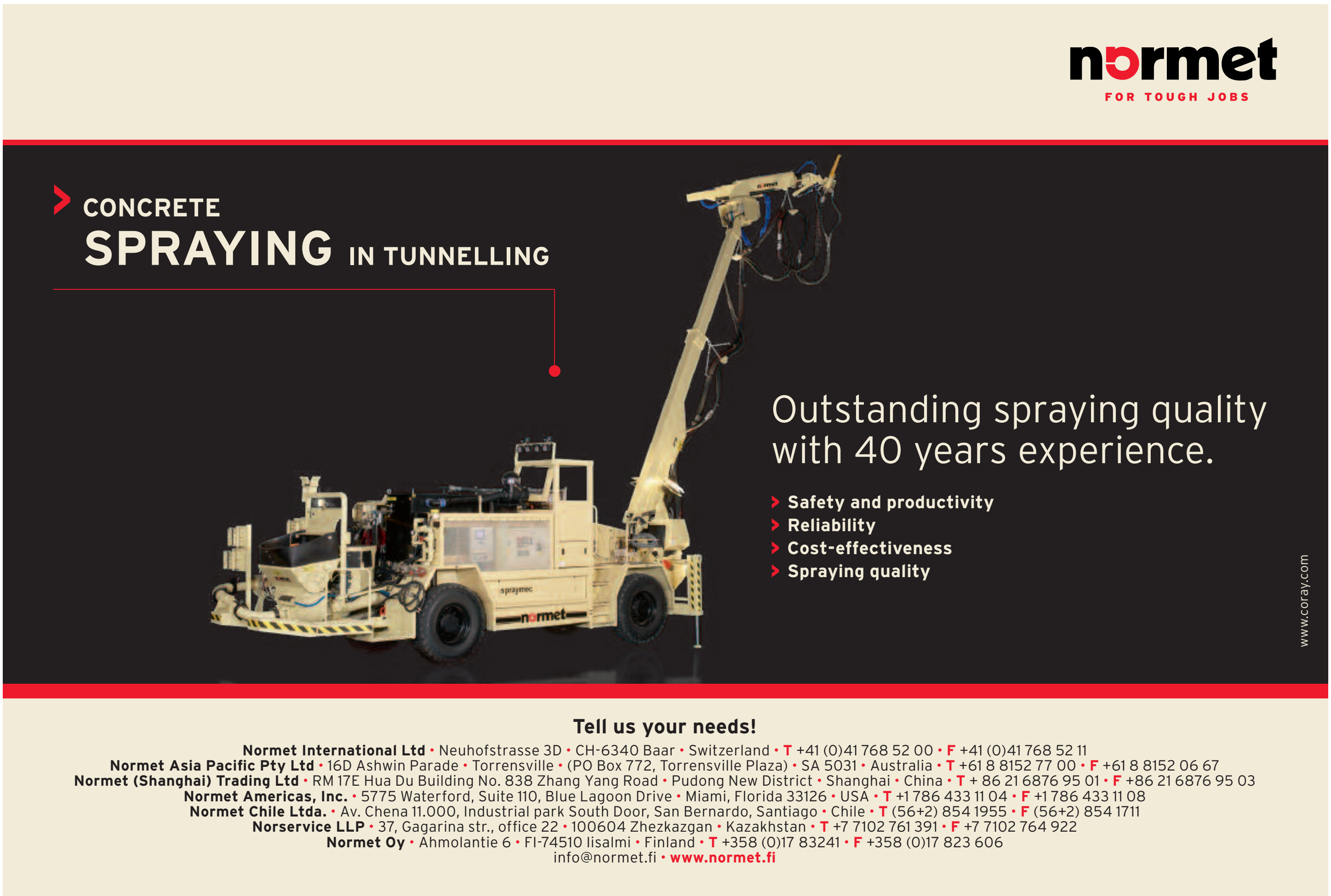
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Stuck in the mud

A major challenge faced Seli when a TBM drive met a fault with up to 40 bar mud on the Gilgel Gibe II headrace tunnel, in Ethiopia. Patrick Reynolds reports

When one of its two double shields driving the headrace for the Gilgel Gibe II hydropower scheme, in Ethiopia, met a fault with mud at up to 40 bar, Seli knew it was facing one of its biggest ever tunnelling challenges.

In Oct 2006, after the face of the Inlet Drive had slowly, and relentlessly, collapsed there began a trident of excavations over months to probe, relieve pressure and help extract the 6.98m diameter TBM. Finally, after mudflows and repeated clearing up, and successful drainage following good borehole data from beyond the fault, the rock mass pressure was sufficiently reduced but insitu repairs were not feasible.

The TBM was retrieved and taken outside of the tunnel to be rebuilt and refurbished with some modifications. It was relaunched in late 2008 on a bypass alignment and the job didn't look back.

Excavation of the entire, almost 26km long tunnel by the two TBMs was completed this year, the outlet drive having enjoyed a relatively easier passage, even though it bored far more than initially planned and the ambient conditions were hotter for the crews than expected.

Gilgel Gibe II

The Ethiopian Electric Power Corp (EEPCo) is developing the hydropower project about 250km southwest of the capital Addis Ababa. It awarded an engineering, procurement and construction (EPC) contract to Salini Costruttori.

Salini was previously involved in construction of EEPCo's Gilgel Gibe I scheme, which includes a 9km long headrace tunnel and an underground powerhouse.

Gilgel Gibe II scheme has a 6.3m internal diameter concrete-lined headrace tunnel. Salini appointed Seli to undertake the tunnelling works. Seli also supplied the TBMs, back-ups and ancillary equipment.

The tunnelling works have been completed and recently the headrace began to convey water, starting in the Gilgel Gibe river basin, just downstream of Gilgel Gibe I power plant, and running to the new powerhouse in the adjacent Omo river basin. The first generation units have just started to come online.

Headrace – Geology, TBMs

The anticipated geology along the headrace alignment included five main rock formations – tertiary volcanics, rhyolite, trachyte, basalt and some dykes. Aerial surveys had also identified fault zones.

The inlet drive was foreseen to be mainly in the massive, amygdaloidal and scoriaceous layers of the Omo basalt formation, and these were inter-bedded with some weak layers of sedimentary tuff and red paleosoil.

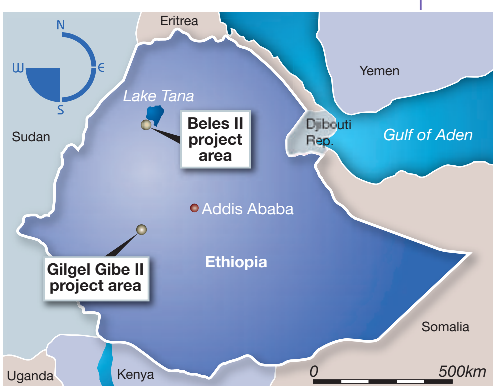
Two double shields were selected for the inlet and outlet drives as the headrace was foreseen to pass through hard basalt.

The 6.98m diameter TBMs had a front shield outer diameter of 6.93m, and the gripper and tail shield was just under 6.9m. The five-part cutterheads were equipped with 44 discs of 17" (431mm), and with a maximum recommended average load per cutter disc of 222kN. The total thrust, based on 39 discs, was almost 8,700kN. The maximum torque was 2,590kNm.

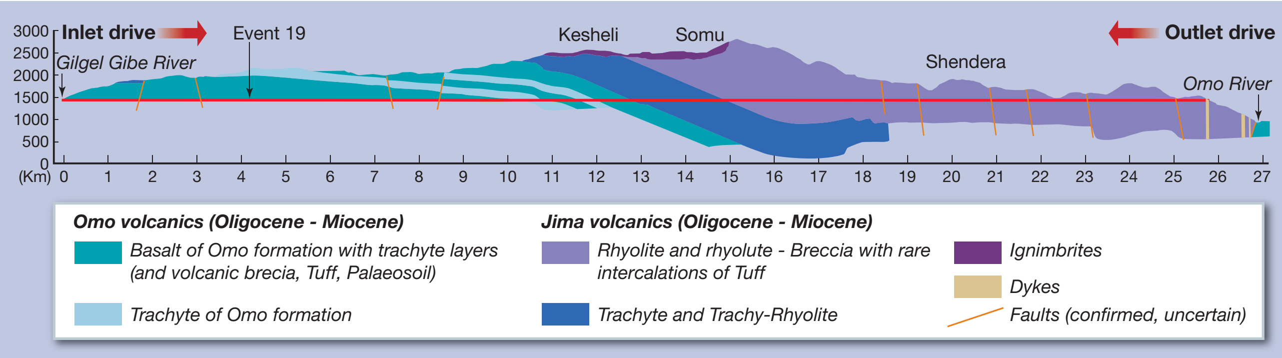
The machine on the outlet drive a was new build by Seli whereas the inlet drive TBM was an overhauled and enlarged Robbins hard rock machine with an original diameter of 4.9m.

The tunnel lining was built as 1.6m long precast concrete rings with four hexagonal, 250mm thick honeycomb segments. The external diameter of the rings is 6.8m.

The TBM on the inlet drive was launched at the inlet portal in August 2005. Towards



Above: **Map of Gilgel Gibe II, Ethiopia**



Above: **Geological cross-section along headrace**

the end of the year the second TBM commenced its drive from the Outlet Portal. The drives were to be completed in 2008 but the nature and scale of the challenge presented by one particular geological difficulty, at Event 19, resulted in the TBMs not being able to meet until the middle of this year.

Early Events

Initial progress on the drives was reasonable, both TBMs advancing normally, says Seli. Generally, the difficulties that there were during the excavations of such a long tunnel were not due to any differences between foreseen and encountered lithologies but due to the mechanical characteristics of the rock masses.

Generally, progress of 10m-20m per day was being achieved, but the TBM advance was being slowed by the almost continuous presence of weaker rock of Rock Mass Class IV-V. Boreholes were being drilled up to 50m ahead of the machines. The advance was also slowed by ravelling faces.

Even before the severe difficulties of Event 19 on the tunnelling, the inlet drive had relatively more geological problems, or events, to deal with than the outlet drive, – 14 compared to four, respectively.

Chemical grouting was used where local face stabilisation was needed, and there were also a few bypass digs required before the TBM could proceed. Squeezing ground was handled by overcutting.

A few early events caused long delays, most difficulties delaying the advance of the inlet drive by only a few days at a time. As the outlet drive was just getting underway, however, the Inlet Drive, in handling its fourth event, would find that problem to be the longest experienced until then – 31 days standing time. The records to the end of 2008 show only two other comparable standing times – for Events 14 and 17.

When it came to Event 19, though, that was to be a challenge of a different magnitude. The consequent standing time was more than 20 times longer than any previous hold up.

Below top and bottom: **Event 19 starts - damage to lining, shield where Inlet Drive met a high pressure fault zone**

Event 19 – inlet drive

By October 2006, about 14 months into the Inlet Drive, the TBM had advanced more than 4km. In that stretch the overburden was approx 670m, and the rock masses comprised weathered brecciated and decomposed basalts. The Rock Mass Rating (RMR) ranged 17-19 and the Rock Mass Class was V – very poor. There was no groundwater, only damp conditions.

However, slightly short of chainage 4.2km, the TBM unexpectedly met a fault zone that would be found to have mud at pressures up to 40 bar. The machine had stopped and then there was a sudden extrusion and collapse of the face against the cutterhead and the front shield. This was logged as Event 19.

The rock mass squeezed against the TBM at a semi-horizontal angle, in particular from the left side of the drive. No support could prevent the ground movement as the rock mass moved at 40mm-60mm each hour. The pressure from the rock mass pushed the TBM back more than 600mm and displaced it laterally more than 400mm.

The connection bolts of the front shield were broken, the shields and cylinders were bent, and the last seven built rings were destroyed with segments either having moved or been severely damaged. Ribs and other support were installed to prop the damaged lining.

The rock mass had an elasto-plastic behaviour that was unforeseen, and neither was extreme squeezing anticipated. Only a few hours prior to the face pushing out onto the TBM – it was not a brittle, sudden failure – the poor quality, decomposed rock was being checked.

Rock ahead of the stuck TBM was probed only a little and with some difficulty. Sometimes the 20m probes were blocked not far out and other times the rods were ejected by high pressure mud and clay, at 40°C and up to 35 bar-40 bar. Such conditions were found when boreholes were drilled through the shields and into the rock mass that had bent the TBM's left side.

Back chamber

Seli brought in consultant Lombardi to help plan how to rescue the machine and the inlet drive. Neither firm had been up against such rock mass conditions in a TBM drive, says Seli.

A recovery plan was drawn up in January 2007 that called for five steps: monitoring; more boreholes and geophysical surveys; construction of a rescue chamber – the back chamber – that would open up the rock around the entire TBM, enabling in-situ repairs and re-alignment; repair of the damaged rings; and, opening up an adit to the left of the drive to explore the weak rock mass towards the fault.

A back analysis of the collapse was undertaken to estimate the geomechanical properties of the rock mass and loads on the TBM. Then, the design of the back chamber was developed as a four-step process with a top heading, upper and lower benches, and the invert to be opened up and supported by typical mining methods.

The support lining for the back chamber comprised bolted ribs, longitudinal reinforcement, steel mesh and shotcrete. There would be 59 ribs in the full section of the chamber and, eventually, 23 in the crown area that continued into the top heading ahead of the cutterhead.

Monitoring collected data from strain gauges and manometers, for water pressure. Key spatial dimensions that were closely watched included triangulation of the crown and upper walls in the top of the back chamber, and at the level of the TBM axis just above the widest distance between the walls.

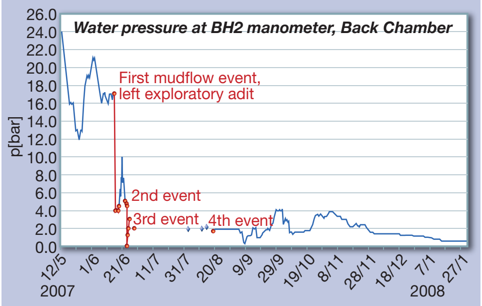
Left exploratory adit

The left exploratory adit was started in the wall between back-up cars no. 1 and 2. Excavation began in February 2007 and the adit was gradually opened up with some difficulty, being mined in a right-sweeping alignment towards the fault. Support lining comprised ribs, mesh and shotcrete.

