

INTERNATIONAL EDITION

December 2013

Tunnels

AND TUNNELLING



Tunnels 2013 Photo Competition



Joint Win

The client, customer and Herrenknecht have beaten an **extremely complex mountain** to create twin tunnels 8.7km long. We powered through **abrasive rock** with up to **250MPa**, partly highly fissured, and **water pressures** of up to **10bar**.

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CANADA'S PROJECT OF THE YEAR

AS TUNNELS went to press the Tunnelling Association of Canada's annual awards were in full swing. The award for best Canadian tunnelling project for 2013 went to a project that had to endure some of the toughest ground conditions, consistently varying, and continually testing the skills and knowledge of the teams involved.

Utilising the largest hard rock TBM built to date, the 10.2km Niagara Tunnel project bored steep inclines through the Queenston shale. The conditions were not as expected and the high horizontal stresses of the shale located in the lower strata led to overbreak. "The biggest technical challenge was dealing with overbreak. In our case this means a break that exceeds 3m and we sometimes had the equivalent of a long tube above our heads like a 4m tunnel," Strabag project manager Ernst Gschnitzer told *Tunnels* in 2010. Progress slowed to just a metre a day when facing the worst ground conditions.

This meant contractor Strabag, designer Hatch Mott Macdonald and TBM supplier Robbins had to react and rethink much of the project. Handling a 14.4m diameter TBM presents enough challenges, couple that with the unexpected ground conditions, the need for grouting almost continuously and the ever present threat of water ingress, the project team are right to be congratulated.

The rock support system, which used rock bolts, wire mesh, steel ribs and shotcrete had to be adjusted for the encountered ground conditions, as did the methods for installation. "We had to do a series of adjustments and improvements on the rock support system and we had to change the original fixed working platforms. When there is a 3-4m overbreak above the TBM it is difficult to get there to support and prevent it deteriorating," explained Gschnitzer.

After losing months to the unexpected overbreaks the team decided that the only way to get the project back on schedule was to change the tunnel alignment. By the end of

Jon Young
Editor



2008 the new route was underway. "The main problem area was on the vertical alignment, 140m below surface in the Queenston shale under the Barry St Davids Gorge, but we changed the alignment such that the tunnel was ramped up to 90m below the surface minimising the amount of remaining excavation in the Queenston shale," says Gschnitzer.

Project client Ontario Power Generation required a 100-year design life for the project. Achieving this meant fitting a permanent membrane that could cope with the 15 bar pressure found in parts of the tunnel.

The final membrane consisted of a geotextile fleece fixed to the shotcrete. A vacuum testable dual-layer polyolefin (FPO) membrane system used in the tunnel invert in rock formations with swelling potential and a prototype electrically testable FPO membrane used in the tunnel arch. The system can cope with 20 bar pressure.

For full details of the awards see the December issue of *Tunnels North America*. To read more on the Niagara project see *Tunnels North America* May 2010 p.8 and June 2011 p.30

editor@tunnelsonline.info

What do you think? Send your views to the editor and join the debate



This month...

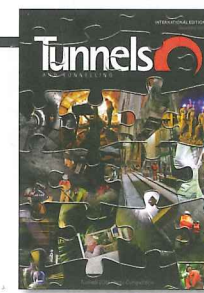
10 YEARS AGO

The A3 Hindhead tunnel project in the UK will have an SCL lining. Contractor Balfour Beatty will construct the 1.9km tunnel with the method that has not seen major use in the UK since the North Downs Tunnel over three years ago. The contractor was awarded the Early Contractor Involvement (ECI) contract in September 2002 by client The Highways Agency and has developed the design with consultant Mott MacDonald. Other construction methods were considered, TBMs were thought to be overly expensive considering the number of cross passages required (every 100m). *Tunnels and Tunnelling*, December 2003, p.6