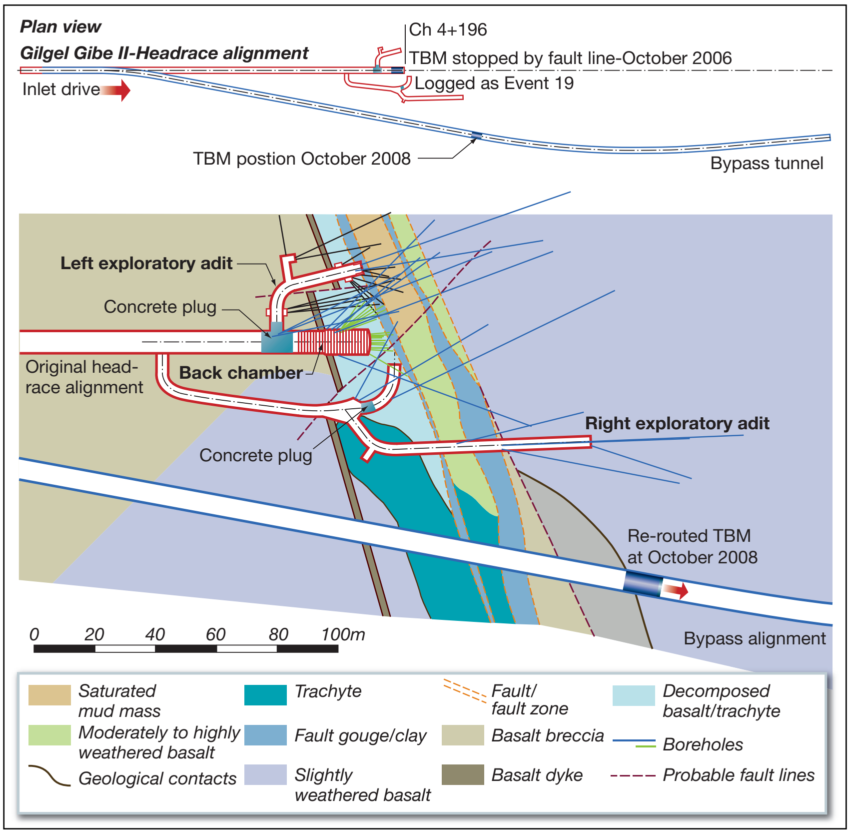
A short way in, a first niche was formed to drill boreholes forward towards the fault. Advancing farther, closer to the fault and just after support rib no. 42 another right-side niche was formed, near the face of the adit, and boreholes were drilled. However, high-pressure mud extruded and the face of the adit collapsed.

The section of tunnel was dug out, some rib inverts lifted and the area repaired before the excavation proceeded once again but with smaller open face area and double ribs.

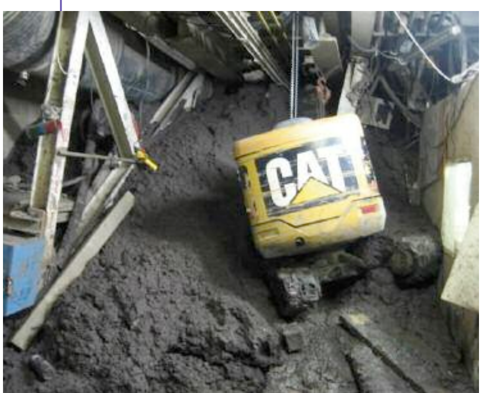
Slightly back and opposite the right probe hole niche another was formed. However, a drill withdrew unexpectedly due to pressure and resulted in shotcrete being broken at the front face, and mud leaked out. This prompted installation of a bulkhead at the



Above and below: Mudflows buried adit, part of main tunnel but rock mass pressure was reduced



Above: Plan of headrace alignment, stalled drive and exploratory adits, and bypass tunnel at fault zone
Below: Further mudflows from the left adit buried more of the main tunnel



portal to the main tunnel with space to remove mud over the top, if need be.

By May, the boreholes had drilled approximately 550m from within the adit and also the back chamber. By then about 60% of the back chamber had been built and the adit had reached the fault zone. However, not too long after, in June, the front face of the adit collapsed and that tunnel had to be abandoned due to severe mudflow.

The first outflow of mud was approx. 750m^3 and there was also approx. 2000m^3 of 50°C water. The outflow also carried forepoling and some ribs over the bulkhead, which was overtopped and destroyed as the mud kept coming, extruding out the full cross-section of the adit.

A second outflow, and then a third, brought approx. 900m^3 and approx. 500m^3 of mud, respectively, with reducing, occasional water flows to the main tunnel, reaching the crown and spreading from the adit portal area.

When the mud stopped coming there was some 3,500m^3 in the adit and main tunnel. About 80m of the main tunnel was covered, including the TBM and three back-up cars in the partly-built back chamber. Instrumentation showed that each of the three outflows brought rapid reductions in acting pressure and also convergence.

The mud was removed from the main tunnel in July, some of the back-up cars were withdrawn and construction of the back chamber was then suspended. The revised strategy saw more drilling power brought up to probe farther ahead into, and hopefully beyond, the fault zone to basalt. The initial, longer drilling was done from behind the TBM shields. The strategy also called for a new adit to be opened up.

Right exploratory adit

In August, work began to re-open the left adit with the dense mud and muck being removed in large blocks as far as the bend. Meanwhile, on the opposite side of the main tunnel, starting some 40m back from the left adit portal, excavation began on the right exploratory adit.

However, a further mudflow – the fourth – happened in the still only partly re-opened left adit, pouring into the main tunnel as far as the portal to the right adit. The flow was approx. 1000m^3 of mud and approx. 100m^3 of water. After cleanup began, a safety wall was erected at the bend in the adit. Back-up car no. 1 was then dismantled and removed from immediately behind the TBM.

In late August and into September, 2007, the first of the longer boreholes were drilled from the back chamber and the right adit, which by then had completed its first planned stretch of excavation for the face to be in-line with the front of the TBM. The exploratory plan had the longer boreholes from this right adit fanning out before the TBM and also into the fault.

Piercing the fault zone contributed to water drainage and pressure reduction in the rock mass. Then, when competent basalt beyond the fault was finally located a programme of drainage began to further lower pressure within the rock mass around the TBM head and back chamber, extracting about 39,600m^3 of water.

In October, construction of the back chamber resumed. The left adit was fully re-opened for longer boreholes to also be drilled into and beyond, hopefully, the fault zone. Meanwhile, excavation was restarted in the right in a bid to close-in on the front of the TBM and so open up the rock mass for the cutterhead recovery operation. However, as the bore was closing the distance to the cutterhead the loads and deformation measurements at the forward section of the back chamber increased and the work was terminated.

Farther back up in the adit, where the dig had first stopped almost in-line with the TBM, the excavation took off again at the end of the year. That branch tunnel was advanced to cross the fault zone, more

Table 1: Gilgel Gibe II-Headrace tunnel rock class

Description	Unit	Rock class (RMC)					
		I	II	III	IV	V	Total
Design data							
Length of tunnel for each rock class foreseen in the design	m	577	9,765	10,500	3,396	762	25,000
Percentage for each rock class foreseen in the design	%	2.31%	39.06%	42.00%	13.58%	3.05%	100.00%
Total headrace tunnel							
Real length of the tunnel for each rock class	m	6,395	8,873	4,056	5,412	1,053	25,788
Percentage for each rock class	%	24.80%	34.41%	15.73%	20.98%	4.08%	100.00%

long boreholes being drilled on the way. The branch tunnel penetrated sufficient competent basalt that was estimated to be approximately 70m ahead of the TBM.

In total, some 230m of adit had been excavated on the left and right, and 1600m of boreholes drilled to investigate the rock. In addition, drainage boreholes were drilled.

The tunnelling strategy for the intake drive moved next to focus on the extraction of the TBM, which could not be repaired insitu.

Work got underway to complete the back chamber and from a top heading a concave wall was constructed in front of the cutterhead, using horizontal ribs and shotcrete, to create the space needed to dismantle the TBM. The machine was successfully removed in parts by the end of February 2008.

The walls of the empty cavern were further strengthened using cast concrete. Some tunnel rings were also dismantled. Less than 400m back along the main tunnel a concrete plug was cast, sealing off the stretch which would be abandoned.

Outside the tunnel, the TBM was refurbished, rebuilt and re-assembled between March and May.

Modifications to the machine included increasing the excavation diameter of the cutterhead to 7.074m , which included moving eight peripheral cutter housings. The change would enable the relaunched TBM to reduce the squeezing effects from rock mass with plastic behaviour. The sizes of the shields were unaltered.

The repair and restoration work on the TBM also included reinforcement of surfaces exposed to abrasion, dismantling and replacing the main bearing, and repair and reconstruction of the material hopper on the conveyor.

The TBM was taken back underground for assembly in a newly constructed chamber, which was excavated by drill and blast and completed in May.

Relaunch & Completion

The intake drive TBM was relaunched on 1 August 2008.

The TBM traversed the fault zone in October, which went well using resin injection to consolidate the clayey basalt and limit squeezing around the shields.

The headrace tunnel excavation was completed on 6 June 2009, the TBMs meeting at Ch. 8+521, which meant in effect that Event 19 was approximately in the middle of the final length of the Inlet Drive.

In the end, there had been 24 geological difficulties of varying nature and scale to deal with on the headrace drives of Gilgel Gibe II – 15 in the inlet drive and nine in the outlet drive. But by far the most difficult challenge in tunnelling experience was Event 19. T&T

Robbins' deep mountain drives are standing up to the pressure. Desiree Willis reports

Figure 2 – The 5.3m diameter Robbins TBM was launched in Peru in March 2007

Lowering the stakes of deep bore tunnelling

More than 100 years in development, the complex geology at Peru's Olmos Trans-Andean tunnel site has thwarted multiple excavation attempts since the 1950's. The project route sits under the weight of 2,000m of complex rock formations, making it the second deepest mountain tunnel in the world. Multiple fault zones, squeezing ground, and rock bursting have made the water transfer tunnel a difficult prospect. New concepts are changing the game, however, with comprehensive ground support and pre-conditioning programs to stabilize the tunnel while maximizing safety.

An ocean away, a similar deep bore project was recently excavated 600m below the Alps. The Ceneri adit tunnel, located in Sigirino, Switzerland, was completed ahead of schedule and with exceptional results. The 9.7m diameter Robbins Main Beam TBM was designed with larger diameter disc cutters for high cover tunnelling.

Taken together, these two projects demonstrate that open-type machines, paired with the proper ground support and cutterhead design, are capable of excavating some of the deepest tunnels in the world.

Excavating the Olmos Trans-Andean Tunnel

The 5.3m diameter machine was launched in March 2007 for sub-contractor Odebrecht Peru Ingenieria y Construccion, S.A.C (OPIC). General contractor Concesionaria Trasvace Olmos, S.A. won a 20-year build-operate concession from the Peruvian National Government and Lambayeque Regional Government in July 2004.

The Robbins Main Beam TBM is boring the 13.9km long tunnel, which will transfer water from the Huancabamba River on the Eastern side of the Andes to drought-ridden areas on the Pacific Ocean Watershed. Nearly 40,000 hectares of plains will be irrigated with the tunnel's completion—a critical development for the Lambayeque region of Peru, which only receives about 215mm of rainfall annually.

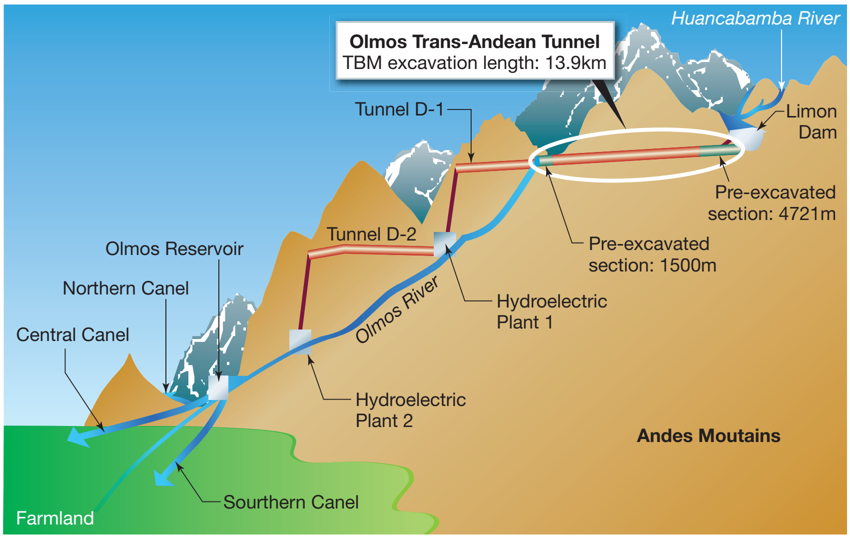
Geologic Conditions

The tunnel's location in the Andes Mountains presents numerous challenges—the range is relatively young and geologically complex, formed as recently as 24 million years ago. Within the Olmos tunnel is a wide variety of rock types, from schists, argillaceous rock, quartz mica schist, and quartz porphyry to andesite, tuff, and pyroclastic breccias. Rock varies from 60 to 175 MPa UCS for most of the tunnel length. "The presence of these moderately strong volcanic rocks is a recognized risk, as the contacts between the intrusions and the host rock can comprise highly sheared and fractured zones associated with groundwater," says Dean Brox, a senior project manager for tunnel projects with Hatch Mott MacDonald.

The high cover of the tunnel creates additional reason for caution. "One of the main risks of this tunnel is its location at a depth of over 1500m for a significant length, which is therefore subjected to high stresses. If various volcanic rock units are present that are only of moderate strength, then significant overstressing and failure of the rock around the TBM tunnel can be expected. At great depths, this includes violent or sudden failure of the surrounding rock, referred to as rockbursts," says Brox. This overstressing typically manifests in front of the TBM, so that ground support must be installed immediately behind the cutterhead to protect workers and stabilize tunnel walls.

TBM and Back-up Design

Robbins engineers designed the machine with high cover tunnelling in mind, including two roof drills and a probe drill with 360 degree grouting capabilities. A shielded



Right: **The 13.9km Olmos Trans-Andean tunnel is the second deepest mountain tunnel in the world**

design was not considered, as the shield body creates a high likelihood that the machine can become stuck in squeezing ground. "For us, an open-type machine was the only option. We chose this design after many consulting meetings," says Jose Luis Torres de la Piedra of Odebrecht.

The high cover also necessitated a unique back-up design to combat expected in-tunnel temperatures of up to 54°C. Robbins engineers designed a customized ventilation and air cooling system for the high jobsite elevation (1,080m), which results in less dense air and less heat transfer capacity. Four active chiller systems are being used to cool the tunnel to provide a maximum working temperature of 32ºC at the TBM and back-up.

Two chiller systems mounted on the back-up decks work in series. Main air flow from the tunnel entrance, at about12 m3/sec, passes into the tunnel through a 1600mm diameter flexible vent line, where it is fan-boosted through the two back-up mounted chillers via 100m of 762mm diameter duct. This air is carried further forward and transferred over the back of the TBM using a steel trombone section, which allows relative movement between the TBM and backup. Two additional free-standing chillers re-circulate and further cool tunnel air at the rate of 7.5 m3/sec.

Ground Support Methods

At the outset of the machine's launch in March 2007, ground conditions were challenging with some moderate tunnel deformation. By 2008, however, the TBM had entered sections of high cover up to 1,000m, where crews experienced large overbreaks and cathedralling, along with rock bursting that could not be contained using wire mesh, rock bolts, and ring beams. "We encountered about 1,200m of highly fractured ground, with over 8,500 recorded rock bursts. Cavities also formed during tunnelling that had to be injected with grout," says John Simm, Robbins field service superintendent.

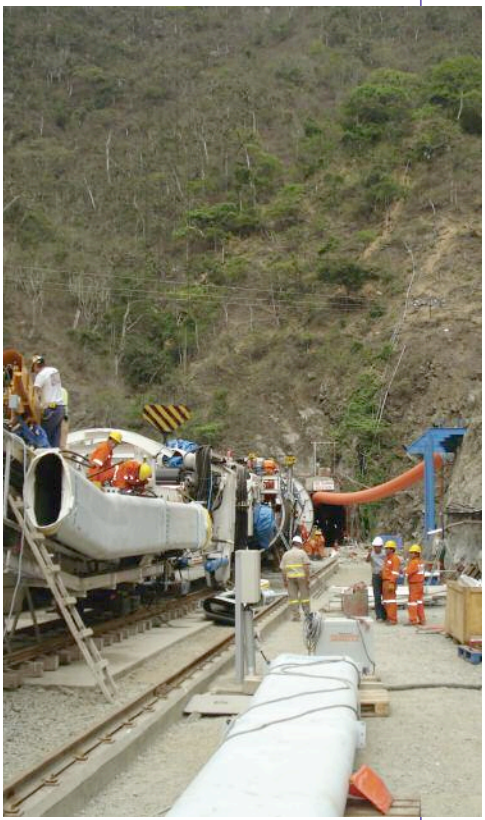
To better contain the fractured rock, Robbins and Odebrecht elected to make changes to the original ground support system by installing a novel type of TBM ground support. The machine's roof shield fingers were removed and replaced with the McNally Support System, supplied by C&M McNally Engineering of Toronto, Ontario, Canada.

"The McNally support system provides the benefit of a continuous support system along the roof area of the tunnel and immediately behind the cutterhead, which protects workers from falling rock," says Brox. The support structure can also be installed down along the sidewalls to provide additional protection from high stress conditions. The system is customizable depending on the rock conditions. For shallow tunnels in horizontal geology, the system can comprise relatively low capacity support components that are easy to install. For deep tunnels where high stress conditions exist, support can be enhanced with higher capacity, larger components that can still be practically installed with TBM excavation.

The McNally system works by replacing the curved finger shield plate for a curved assembly of pockets with rectangular cross-sections. The pockets extend axially from the rear side of the cutterhead to the cutterhead support, within the area where roof drills can work. Before a TBM stroke, crews slide slats of metal or wood into the pockets. These slats are installed in an alternating pattern that in essence covers half the available area - ample coverage for effective ground support. The ends of the slats protrude from the pockets and are bolted to the roof of the tunnel using a steel strap. As the machine advances, the slats are extracted from the pockets and continuously bolted to the roof using subsequent straps. Slats are reloaded and used for sections containing unstable rock to control deformation and rock falls.

To reduce rock bursting ahead of the machine, a unique ground pre-conditioning system was developed by Winston Lewis, Odebrecht Production Manager. The system consists of damped explosive charges placed in 12 to15m deep boreholes. "We have developed this method to create voids and fractures ahead of the machine and relieve the concentrated energy in the rock mass before it can damage the equipment," says Lewis. A version of the system was originally created at mines in Chile to open up better access to rock for mining purposes.

Below: Machine design at assembly and startup of the Robbins TBM included a specialized air cooling system to reduce in-tunnel air temperature to 32°C.
Right: With up to 2,000m of cover, the Robbins TBM at Peru's Olmos tunnel faces squeezing ground and rock bursting conditions.



During tunnelling, the probe drill is used to make three to five boreholes in the tunnelling face. Each hole is angled at a downgrade of between 6 and 12 degrees, matching the angle of the bedding plane to make it more likely that the fractures will be widened. Pressures on the surrounding rock are relieved, thereby reducing or preventing severe rock bursting.

Tunnelling through fractured and broken rock at the face can also create undue wear on the cutterhead. Robbins engineers added 19mm thick wear plates and 50mm thick square bars, known as 'Boomerangs' in front of each cutter. The boomerangs protect each cutter hub from blocky rock and bursting at the face. "The installation has reduced downtime for cutter changes, and the need to enter the cutterhead for maintenance, which is dangerous in rock bursting conditions," says Simm.

Since modifications were done to the TBM, advance rates have steadily improved, with the machine boring as much as 674m per month. The improved rates are all the more remarkable considering two hazardous local floods in April 2008 and March 2009, which both inundated the site with more than a meter of mud and wiped out access roads.

By November 2009, the machine had advanced approximately 9,500m, or 68%, of the full tunnel length. All tunnelling is expected to be complete by the last quarter of 2010.

Right: **Since installation of the McNally support system, the Robbins machine has achieved advance rates of up to 674m per month**

Above, top: **Crews removed the roof fingers from the Robbins TBM and installed a new support system consisting of steel slats bolted to the roof of the tunnel.**
Above, bottom: **The McNally support system installed on the Robbins TBM is capable of stabilizing the tunnel walls from rock bursts and squeezing ground directly behind the cutterhead.**

Larger diameter cutters at the Ceneri Tunnel

While ground support is a critical factor in the success of high cover projects, design advancements on the TBM cutterhead itself are resulting in greater efficiency. Larger diameter 19-inch (483mm) disc cutters have the potential to excavate harder rock and squeezing ground with fewer cutter changes overall.

In 2008, the main adit for the Ceneri Base Tunnel was excavated under 600m of cover using a 9.7m diameter Robbins Main Beam TBM. The adit, located in Sigirino, Switzerland, will provide access to the site of the twin 15.4km long Ceneri Base Tunnels. The tunnels are part of AlpTransit's massive effort to reduce passenger and freight rail times across the Alps.

An initial exploratory bore was used to determine the geology at the adit site, which consisted of schist, Swiss molasse, and Ceneri orthogneiss between 30 and 130 MPa UCS.

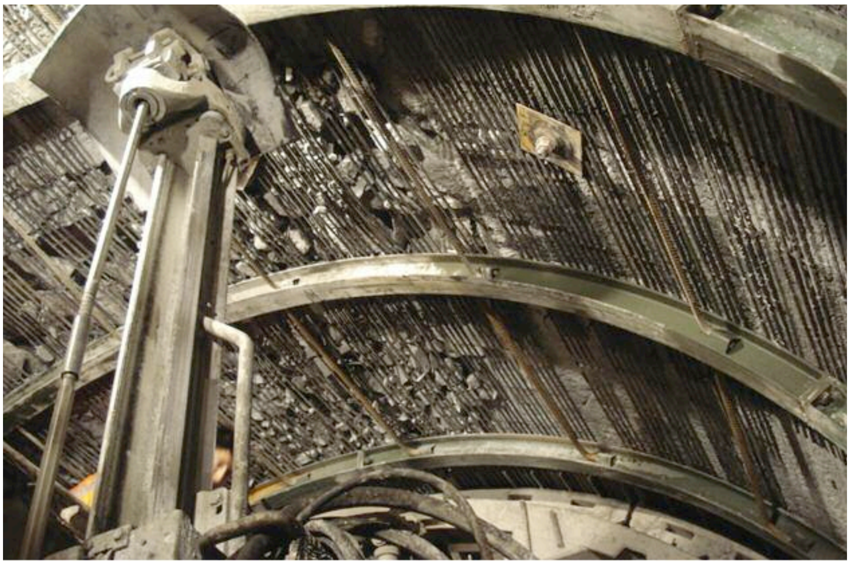
The TBM was designed accordingly, as a High Performance (HP) Main Beam machine utilizing larger diameter cutters. The cutterhead design was the first of the TBMs on the AlpTransit tunnels to use back-loading 19-inch (483mm) disc cutters, a design that offers longer cutter life, reduced cutter change downtime and provides higher penetration rates compared to the standard 17-inch (432mm) size.

A large, open working area behind the cutterhead also allowed crews to install a variety of ground support depending on the conditions encountered. Ground support included installation of wire mesh on the top 240 degrees of the tunnel diameter, as well as three rock bolts and 1.4 m3 of shotcrete per metre bored. Crews also installed continuous drainage pipe and filled the invert with 1.6m thick concrete behind the TBM to prepare the tunnel for track installation.

The Robbins machine successfully completed the adit tunnel within its project schedule on November 6, 2008. Correct cutterhead design, resulting in low cutter usage and high advance rates, was arguably a contributing factor in the machine's success. "Cutter performance has been the single most impressive result of this project," says Ferruccio Borroni, General Manager for Robbins Europa.

The disc cutters excavated a combined total of 167,000 cubic metres of hard rock during the bore, and the machine recorded average advance rates of 18.5m per day. Cutter wear was minimal throughout the bore, requiring less downtime for cutter changes. "We changed only 30 cutters in the last kilometre of boring. This is a very good result," says Emanuele Tabet, Jobsite Director for the CMC consortium.

Greater cutter life and penetration are the factors that result in higher advance rates for TBMs employing 19-inch (483mm) disc cutters. The 19-inch (483mm) disc cutters can be operated at 311kN load compared to the 267kN load limit of a 17-inch (432mm) cutter. Even at the higher



Left: **The 9.7m Robbins TBM used at Switzerland's Ceneri tunnel featured 19-inch diameter disc cutters for tunneling under high cover**

operating load, roller bearing life is higher in 19-inch (483mm) cutters. When operated at 311kN, the 19-inch (483mm) cutter bearing is only at 84% of its roller bearing load rating whereas the 17-in (432mm) cutter when operated at 267kN is at 93% of its roller bearing load rating. The higher capacity roller bearing, together with improved lubrication, results in fewer bearing failures and better penetration in harder rock and squeezing ground.

The increase in cutter ring diameter results in increased cutter life. Allowable ring wear volume, the amount of ring material that can be worn before a cutter must be changed, is increased by over one-third in 19-inch (483mm) cutters. The increased wear volume means more cubic meters of rock can be excavated per cutter ring, resulting in fewer cutter changes. Fewer cutter changes results in less TBM downtime and ultimately faster tunnel production rates overall.

Conclusions

Much can be done to mitigate risk on deep bore projects and achieve higher average advance rates. Proper ground support, coupled with attentive machine design and large diameter disc cutters, all maximize TBM availability.

The challenges that remain are for deep bore projects in remote, mountainous areas, according to Brox. "It is difficult to investigate the geology and ideal locations for deep TBM tunnels due to the high cost of drilling. In rugged, mountainous terrain, access can be very difficult and often cost prohibitive." In such situations, the only geological information available is obtained from surface mapping and representative rock blocks, which are collected from the surface for laboratory testing of rock properties. Other data collecting methods include drilling sub-horizontal holes at varying elevations, as well as airborne geophysical surveys.

While initial geotechnical studies may be difficult, the technology of excavation is moving forward. Today's TBM projects, such as Switzerland's AlpTransit scheme with over 2,500m of cover, are becoming less risky with the use of the latest in rock excavating technology. T&T

Reading from the same page

Tunnelling information systems are improving project management of mechanised tunnelling projects. Katja Remus and Nod Clarke-Hackston of VMT describe the advantages of the firm's latest system

Excavation by TBM is often considered to be a continuous process but it is more accurately described as a cyclical one. The processes of excavation, spoil removal and tunnel support should all be coordinated as they are all interdependent. Keeping track of all these activities, how they affect both the ground and the structures located above the tunnelling activities and maintaining a traceable record is now a common requirement by the owners of many of these projects.

As it is unlikely that any one supplier will be responsible for all the monitoring and recording activities taking place on a given project, the method and format of the data produced will typically vary according to the specifications of the sensors and the systems of the individual manufacturers. In order to make full use of this data VMT has created the "Tunnel and Underground Information Software Structure" or TUnIS. The core of TUnIS is a sophisticated data exchange facility that enables data types of all common formats to be integrated in to a common database. Modules are available that cover all aspects of data on a tunnelling project including the machine, navigation system, tunnel supply and equipment logistics. These also include a complete segment documentation system, measurement systems both inside the tunnel and on the surface structures along the course of the tunnel, geological and geotechnical investigations as well as project design.

During TBM tunnel construction the ability to make fast decisions in potentially critical situations is very important; these decisions are dependent on the amount and quality of available data and information. To this end the TUnIS information system greatly assists project management but to be most effective it is of paramount importance that the system is fully established at the commencement of the project so that all parties are committed to the system from day one.