20 YEARS AGO

RuhrKohle, a German coal producer responsible for 80 per cent of the country's output, is pushing ahead with a plan to build a 36km toll road tunnel under the Ruhr to breathe new life into the traditionally industrial heartland of the country. The region is currently suffering from the ravages of an economic recession. The USD 5.9bn project would be a twin tunnel, each bore with two lanes and an emergency lane. It is expected that roadheaders will be used to excavate the 130m² cross section at a depth of 25 to 30m underground. Rockbolts and shotcrete will provide temporary support. The project is now going to the Federal Government's transport ministry for consideration for some central funding. The plan could see construction begin in five, and finish in 15 years. *Tunnels and Tunnelling*, December 1993, p.14

Cover
The Tunnels Photo Competition 2013 has received higher quality entries than ever before.



Next issue

In the next issue of *Tunnels* we dig into the market of North America, with reports from the Seattle U-Link and John Hart Generating Station projects. Additionally we cover 'understanding rock classes', ground freezing, and we also return to the Second Coentunnel

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BANGKOK METRO: TOTAL TUNNELLING SYSTEM

Bangkok's Mass Rapid Transit network is quickly expanding to meet the needs of this growing Asian Mega-City. TERRATEC is participating in this challenge by providing its equipment and expertise to General Contractor, Italian-Thai Development PCL.

For the Blue Line Extension Project, TERRATEC has delivered a complete tunnelling solution composed of the EPB Tunnel Boring Machine and the tunnel logistics system which includes a Continuously Advancing Conveyor. All supported with a comprehensive package of field service to ensure the smooth performance of the whole system from assembly to breakthrough.

TUNNELLING SOLUTIONS | METRO



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Above, middle: Photo competition entry, p.41

Above, right: Crane use on tunnel projects, p.49

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Contributors

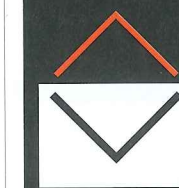
Bernadette Ballantyne

Bernadette is the editor of *Tunnels'* small bore sister publication, *Underground Utilities*. She also works as a freelance technical journalist specialising in infrastructure and construction. Currently also a contributor to *Cranes Today* magazine, in this issue she explores crane use on tunnel projects, as cranes industry strategists take interest in a tunnelling industry going from strength to strength.



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Ofwat tries to block Thames Water price hike

Great Britain The water regulator Ofwat plans to block an eight per cent increase in customer bills proposed by Thames Water, the company announced last month. Ofwat's final decision was due as Tunnels went to press.

Thames Water has requested to add GBP 29 (USD 46.70) to the bills of its 14M customers in London and the south of England, arguing that the one-off charge is needed to help pay for the Thames tideway "super-sewer" in the capital, as well as an increase in Environment Agency charges and a spike in unpaid bills. Ofwat argued the company had failed to justify the increase, having only made the case for a GBP 7 (USD 11.20) increase to bills.

Sonia Brown, Ofwat's chief regulation officer, said: "We said we would challenge Thames Water's request. We have looked at the details and do not believe the current evidence justifies an increase in bills.

Ofwat's consultation on its draft decision gave all parties, including Thames Water, the opportunity to submit new evidence. Ofwat was due to consider any new evidence, which could then result in a change in its assessment of justifiable costs, before announcing its final decision in November.

Hanoi urges investor to expedite mountain tunnel project

Vietnam Transport Minister Dinh La Thang has urged relevant authorities to speed up the construction of the Ca Pass Tunnel in the central provinces of Phu Yen and Khanh Hoa.

The project aims to replace Ca Mountain Pass and Co Ma Mountain Pass, parts of National Highway 1A that run through Dai Lanh Mountain and have dangerous bends prone to avalanches and landslides, with two tunnels.

Originally scheduled for completion in 2016, along with other parts of National Highway 1 that are also being repaired, the VND 15.6tn (USD 742.8M) project is currently one year behind.

The construction was supposed to be carried out under the Build-Operate-Transfer (BOT) and Build-Transfer (BT) models.

The Deo Ca Investment Joint Stock Company was to mobilise capital to finance the project and see a return on its investment later, while the two provincial authorities and transport ministries were in charge of providing land for the worksites.