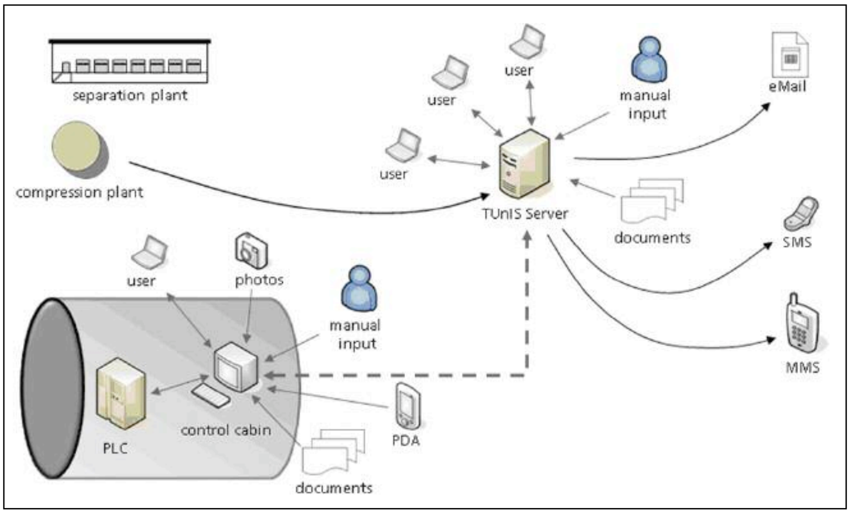
The objective of the system is to improve the overall performance of the project, not a means for each side to score points over the other. An agreement should be made between the contractor and the client at the beginning of any project where it should be decided what information shall be collected and to whom this information is available. Job specific access should be made for those who will benefit from access from mechanics and electricians to surveyors, TBM operators and project engineers.

Countless analysis options

The structure of the system is simply a collection of all relevant data contributing to the construction project into a single comprehensive real-time database where there are manifold applications for the correlation of data from the differing data sources. Indexing of all these activities is determined by time, ring number and chainage. Clock synchronization ensures that the correct time stamp for all data is applied and navigational data and monitoring results give the relevant positional information.

The heart of the system is a server, based at the site office, which is within a local area network and/or a broadband connection for VPN access. There will typically be a fibre optic connection between the TBM and the server. At the TBM (control cabin) another PC is connected to the PLC.

This enables further input and evaluation facilities for the tunnel crew. On projects where multiple sites are all working simultaneously, links to a central control room (manned 24 hours per day) would be established to enable the project management team to have an overall view of all activities throughout the project and to respond to any unforeseen situation that may arise. Furthermore areas at risk of settlements are detected at an early stage and are displayed clearly, in order that corresponding measures can be initiated if necessary.



Right: **Typical TUnIS network**

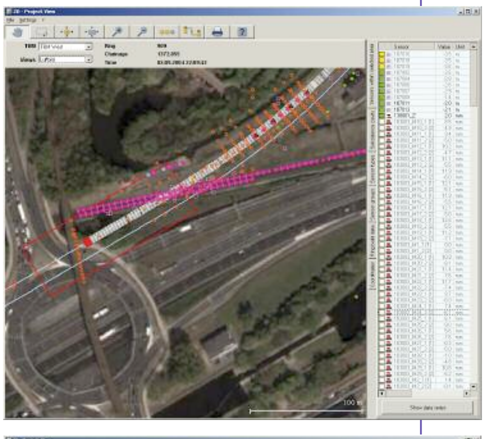
All relevant data can be inserted either automatically by an electronic interface or by manual input either during the tunnelling process on the TBM, in the tunnel, from the office or from remote locations off site. The option to have handwritten notes or photos that can be introduced into the data base is also included. Using these various input streams, TUnIS gives composite displays and fully customized reports of the information and trends for all monitored activities to those directly responsible for controlling the tunnelling activities. This in turn means that the system will give suitable warnings when preset limits are approached or exceeded. In addition to the real-time benefits of the system there are also substantial advantages when negotiating claims at the end of a project. Having all the necessary substantiated evidence will enable both sides to amicably conclude settlements.

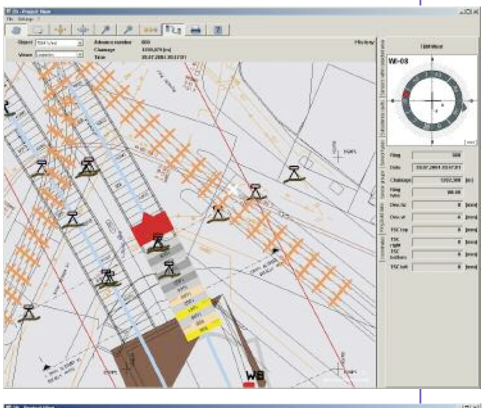
Composite displays

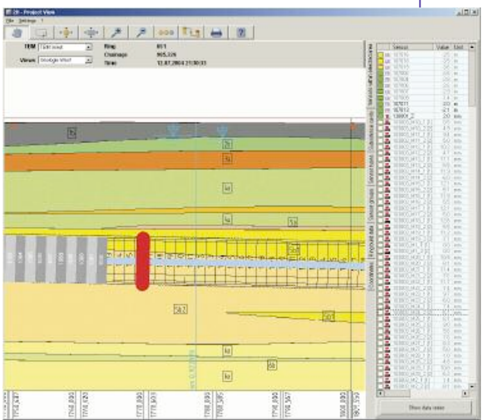
One of the CBP's core tasks is the visualization and analysis of the captured data. This is processed and displayed for the various users in the appropriate form. The spectrum ranges from cross-disciplinary data views to integrating guidance assistance for the shield driver. All modules display the current measurement values. Data of previous periods can be displayed either statically or dynamically, i.e. as snapshot or as an animation, by means of the history function.

The "2D project view" uses maps and aerial view material to show the project area with tunnel alignment, advance information of the TBM, the as-built rings and related information. Measurement data from geomonitoring and the sensor technology in the tunnel can be directly visualized and settlement cross-sections can be observed. It is also possible to define an area of influence around the TBM in order to visualize the values of its geotechnical sensors with warning lights. The warning lights helps to detect settlements quickly and if possible initiate any countermeasures programme and sensor systems used both inside the tunnel and on the surface can be shown in relation to the TBM position.

The display of the machine position and measurement values in the geological cross-section help the shield driver estimate the current and future behaviour of the machine as it is driven, in order to avoid errors and to detect changes in geology and already known potential barriers earlier. All navigation data can be viewed in the control cabin of the machine. The driving behaviour can be







Right from top to bottom: **Figure 2 – Projects area shown in relation to local infrastructure;**
Figure 3 – Areas of influence can be clearly highlighted;
Figure 4 – Machine position can be viewed against geological cross section

displayed in a "shield drive diagram" at the same time as well. Thus the drive can be re-enacted during an advance; results from incorrect shield navigation can be understood more quickly and future problems can be kept to a minimum.

Using the system "Diagram Manager" function data can be edited into schematic form including line, XY, polar and bar diagrams. Combinations of all available measurement data, reference and limit values are possible. Data views may consist of one or more diagrams with one or more arrays allowing different advances to be compared directly to each other. This means that graphical analysis of data, even immediate comparison with previous advances, is possible at any work station as well as directly on the TBM in almost real time.

In order to execute for example a settlement analysis, the results of the geotechnical measurements above ground are correlated with the automatic recorded process data. The shield passage can be divided into the following phases: quick settlements in front of the working face; settlements during advance; effects of consolidation and time until final settlement.

Several advance parameters have to be kept in mind in the settlement analysis and have to be correlated from advance speed, support pressure (target/actual) and ring gap grouting (target/actual) to mass and volume balance during excavation

Automatic shift reports replace conventional manually created reports. This automation saves time and provides an extensive report on the events within a shift.

Documentation of events and information

The "Document Management" function serves for collating and filing of information and notes. It provides digital filing of documents (for example pictures, tables, written documents) and it is a platform for information exchange during the construction operation. Due to the fast availability of information in different locations, this makes for time saving through "short cuts" – whereby direct entry to the tunnel is often unnecessary.

Within a standard advance with damage-free installation of the segments, all relevant data is recorded and analysed automatically. In case of segment damage or excessive structural ring deformations, damage analysis is executed. To support this, photos and measurements are taken. This together with the information supplied from the segment documentation system and any 3D dimensional measurement of the produced segments will give thorough QA throughout the entire ring production and installation.

The warning and messaging system helps to control and optimise the boring process. It is based on the functionality of an "Integrity Monitoring System". Both intra-system processes and measurement data are monitored and deviations are reported to the respective responsible or

CASE STUDY: Analysis from the City Tunnel in Leipzig

For the first example the time sequence of events was as follows:

16:27 hr: During breakthrough of TBM to reception shaft there was a sudden loss of pressure at compressor station – all available compressors started to run simultaneously.

16:30hr: Complete overview of the situation for the operator, the shift engineer on the TBM and construction site management personnel was carried out by 16.44

16:44 hr: Decision made to continue the advance of the TBM at a pressure of 4 bar, followed by the flooding the reception shaft with bentonite.

17:14 hr: Achieving of critical pressure, beginning to fill the reception shaft

17:20 hr: Situation under control

Fast available recorded data (not only TBM data, but also data from the compressor station) in the necessary combination made the estimation of residual time possible – with this VMT were able to successfully handle the situation.

For the second example the time sequence of events was as follows:

23:22 hr: Loss of bentonite during the advance (120 m³/hour)

00:36 hr: Halt of the advance

00:40 hr: Start injection with sealing compound (losses at 180 m³/hour)

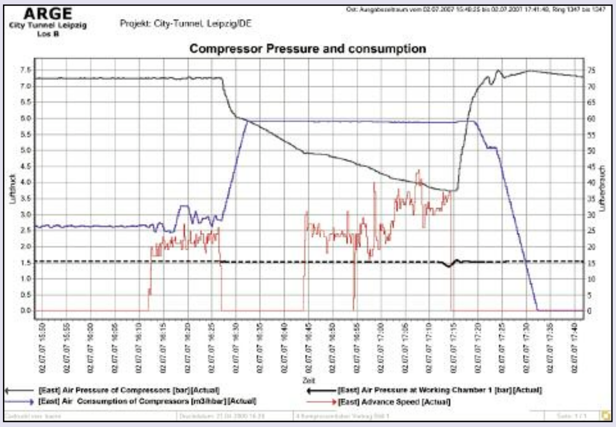
02:15 hr: Despite of injection and grouting of the annulus the losses increased to 250-300 m³/hour.

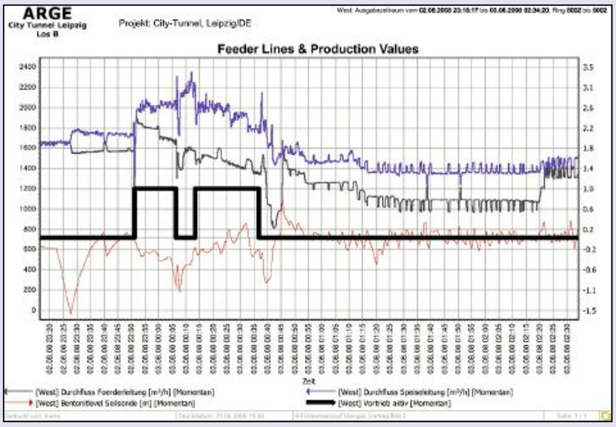
02:15 hr: Face support pressure reduced to absolute minimum.

02:20 hr: Losses reduced to 100 m³/hour.

04:00 hr: Losses reduced to nearly zero.

Only the clear visual control of the feeder and production lines and simultaneous knowledge of the relevant operations in various locations permitted the assessment and efficiency of these corrective actions. The importance of having a clear and convincing display of all the relevant data readily available proved itself in this case whereby a potential catastrophe was satisfactorily avoided.





Above left to right: **Breakthrough situation at the reception shaft; Loss of bentonite during start of TBM**

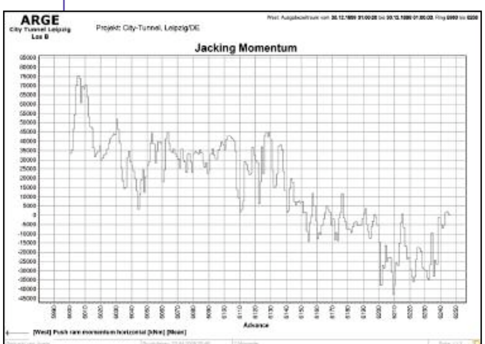
defined personnel. Warnings and messages are obligatorily saved in the system data bank and are displayed in the archive. Messages can either be shown on screen, or sent to email addressees or by mobile phone (SMS).

Often, only a combination of various measurement values will lead to the desired result. It should be possible to define on-site "artificial sensors", which result from a mathematical combination of measured values from various real sensors.

As an example, the "artificial sensor", was introduced for the (horizontal) momentum by the push rams along curved drive sections – in each case as the mean value over a complete stroke. The formula depends on the TBM, for the TBM used in Leipzig (see case study) the formula is based on:

Jacking momentum [KN/m] = (Pressure Group E + Pressure Group C2 - Pressure Group A - Pressure Group C)[bar] x 4 [Cylinders] x 8 [KN/bar*Cylinders] x 1.747 [m] + (Pressure Group D - Pressure Group B)[bar] x 6 [Cylinders] x 8 [KN/bar*Cylinders] x 3.8573 [m].

The enhanced analysis options offered by information systems such as TUnIS for the mechanized tunnelling offer a large range of possibilities including interdisciplinary administration of one or more tunnelling advances and use of data of different advance or construction machines of one project at the same time. What is more there can be an unrestricted number of users and also is the option of defining precise user rights. The system itself is self-explanatory allowing users from beginner to expert to produce meaningful analysis. It is also highly stable with sophisticated data back-up. Its digital document management system and automatic report creation options replace work intensive tasks. Automatic monitoring of parameters also saves time and enables the generation and sending of warnings and messages if required. Finally the flexibility of the data interfaces allows information to be easily shared with other parties involved in the project. T&T



Left: **Jacking momentum through an advance**

Belfast Sewers Project - part 1

The Belfast Sewer Project was presented at the November meeting of the British Tunnelling Society. In the first of two articles on the project, Alan Skates of Atkins gives an overview of the construction works and design challenges

It rains a lot in Belfast. This is hardly front page news but when that 'soft' Irish weather is pitted against a creaking Victorian sewer system, then the ensuing floods certainly do make headlines. The unappetising prospect of overburdened sewers failing to handle the torrential downpours and city effluent is one which inner city locals are facing on an increasingly regular basis. Northern Ireland Water had the unenviable task of resolving this issue, which culminated in the Belfast Sewers Project.

Belfast, like a lot of estuarine cities, is typified by numerous low-lying areas which are very vulnerable to flooding and unless surface water can be conveyed away swiftly, these areas are at the mercy of extreme weather events, which appear to be occurring with increasing regularity.

The Victorian sewers are simply no longer large enough to deal with the amount of stormwater that is flowing into them. A new stormwater system therefore needed to be built to handle all of the excessive flows entering the old sewers, to deal with pollution, avoid the flooding and convey the surplus rainwater down to the Belfast Waste Water Treatment Works. Crucially, the scheme had to fulfil the extensive criteria set out in the EU's Urban Wastewater Treatment Directive.

In July 2003, Atkins was appointed to undertake the project management for the delivery of the Belfast Sewers Project. The scheme included the design development of a new stormwater management system to resolve the problems of flooding and pollution within a large part of the central catchment area of Belfast city.

The construction work on the £160M (US$267) scheme started in September 2006 and is currently nearing completion after three years of tunnelling some 30m below central Belfast. Over this time the people of Belfast city were generally unaffected by the construction works and oblivious to the tunnellers who were tirelessly working deep underground 24 hours a day, seven days a week to construct the tunnels.

Above: **The Victorian sewers are 130 years old**

Below: **The main tunnel runs 9.4km with a maximum diameter of 4m**

The key design considerations were the size, route and depth of the tunnel. The diameter of the tunnel sections were derived from the hydraulic model which was developed by Atkins for the Belfast catchment. The model comprised over 40,000 nodes and 1,181km length of sewer pipes. The model examined the impact of stormwater flows entering the tunnel system for a variety of rainfall events up to a maximum one in 30 year storm event.

Much attention was given to the planning of the tunnel route and the access shafts. The locations of the shafts were generally selected to be on sites where future access would be easy, in areas such as car parks, green spaces or in publicly owned land not likely to be developed in the future.

The route was kept as much as possible along the centres of the existing road system and within open areas such as parkland. However, the route however did necessitate the need to pass under both existing and future buildings. In this particular case the depth of the piled foundations dictated the level of the tunnel horizon which was chosen to clear the longest piles.

The main 4m tunnel starts at Cromac Street and terminates at a new pumping station located within the Belfast wastewater treatment works in Duncrue Street near the M2 motorway where the storm water will be screened and released into the Herdman Channel. Tributary tunnels join this main tunnel from Glemachan Street, Queen's Quay and Park Road.

The tunnel runs for a total of 9.4km at depths down to 30m below ground through the city centre. The 4m diameter tunnel runs for a total distance of 4km, with a further 3km of 2.4m diameter bores; and around 90m at a bore of 1.5m while the remainder is bored at 1.95m diameter. The project also involves the construction of 19 access shafts with diameters ranging from 6m to 15m.

Atkins' responsibility also included the procurement of a design and build contractor to undertake the construction of this ambitious project.

Following completion of the design by Atkins the works were tendered to the market. The design and build contract was won by a joint venture comprising Morgan=Est and local contractor Farrans and the ground was broken in September 2006.

Above left: **The terminal pumping station has a 37m diameter and is 40m deep**
Above right: **A wall separates the dry well from the wet well**

Belfast geology

The biggest challenge on the project, perhaps unsurprisingly, has been the geology of Belfast (see box). Many of the challenges faced by the project team were due to the complex ground conditions encountered during shaft construction and tunnelling.

The geology of course determines the working conditions and the ground below Belfast is extremely variable; comprising fluvial glacial deposits; weak sandstone bedrock and boulder clay topped by sandy gravel. There is also the presence of the dolerite dykes to contend with. Dolerite dykes are random, vertical intrusions of hard igneous rock that rise like jagged shards through the intervening layers of sandstone. This gave the tunnellers all sorts of challenges to overcome and of course headaches.

There was an eight man tunnelling team for each of the two Lovatt EPBMs which undertook the main 4m tunnel drives. In support there were up to three locomotives working to service the TBMs. Precast segments were supplied to the TBM as it constructed the concrete tunnel lining, whilst excavated material was carried out on muck skips and taken up to ground level by crane and a high angle conveyor system. Over 250,000 cubic metres of muck was removed during the tunnel's construction and this spoil was used to cap Belfast's recently closed municipal landfill site.

Pipejacking was also used for some difficult ground conditions in Ormeau Park. Other issues encountered during tunnelling included high levels of contaminants evident around the Cromac Street Gasworks site which slowed work on sections of the 2.4m diameter tunnel, due in no small part to the stringent and strictly observed environmental and health and safety regulations concerning working at depth with ground contaminants.

Contamination discovered during sinking of shafts 7 and 25 (around Cromac Street) required the groundwater to be treated using a carbon filtration system before discharge to the sewer system.

Pumping out

A major part of the project was the Duncrue Terminal Pumping Station TPS. At the time the TPS was one of the largest excavations in UK, and the projects understands it is the deepest excavation ever carried out in Ireland. The sheer scale of the project was a challenge. The terminal pumping station is 37m in diameter and 40m deep and is bisected by a massive dividing wall to create a wetwell to receive the stormwater from the tunnel system and a dry well for the pumps.

The design also includes a new stormwater tank with a four-million gallon capacity (equivalent to eight Olympic swimming pools). The pumping station is fitted with six Bedford pumps which collectively can handle up to 4,000 gallons per second. The pumping station also includes two smaller low-flow pumps rated

BOX: Belfast's Geology

- Made Ground – recent deposits of fill of various types deposited during the construction of Belfast and harbour
- Estuarine Clay – locally known as 'Sleech' very weak clay (bulk density approximately 1.7)
- Glacial deposits – both fluvial glacial and glacial divided into the following local units;
  i) Lower Alluvium - an upper sand layer which is often can contain thin clay layers,
  ii) Upper boulder clay - chiefly a firm to stiff sandy silty clay but can be likely to contain sand lenses, sandy horizons, cobbles and occasional boulders,
  iii) Malone Sands – a sand layer containing occasional cobbles and boulders generally found between the upper and lower clays, not always present;
  iv) Lower boulder clay – a very stiff brown sandy and gravelly clay containing sub-rounded cobbles and boulders.
- Sandstone – Triassic age Sherwood sandstone, weak rock. The sandstone has been eroded to form valleys which were subsequently in filled with glacial deposits. Marls can also be present but have not been encountered within the works.
- Dolerite – intrusive dolerite forming dykes within the sandstone (bedrock) found in the various states of weathering. Approximate spacing of intrusions is 110m and can be 1m to 10m in thickness.
- Dolerite material (intrusive dyke within sandstone) at face of tunnel, taken during intervention to check and repair cutter head tooling.

for day-to-day operations.

As with the rest of this job, ground conditions for construction of the TPS were to prove knotty, partially due to the ancient wooden piles found throughout the site. Before the contractor could even contemplate construction of the diaphragm walling, the high level of the water table necessitated the installation of a dewatering system to lower ground water levels sufficiently for works to begin. Furthermore, the Duncrue Street site is only a stone's throw from the River Lagan. This necessitated the sinking of dewatering wells to a depth of up to 80m to take the water table down in order to facilitate the construction of the 40 metre deep excavation for the TPS.

Once the water level was lowered the diaphragm wall section could be constructed and excavation work could continue using sprayed concrete for the rest of the deep excavation. A concave concrete base slab was constructed at the bottom allowing works on the pumping station's internal walls to begin.

Above left: **Six, 20t pumps sit in the TPS dry well**

The terminal pumping station work comprises two additional structures; namely the primary screening system for the treatment of the storm water discharge and secondly, the outfall diffuser structure which moderates the storm flow velocity into the Herdman Channel.

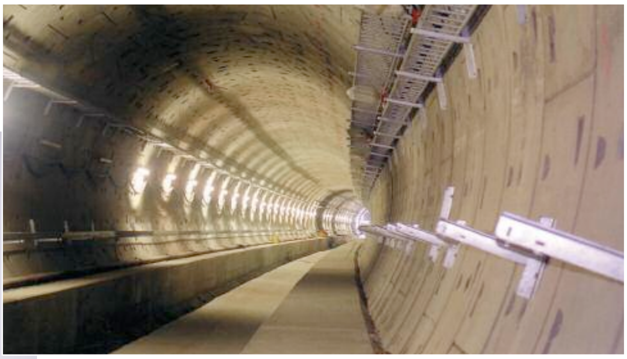
Discharging into a shipping channel was never going to be completely straightforward. Belfast's Harbour Commissioners were concerned about the velocity of the stormwater discharge, given the large volumes of stormwater flow potentially involved up to 16 cubic metres per second which had to be addressed in the design.

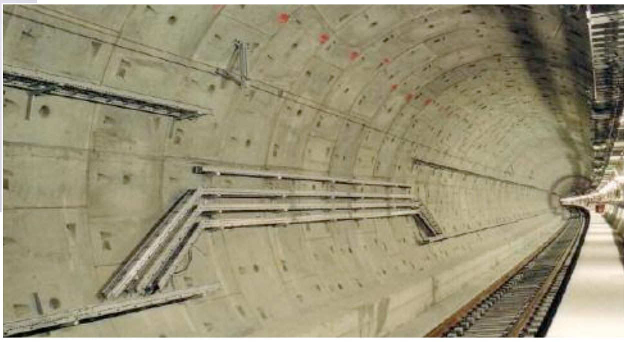
To this end a scaled laboratory model was developed to aid in the design of the outfall diffuser. This physical model allowed the design characteristics for the performance of the outfall to be refined. The basic design principle for the outfall was to disperse the flow through the uniform distribution of discharged stormwater over a wide area, thereby minimising the risk of taking passing ships off course with the current generated by a concentrated flow from the outfall.

The project is currently at the stage of testing the storm pumps and the associated mechanical and electrical control systems. A lot of effort is concentrated on completing the fit out work for the access shafts in readiness for the turning of flows before the end of the year.

Tunnelling completed in September 2009 and handover of the project will take place in the New Year. T&T

Screw it





The company Excalibur Screwbolts was this year awarded the Queens Award for Enterprise and Innovation for its range of fittings. Barbara Stack of Excalibur Screwbolts explains that since the firm's first fittings range was launched 1992 it has grown and developed to meet the increasing demands of the sector.

Managing director and owner of the firm Charles Bickford invented the bolts in the late 1980s. It initially launched offering 4mm, 6mm, 8mm, 10mm and 12mm diameter screws. Later, in 1997, 16mm and 20mm diameter sized Screwbolts were added to the set, (with corresponding lengths of 100mm, 150mm and 200mm).

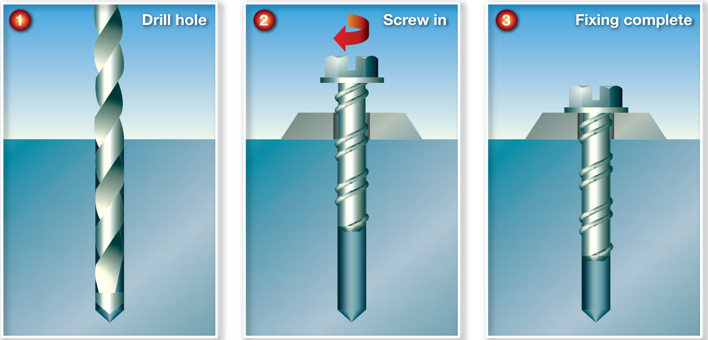
Although there are several different types of head design, at present, the 16mm and 20mm Screwbolts are only available in the hexagonal head style.

The original, case hardened and tempered, twin helical thread screw bolt is manufactured from Boron steel (BS3111/9/2.1A/10B21). The designer argues its advantage is two-fold. It is a very effective anchor and is simple and cheap to install, using various wrench types, including an impact wrench.

Because of its non-expanding design, the Excalibur screwbolt provides high tensile-shear safe loading close to edges and when positioned with close centre spacings. The Screwbolt's self-tapping, twin helical thread permits it to be removed and replaced when necessary.

Apart from its use in securing ventilation equipment to tunnel walls, etc., where suitable substrata exist, the Excalibur Screwbolt can often be used effectively in place of resin or traditional expanding anchors for attaching all types of infrastructure, including heavy equipment, to the concrete or rock walls.

According to the manufacturer, it is able to cut its thread in virtually all known substrates, including concrete, rock/natural stone and steel. However, as conditions on site may vary considerably, the firm recommends that clients satisfy themselves regarding the suitability of the material to which the screwbolt will be attached. In major projects Excalibur offer 'on site' testing facilities to assist their customers determine product suitability.



Installation

The company stresses that, in addition to ensuring the Screwbolt selected is right for the type of substrata concerned, the drill bit diameter should also be the correct size for the specific Screwbolt chosen. When using the Screwbolts it is essential to drill deep. That is, the hole depth should be at least the embedment depth of the Screwbolt, plus twice its diameter. (See Figure 209i).

During the drilling of the pilot hole excess dust or debris should be removed, or some resistance may be experienced. However, this problem is often rectified by unscrewing the bolt for a single turn or more, and then continuing to fix to full embedment.

Use in the Chunnel

At the beginning of the Channel Tunnel Rail Link project, several 'fixings' manufacturers and distributors were invited to submit samples for evaluation.

With a view to using them for attaching cable tray brackets inside the tunnel Excalibur Screwbolts were rigorously tested by inserting them into fibre reinforced tunnel lining segments. The tests (using the HSB12 X 100 bolts) involved timed drilling and installation methods, which utilized both hand and impact wrenches. These tests soon showed that for so large a project, the impact wrench was the only method that was acceptable as viable.

The tensile (pullout) capacity of the bolt was then tested and this gave a result of 78kN. Following this, further successful tests were conducted with HSB16 X 100 bolts to determine their suitability for fixing the fire mains brackets and with HSB16 X 200 for attaching services brackets to the approach diaphragm walls. The tensile tests for this latter application were stopped when the results indicated 100kN as this figure was well above any live load to which the bolts would be subjected.

Of particular interest was the decision to use diamond drills when it was necessary to insert Screwbolts for brackets at 'specific centres'. Apparently the Special Direct System (SDS) drill bit was inclined to 'bend' when rebar was encountered and thus prevented the achievement of full embedment of the Excalibur Screwbolt. The diamond drill produced a straight hole through any rebar, and so allowed full embedment of the hardened Excalibur Screwbolt.

Apart from the above applications, a large number of Excalibur Screwbolts sizes M6, M8, M10, M16 and M20 were used for a variety of purposes, including the supports for Extractor fans within the tunnel, to secure cable clips to the concrete sleepers and to support the temporary lighting cable by means of hooks and eye headed Screwbolts.

Excalibur Screwbolts
Web:
www.excaliburscrewbolts.co.uk

Shipping out

A Herrenknecht tunnel boring machine and ancillary equipment totaling an enormous 6,000m³ for Barcelona's metro expansion was earlier this year transported from Germany to Spain by freight specialists Abnormal Load Services.

The heaviest and one of the highest pieces in the metro consignment was a shield segment which measured over 7m long, 7.5m wide, almost 4m in height and more than 130 tonnes in weight. In addition a screw conveyor totalling 19m in length, 2m wide, almost 3m high and weighing 84 tonnes was the longest piece transported.

The movement involved local road transportation from Herrenknecht's factory to a German river port and transhipment to a barge using Herrenknecht's preferred local partner and supervised by ALS' project team from Hull, UK & Moerdijk, Netherlands.

At Barcelona port the TBM and ancilliary equipment was offloaded onto waiting vehicles and quayside storage area by shore-based cranes, using registered stevedoring personnel and facilities. ALS supervised reloading to trucks from Barcelona Port and transportation to jobsite.

ALS' project teams in Hull, UK & Moerdijk, Netherlands have been responsible for the whole project, which has involved: undertaking road surveys, arranging permits, removal of street furniture, barge movements, sea freight, handling and craneage.

Abnormal Load Services
Web: www.abnormal-loads.com

Right and below: Screw conveyor, shield segment and cutterhead in transport

Stepping up

For many years Transforge has been supplying the tunnel industry with modular bracket and walkway systems. The system works on the principle of lightweight shelves being clipped into a backplate to support the pipes and cables. Walkways themselves are produced using 3m long panels with an anti slip surface. The walkway panels also clip into the bottom of the backplate and can be available from 460mm wide to 900mm wide.

The backplate can be fixed to existing segment bolts or via holes drilled into the wall.

Shelves normally cater for standard sized cables and pipes. Additional roller or lighting shelves are available and reduce the need for additional drilling and fixing to the tunnel lining.

All products are designed to weigh less than 25kg to enable ease of handling. Shelves, backplates, etc. pack onto pallets for easy transportation and can be re-used for future projects.

Lightweight temporary sleepers and bespoke tunnel steelwork of all types are also part of our large range of specialised tunnel steelwork.

Transforge
Web: www.transforge.co.uk

Cutting edge

One of TunnelTec's core competences over the past 30 years has been the supply of specialized, robust and low-wear drilling tools for TBMs. The special features of these tools are their long durability and high economic efficiency. These tools can be mounted on existing cutterheads or cutting wheels without any further alterations. TunnelTec argue that their tools can improve the daily headway of the TBM and reduce tool changes and down times.

The firm supplies wire brushes for the tail shield of TBMs and, since 2007, it also supplies complete cutterheads for Microtunneling machines and equipment for Electrical Ahead Monitoring.

The company offers various kinds of services for overhauling and refurbishing TBMs, such as the supply of specialized staff, engineering and the purchase of spare parts. Additionally, full service for tunnel construction projects from consulting, project planning up to construction and sale can also be offered.

TunnelTec
Web: www.tunneltec.com

Factory to face - support to the tunnel

The manufacture and installation of uniform tunnel linings using pre-designed standard elements is important in maximising tunnelling efficiency. However, tunnelling is not a uniform activity, and such procedures must be able to handle unforeseen circumstances and non-uniform design requirements. Technical editor Maurice Jones reviews aspects of current practice

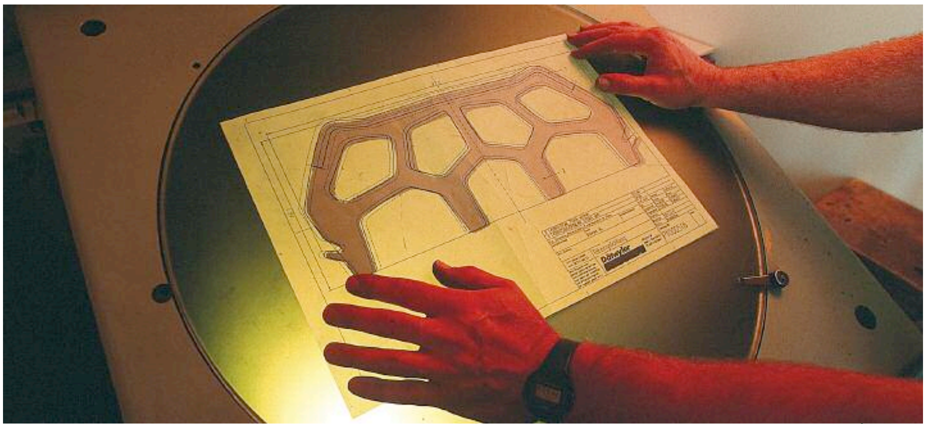
Pre-manufactured structural linings were developed to fit naturally with the growth in use of mechanised tunnelling shields. Previously, cast-iron units were used with semi-manual installation to support squeezing ground, but the weight and bulk of the elements made their use laborious. These were replaced as technology evolved with cheaper, lighter and easier-to-handle alternatives.

As excavation efficiency improves and the maximum diameters required increase, so more demands are placed on the supply of lining elements to provide temporary support and a secure reaction for the shield machine thrust, as well as forming at least part of the permanent support. In the longer-term the completed support ring has to withstand ground pressures, possible groundwater and chemicals attack and any internal erosion or physical impact for the design life (usually 100 years) of the tunnel.

Pre-cast concrete elements also have important roles to play in other aspects of tunnelling, especially in the support of shafts with special segment rings or caissons. For example, Bucline caisson shaft linings from Buchan (owned by Roger Bullivant Group) are available in diameters from 6m to 15m. Of the Smoothbore, single-pass type, these segments offer fast construction needing minimal finishing. Installed as a caisson but with bolted and gasketed joints, the system retains the strength, flexibility and speed of erection of standard bolted rings but with a safer method of working by reducing man-entry to the shaft.

Other precast uses include furnishing the tunnel with inverts, rail sleepers, walkway supports, and special accommodation units. These uses do not have such high structural demands but may be accommodated by a modified version of the same plant used for lining.

The modern versions of cast iron segments, now in spheroidal graphite iron (SGI), are widely used where the design demands greater strength such as at junctions or to accommodate design elements such as ventilation louvres and crossovers.



Above: **Optical quality control of a profile for a segment rubber compression gasket extrusion by Dätwyler**

Design

Whereas the correct composition of concrete mixes for segment casting are well known, some other development aspects of segment design are still being achieved, such as in reinforcement and beneficial additives.

The activities in segment manufacture that show most potential for greater efficiency are reinforcement and curing. Reinforcement is used to provide the necessary strength during installation and in the tunnel structure, and has traditionally been supplied, as in other concrete casting, by a steel rebar structure to add toughness throughout the casting. This necessitates a separate operation within the works likely to require additional investment in equipment to cut, bend, assemble and join the rebar according to the designed reinforcement 'cage'.

The introduction of fibre reinforcement can not only improve the toughness of concrete segments but also holds out the promise of cost reductions. Fibres deter crack formation in the concrete and, in the event of impact during handling, reduce damage and exposure of any rebar cage. In some cases a cage may not even be necessary. Tunnel concrete specialist Charles Allen of Tunnelling Limited maintains, "Only very large segments will require rebar cages and even then a hybrid solution of cages and fibres will reduce the risk of damage to the segments during handling and erection. It is only when tunnel segment rings get to 8m diameter and over that rebar cages might need to be used."

The possible elimination of steel rebar cages in smaller diameters can reduce costs by using fibres instead. Table 1 shows a spreadsheet template for making costs comparisons (with sample figures). "The benefit of steel fibres is that reinforcement can be delivered with the concrete and requires no separate fabrication labour or factory areas," says Allen.

Comparison of costs steel fibre reinforcement vs. cage reinforcement in segment production

No. of rings in project	Segments/ ring	m^3 of concrete/ ring
3,000	8	6.48

Steel fibre reinforced segments			
	Unit cost	**m^3 per ring**	**Cost/ring**
C60 Concrete	84.00	6.48	544.32
	Unit cost	**kg/m^3**	
Fibre dispenser	32,000	0	10.67
Fibres	1,200	0.035	272.16
Repair of damaged segments	**Percentage**	**Segments for repair**	
% of segments requiring major repairs	5%	150	
Labour for repair	1	14.00	0.70
Cost of cranage in/out repair areas	0.25	25.00	0.31
Administration/ QC costs	0.25	14.00	0.18
	Cost/segment	**Total cost**	
Cost of repair materials	10.00	1500	0.50
Total cost/ring			**828.83**
Reinforcement cages			
	Unit cost	**m^3 per ring**	**Cost/ring**
C60 Concrete	84.00	6.48	544.32
	Unit cost	**kg/m^3**	
Reinforcement	500	0.080	259.20
Cage fabrication	**Man-hours/ ring**	**Cost/hour**	
Labour for fabrication	16	12.00	192.00
Administration/ QC costs	1	12.00	12.00
	Total cost		
Jigs	25,000		8.33
Rebar fabrication shed area	200,000		66.67
Welding/tie wire	3,000		1.00
Placing of cages into moulds	**Man-hours/ ring**	**Cost/hour**	
Labour to place cages	3	10.00	30.00
Cost of cranage	3	25.00	75.00
QC costs (checking cover)	1.5	12.00	18.00
Repair of damaged segments	**Percentage**	**Segments for repair**	
% of segments requiring major repairs	10%	300	
	Man-hours/ ring	**Cost/hour**	
Labour for repair	1	12.00	1.20
Cost of cranage in/out repair areas	0.25	25.00	0.63
Administration/ QC costs	0.25	12.00	0.30
	Cost/segment	**Total cost**	
Cost of repair materials	10.00	3,000	1.00
Total cost/ring			**1,209.65**

Right: **Table 1 - Template for costing of segmental lining fabrication, usually showing that steel fibre reinforcement is cheaper than rebar or welded mesh cage reinforcement [Devised by Charles Allen, Tunnelling Ltd.];**
Above: **Segment moulds manufactured by Ceresola TLS for contractor Max Bögl for the 4242m-long second tube for the Kaiser-Wilhelm-Tunnel in the Mosel Valley, Germany**

Elasto-Plastic Concrete has successfully introduced its BarChip macrosynthetic fibres to segment casting to partially replace steel reinforcement on projects including the Malaga airport rail tunnel from Los Prados in Spain. 5kg/m^3 of Barchip macrosynthetic fibres replaced 25 kg/m^3 of steel fibres in the mix to be cast around a steel cage. The objective was to prevent concrete spalling due to TBM ram thrust. The 9.33m-diam. Herrenknecht TBM installed rings of seven sgements in mainly clayish soil. Work was around 24 hours, seven days a week.

Another advantage of using fibres in the mix is to limit damage to the concrete lining in the event of a fire in the tunnel. Monofilament polypropylene fibres can be used to create pressure relief passages on melting and thus reduce the likelihood of spalling of the concrete. Fire resistance may also be provided by installing low-heat-conductive boards or by spray-applied specialist coatings.

Propex and EPC supply both macrosynthetic (structural - as Enduro and Barchip Shogun respectively) and monofilament fibres (for fire resistance).

Some guidance on testing procedures and applications is provided by The Concrete Society's technical report TR65 published in the UK in 2007. Polymer synthetic fibres both in structural and non-structural uses in concrete must comply with the requirements of European Standard EN 14889, Part 2 on Fibres for Construction (British Standard of 2006). Additional testing for particular applications, such as tunnel lining segments, could still be necessary.

Steel fibre suppliers included Propex (Novocon range) and Bekaert with Dramix.

The segment strength required on various axes depends both on the design of the tunnel and the forces that have to be withstood during segment handling, transport and erection. Allen says that although the concrete mix specification used may require a 28-day strength of 50 or 60N/mm^2, a high early-age strength required for demoulding the segments will usually result in much higher characteristic strengths in situ. "The strengths required for demoulding are dependent on the segment size, design and the demoulding system, whether vacuum or mechanical, but they are generally between 12 and 20 N/mm^2 at 8-12 hours of age. The conventional moist curing of segments is generally not undertaken due to the complexity of such an operation in the storage yard."

Manufacture

The location of manufacture will be an important consideration in overall project costs with a positive balance needing to be struck between the additional capital expenditure and dedicated resources of an on-site plant against the extra costs of transport from an existing plant on the other. Main tunnel contractors may set up on-site plants with the assistance of specialist engineers or plant manufacturers.

In recent years there has been a trend for major tunnelling contractors to set up their own long-term precast works where there appear to be prospects of more continuous tunnelling or adaptation to other precast concrete products. Examples include Morgan Est in the UK and Traylor Brothers in the US. In such cases the likely lower unit cost of an existing facility should be able to compensate for higher transport costs. Morgan Est recently completed the supply of tunnel lining segments to the Belfast Sewer Project (see p29), some 240 miles (380 km) away from its Ridham precast works. This was established to supply construction of the London Heathrow Airport Terminal 5 tunnels in 2002.

In the US, Traylor Bothers set up a precast segment unit within its Underground

Division in 2001, also offering its products to other tunnelling contractors and projects, usually in joint venture. A project just commenced by the Traylor-Tecnopref Precast JV is under contract. U220 of the University Link Light Rail project in Seattle involves the supply of 22,800 linear ft. (6949m) on 'one-pass' tunnel lining for parallel tunnels linking the University of Washington to the Capitol Hill area. A plant is being established at the University's Husky Stadium near the northern portal.

Max Bögl is another major contractor with its own precast plant interests. During its contract in the Lower Inn Valley for the new rail route between Münster and Wiesing the contractor set up its own precast plant to operate from March 2007. Situated near the start portals of the twin tunnels to manufacture 23,000 reinforced segments for installation as 2875, 13m-diameter rings, the plant is described as 'mobile' and included its own concrete batching plant. It employed Ceresola segment moulds on a static system in which a travelling concrete distributor pours concrete into each mould for natural curing. Each segment weighs 14t and was put into position using an erector within the Herrenknecht TBM back-up system.

Casting

Although simple in principle, segment casting can require considerable organisation to obtain the production required by many TBM-led construction projects. The moulds for each segment in the ring are assembled in batches to ensure sufficient numbers of each type and their correctly sequenced delivery to a holding area or the tunnel. The precision-fabricated moulds are usually laid horizontally with the intrados down to accept the concrete pours.

Explaining the importance of curing temperature and additives to production levels, Charles Allen says, "In order to get multiple castings per day carousel systems with heated curing chambers are used. In warmer climates this may not be necessary. It is hoped that new developments in concrete admixtures technology will be able to reduce or eliminate heated curing facilities."

In addition to segment moulds CBE manufactures and supplies specialised segment handling equipment and complete plants. Recent orders have included 18 sets of moulds to Bouchier Precast in Canada for the Southeast Collector Trunck Sewer in York and Durham, and five sets for 9700mm-diam. rings, in co-operation with Lovat, for the Kuznetsoy project for Bamtonnelstroy in Russia.

The Ceresola TLS range is similar and includes fully automated carousel plants, concrete feeds and compaction devices. Recent deliveries have included the complete segment product equipment for Max Boegl's plant at the 5835m-long Muenster-Wiesing Tunnel for the Brenner Railway, Austria, and stationery segment moulds for the second (safety provision) tube for the Kaiser Wilhelm Tunnel in Germany, also for Max Boegl.

Quality control

Clients and their engineers are increasingly demanding reduced tolerances (too small some argue) that are virtually impossible to achieve solely on site. Accurate monitoring of manufacturing equipment and casts is therefore vital. Laser guidance and monitoring experts VMT offer a range of equipment and systems for industrial measurement applicable to segment production. Processes include measurment of steel construction including iron segments, surveys of segment moulds, their gauges and the segments temselves, and the measurement of ring circularity.

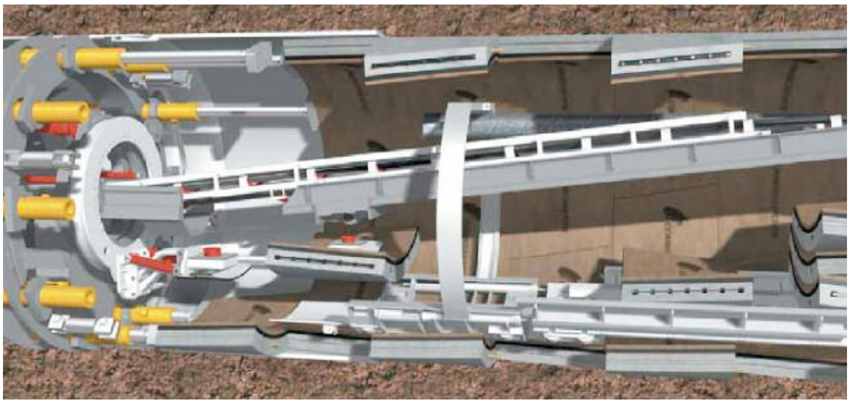
Measurement systems include precision optical systems to determine co-ordinates in three dimensions from angles and distance. These are obtained by instruments such as the VMT Lasertracker, Leica theodolities and digital photogrammetry. Both primary and secondary control procedures employ VMT's TubGeo software to compare monitored geometry with construction design values.

Handling & transport

As mentioned above, the segment handling devices are likely to have a substantial effect on the design, the concrete mix and the segment itself. Whilst segments can be lifted by hoists linked to well-designed eye-bolt fixtures, the use of vacuum-pad lifting has become widespread both in casting plants and at the tunnel face. The principle is to apply the load over a wide area of segments, or at multiple points, in order to avoid any concentrated loading and impact damage to the edges of segments. Similarly, within the casting plants, handling equipment has to spread the loading across as much as possible of the newly cured segment.

Charles Allen explains the differences as, "In small-diameter rings with segments that contain bolt holes, etc., there may not be enough surface area in the segment intrados to accommodate a vacuum pad. In these cases segments have to be erected mechanically with a central locating pin or grout socket."

Below: Cutaway diagram of erection of standardised Herrenknecht Combisegments for utility tunnels within a Herrenknecht TBM backup system; **Right, top:** Pouring into segment moulds for the Malaga Los Prados-Airport rail tunnel in Spain. The mix used Barchip fibre instead of steel fibre in addition to a steel reinforcement cage; **Right, bottom:** Hand-finishing a segment after the pour at Malaga



Carbon cost versus financial

Although centralised manufacture may be able to be justified economically, current concerns about carbon 'footprint' could damage a manufacturer's standing when considering transport logistics. "Obviously, for a major or remote project, an on-site casting facility is preferable," says Allen, "or at least one within reasonable proximity to the site. In all cases the carbon 'footprint' of the project should be evaluated, and the handling of segments over long distances be avoided as much as possible, since the trucks and trailers generally return to the segment factory as empty vehicles."

Nuts and bolts

It is the small things that can often delay progress, so it is important to pay adequate attention to the correct design and installation of gaskets and other seals, fixing bolts, handling attachments, and tunnel furniture fixings.

Crucial amongst the fittings used with tunnel segments are joint gaskets. Their main functions are to resist water and fines ingress to the tunnel and to improve the tolerances of the joint. The water seal properties become particularly important where groundwater pressures may be high or where only a single-shell or 'one-pass' lining is used so that the gasket seal will be the only material at the joints (apart from grout), between the ground and the tunnel interior. Along with the increased parameters expected of tunnels, so gasket sealing properties have had to improve from the 3-bar maximum sealing pressure of the early gaskets to the 45 bar required for the gaskets of the Hallandsas Tunnel in Sweden. Thus various extrusion profiles have been developed with advanced properties and multi-element construction effective when the segment joints are tightened by their bolts.

Gaskets are now often fitted with adhesive to each segment in or near the casting plant. This reduces the chances of poor installation due to human error under tunnel face conditions, but also necessitates additional care during handling and transport before installation.

As well as being able to withstand the expected groundwater pressures immediately after installation and compression, gaskets will also need to be able to tolerate long-term ground movement and to resist the corrosive effect of any contaminants, including oil, both inside and outside the tunnel. In transport tunnels fire-resistance may also be needed. EPDM rubber has been found to meet such requirements, although it is sometimes used in conjunction as a coextrusion with a hydrophilic swelling layer. Gaskets of wholly hydrophilic swelling material, such as Hydrotitie (developed in Japan and marketed by Tarmac Charcon), are also available.

Left: **Careful handling of segment ring sets is essential. Here the segments have been fitted with Heinke gaskets in the segments' precast grooves**

Ring assemblers have often experienced difficulties with locating bolts easily, and it is an activity prone to some error. The product range of Technical Tunnelling Components of England is aimed at easing some of the more difficult aspects of ring building as well as annular grouting. This includes the Dowelock Alignment System. The components are available in various sizes and can be modified to suit customer requirements, working with both hydrophilic and compression gaskets. The dowels' correct performance restrains the forces generated by gaskets to minimise any joint gaps and offsets. Models range from the tensile strength of at least 2t of the Dowelock 20 to over 11t for the Dowelock 450.

Installation

The availability of trapezoidal segments enables an appropriate installation sequence to aid the construction of planned curves in the tunnel, or to correct TBM drift from the planned axis, without losing any structural integrity. Calculation of the correct sequence can be laborious and prone to error if done manually, as well as difficult to predict necessary sequences well in advance.

Using the VMT Ring Management Program (RMP) these difficulties can be eliminated. VMT claims that experienced ring-building teams cannot predict more than one ring ahead reliably. Using the RMP the parameters of influence are considered in each calculation including TBM jacking thrust, shield tailskin clearance, any specific ring design and exceptions for the project, cruciform joints, and the position of the TBM relative to the project tunnel axis. Calculation data is all recorded and stored on a database.

If the TBM has drifted from the design axis an appropriate correction curve will be calculated to guide the machine back on course with the following segment rings back on the planned axis.

Longer term

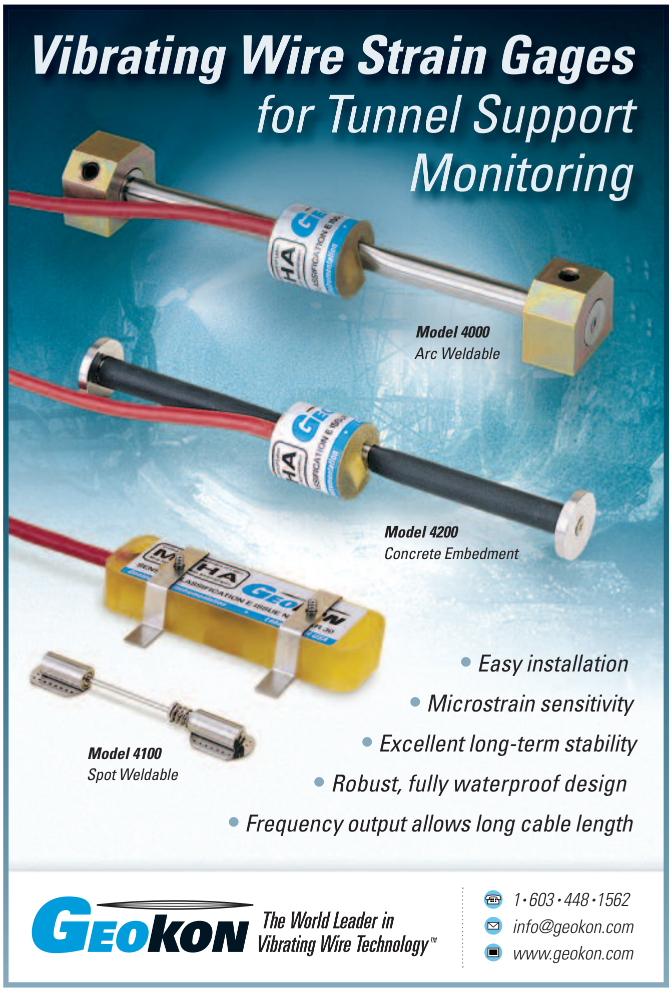
Even when the erection of a segment ring is completed the structure should still receive attention to ensure long-term performance of the structure. With the possible exception of squeezing ground requiring expanded lining, annular grouting will be required to ensure uniform loading of the lining.

Accurate positioning of the segmental lining ring will remain important, particularly in transport tunnels, long after its installation. Therefore monitoring of any movement can be important. VMT's Ring Convergence Measuring System (RCMS) uses a series of inclinometer for data collection of convergence in segmentally lined tunnels. The system is mounted around the intrados of the ring and linked to monitor any deformation continuously with a selected measurement interval. Vertical ring movements can also be determined by integrating a reference prism into the system, logged by the guidance system to an accuracy of less than a millimetre. The data collected can also be integrated into the overall TBM control system.

Resistance of the concrete to aggressive chemicals may be important either due to ground conditions or the use of the tunnel such as a sewer or a transport tunnel carrying such chemicals. Even salt and anti-freeze might be significant. According to Charles Allen a specially designed concrete mix might be sufficient to provide corrosion resistance. "Some sewer tunnels may be lined with an hdpe (high-density polyethylne) membrane to counteract anaerobic attack of the concrete, and abrasion. Alternatively the inside of the tunnel may be coated with a chemically resistant spray-applied lining material."

Conclusion

Precast tunnel segments have proven their worth many times over but maximising cost efficiency requires analysis of much more than just the ground conditions. Contractors have to make difficult decisions when trying to balance capital costs, environmental costs, lifting mechanisms, jointing technologies and reinforcement requirements. However on the bright side technologies are evolving and new, useful products are coming to market that may make the decision making process a little easier and construction a little less expensive. T&T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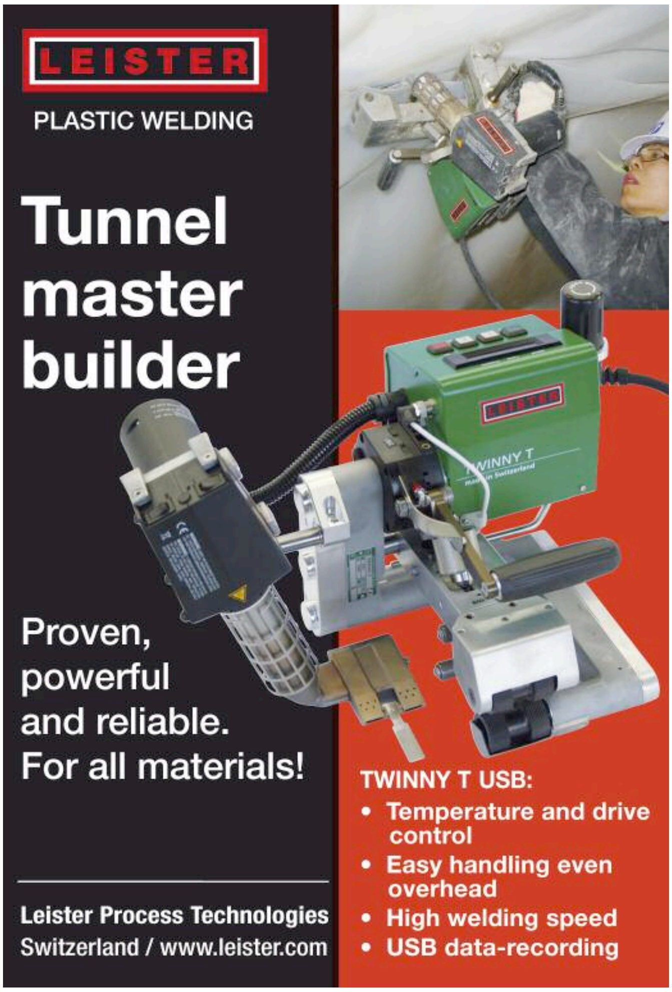
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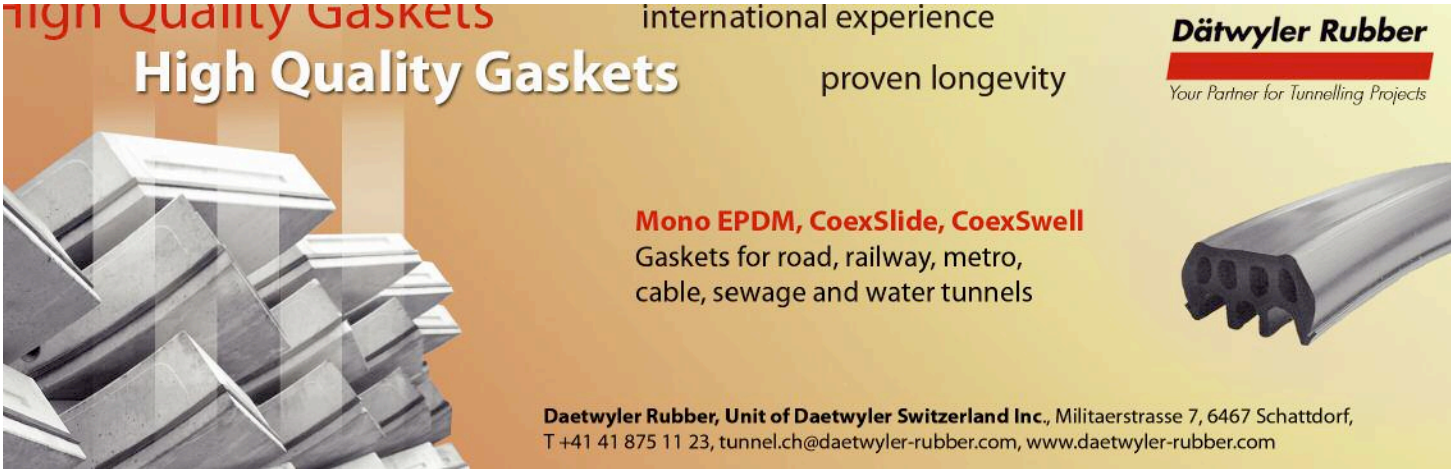
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Editorial index for Volume 41 2009

INDEX OF ARTICLES

AUTHORS OF ARTICLES

SUPPLEMENTS

COMMENT

Classified

RECRUITMENT

WEBSITE DIRECTORY

Dates & Events

27-29 DECEMBER
13th International Conference on Structural & Geotechnical Engineering 2009, Cairo, Egypt
This two day event will cover all aspects in the field of structural and geotechnical engineering, organised by the conference secretariat, Ain Shams University Faculty of Engineering, Structural Engineering Department. Contact: Prof. Dr Eman Soliman; tel: +2 02 26839318; email: Info@ICSGE2009.com; web: www.ICSGE2009.com

26 JANUARY 2010
George A. Fox Conference: Tunnel Shaft Construction, New York, USA
The ninth annual George A. Fox New York construction conference will be held in Manhattan The conference is sponsored by the Underground Construction Association of SME (UCA of SME) Contact: email: bonic@smenet.org; tel: +1 303 948 4216 fax:+1 303 979 3461; web: www.smenet.org

4-5 MARCH 2010
World Tunnel Congress China, Shanghai, China
The WTCC will focus on China's challenge to build 300km of tunnel every year. Contact: email: yi.wang@hnzmedia.com; tel: +86 21 5101 3735 or +86 21 5101 3738; fax:+86 21 5101 6269; web: www.hnzmedia.com/events/WTCC

17-19 MARCH 2010
ISTSS 2010 Frankfurt, Germany
The 4th International Symposium on Tunnel Safety and Security. Manuscript abstracts should be submitted to the Secretariat by 01 June 2009, poster abstracts by the 01 October 2009. Contact: Anders Lönnermark, SP Technical Research Institute of Sweden; tel: +46 10 516 56 91; email: anders.lonnermark@ sp.se; web: www.sp.se

17-19 MARCH 2010
INTERtunnel RUSSIA 2010 Expocentr, Moscow, Russia
INTERtunnel Russia 2010 provides an opportunity for suppliers of products and services to the tunnelling sector to showcase their capabilities and exchange ideas and experiences. INTERtunnel RUSSIA will be held at the Expocentr in Moscow, Russia Contact: email: intertunnelrussia@mackbrooks.com; web: www.intertunnelrussia.com

18-19 MARCH 2010
4th China Tunnel Summit, Shanghai, China
Among the key issues of this summit will be: World & China tunnelling development trends; Hard rock TBM issues & solutions in city subway tunneling; subsea tunnelling and speeding construction. Contact: email: marketing@merisis-asia.com; tel: +86 21 62478898; fax: +86 21 62478838; web: www.merisis-asia.com/tunnel2010

19-25 APRIL 2010
Bauma 2010, Munich, Germany
The 29th International Trade Fair for Construction Machinery, Building Material Machines, Mining Machines, Construction Vehiclesand Construction Equipment will be held in the Messe Muenchen Messegelaende 81823, Munich, Germany. Contact: email: info@bauma.de; tel: +49 89 949 11348; fax: +49 89 949 11349; Web: www.bauma.de

2-7 MAY 2010
North American Society for Trenchless Technology No-Dig 2010, Chicago, USA
The 2010 NASTT No-Dig show will be held at the Renaissance Schaumburg Hotel and Convention Center, Chicago. The conference theme is "Rebuilding North America's Underground Infrastructure Using Trenchless Technology" and will include infrastructure investment; social costs and impacts; industry trends, advancements and new concepts. Contact: NASTT; web: www.nodigshow.com

14-20 MAY 2010
2010 ITA World Tunnel Congress, Vancouver, Canada
Not long after the 2010 Winter Olympics, the International Tunnelling Association (ITA) visits the spectacular city of Vancouver, British Columbia, for its yearly conference and exhibition. The usual combination of working groups, open sessions and technical talks will all be included. Contact: web: www.wtc2010.org

8-10 JUNE 2010
InterTunnel 2010, Turin, Italy
Tunnelling exhibition aimed specifically at clients, contractors and consultants involved in the construction of and equipping and operation of tunnels. Contact: Mack Brooks Exhibitions; web: www.intertunnel.com

9-11 JUNE 2010
Swiss Tunnel Congress, Lucerne, Switzerland
Tunnelling developments in the Apls will doubtless be a talking point at the Swiss Tunnelling Society's STC. The event will be held at the KKL Lucerne. Contact: fgu@thomibraem.ch web: www.swisstunnel.ch

14-16 JUNE 2010
International Conference Underground Construction Prague 2010 Transport and City Tunnels
The Czech ITA-AITES Tunnelling Association will host its 11th International Conference at the Clarion Congress Hotel Prague. Lectures will be simultaneously interpreted into English, German and Czech. Contact: Czech ITA-AITES: tel: +420 266 793 479; email: ita-aites@metrostav.cz; web: www.ita-aites.cz

15-17 JUNE 2010
European Rock Mechanics Symposium (EUROCK 2010)
Eurock 2010 is an ISRM Regional Symposium of Europe. The Symposium covers all the aspects of rock mechanics and rock engineering. Contact: Jean-Paul Dudt, Laboratory for Mechanics of Rock (LMR). EPFL-ENAC-LMR Station 18 CH-1015, Lausanne; tel: +41 21 693 23 25; fax: +41 21 693 41 53; email: lmr@epfl.ch; web: www.lmr.epfl.ch

19-23 JUNE 2010
North American Tunneling Conference, Portland USA
The 2010 NAT will be held at the Marriott Downtown Waterfront Hotel in Portland, Oregon. Conference and exhibition information and registration is available on the SME web site. Contact: Society for Mining, Metallurgy and Exploration (SME); web: www.smenet.org.

BRITISH TUNNELLING SOCIETY

21 JANUARY 2010:
Construction of Deep Shafts
Speakers will discuss the challenges of constructing deep shafts. Presented by Alan Auld of Alan Auld Associates and Dave Setchell of Cementation. 6pm start at the ICE.

10 FEBRUARY: **Joint Meeting with MinSouth. Construction of Road Tunels in Iceland Hédinsfjardargöng Project**
The speakers will present the history and highlight the main problems, which were met during the planning and construction of the Hédinsfjardargöng Project.

23 - 27 OCTOBER, 2010
ISRM international Symposium 2010 and 6th Asian Rock Mechanics Symposium, New Delhi, India
Contact: Mr. V. K. Kanjlia, Member Secretary, Indian National Group of ISRM: tel: +91-11-2611 5984/2688 2866/2410 1591; fax: +91-11-2611 6347; email: uday@cbip.org/ cbip@cbip.org; web: www.arms2010.org

12 - 16 SEPTEMBER 2011
6th International Symposium on Sprayed Concrete, Norway
Sixth International Symposium on the modern use of wet-mix sprayed concrete for underground support will be held in Tromsø, in the north of Norway. Contact: Siri Engen The Norwegian Society of Graduate Technical and Scientific Professionals - Tekna; fax: +47 22 94 75 01

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: Editor, 'Tunnels & Tunnelling International', John Carpenter House, 7 Carmelite Street, London, EC4Y 0BS, United Kingdom.
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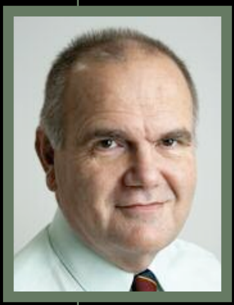

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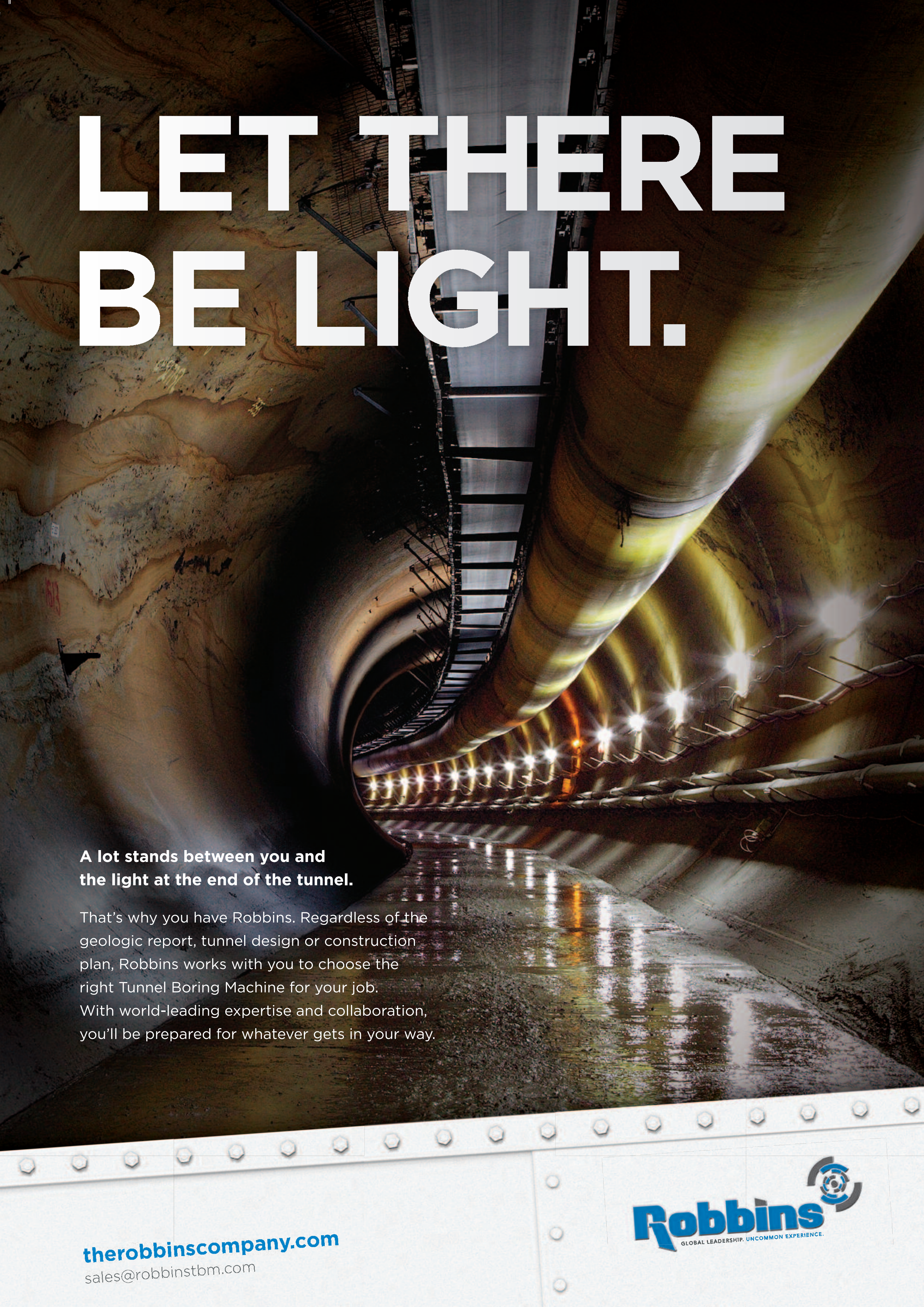
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