"The investor failed to do the necessary preliminary work," said Tran Xuan Sanh, head of the ministry's Department for Management of Traffic Work Construction and Quality. "The investor has

RENNES METRO LINE B CONTRACT AWARDED

France The consortium led by Dodin Campenon Bernard (Vinci Construction) and including GTM Ouest and Botte Fondations, both subsidiaries of Vinci Construction France, as well as Spie Batignolles TPCI, Spie Fondations and Legendre Génie Civil, has been awarded the contract to execute the underground works for Line B of the Rennes metro in France.

The contract, worth almost EUR 320M (USD 431M), includes the construction of 8km of tunnel, nine stations and four associated emergency shafts.

The TBM will start up at the end of 2014; delivery is scheduled for February 2018. Some 500 people will work on the site, including about 60 per cent from the Rennes area, employed by the consortium's local companies, suppliers and subcontractors or hired particularly through social integration programmes.

Vinci companies worked earlier on Line A of the Rennes metro.

not yet finished assessments and strategies for the construction process."

The ministry is also concerned about the investor's financial capacity as its shareholders have committed only VND 1.078tn (USD 51.3M).

Dinh Van Chuong, head of the Project Management Department of Deo Ca Investment Joint Stocks Company, blamed the delay on slow land clearance. He said that the investor had nearly completed the resettlement area for households in Phu Yen Province who had to make way for the construction.

"The province committed

to handing over space for the construction next month, but that is the rainy season, so we have to postpone it until next February," he said.

However, Nguyen Tai, chairman of Dong Hoa District People's Committee in Phu Yen Province, said that land clearance went as scheduled.

He claimed the real reason for the delay was the investor's initial design, which was problematic because the road would have run through a high voltage electrical pole.

Slow disbursement of compensation also delayed some affected households from moving.

News briefs

GERMANY

German engineering firm Siemens has revealed the Inspiro modular vehicle concept, which could be built in Britain if the Mayor of London placed an order for the new trains. The trains are fully air conditioned and a lot more spacious than the current models on the London Underground. The Inspiro is also 30 per cent more energy efficient and 20 per cent lighter than similar modern trains.

GERMANY

Femern A/S has officially handed in its overall application for approval of the Fehmarnbelt Fixed Link in Germany, the

company announced last month.

Femern A/S has prepared the documents together with the LBV's branch office in Lübeck who is responsible for the tunnel's road section that runs on Germany territory. The Fehmarnbelt tunnel is scheduled to open at the end of 2021.

INDONESIA

Jakarta Governor Joko Widodo said last month that the city would aim to build underpasses to accommodate pedestrian traffic, rather than construct more above-ground walkways. "For me, underpasses are more important, more aesthetic," he said. He said the city would earmark money for underpass construction from next year. The 2014 budget will allot funds for five underground pedestrian crossings.

KATHMANDU PROJECT EIA CONFUSION

Nepal The Nepal Purwadhar Bikash Company Limited (NPBCL) has announced dates to initiate construction works on Kathmandu Kulekhani Hetauda Tunnel Highway without completing an environmental impact assessment (EIA) of the project. The Environment Protection Act of 1997 makes it mandatory for developers of large scale projects to complete EIA study before starting construction works.

11 November 2013 will be the ground-breaking for the 58km highway that links Kathmandu with Tarai.

However, government agencies said that the company had not carried out EIA study for the project. The company had only received permission to begin EIA study with approved Terms of Reference (TOR) and scoping document in January from the Ministry of Science, Technology and Environment (MoSTE). It is impossible for the company to get the EIA study report approved before the declared date as it has yet to submit its report to the

Ministry of Physical Infrastructure and Transport (MoPIT).

As per the existing rules, the company has to first submit EIA study report to MoPIT. The MoPIT will then forward the report with well explained mitigating measures to the MoSTE for final approval. The MoPIT officials say it takes about two to three months to study the EIA report with experts. Likewise, MoEST officials said they will take about four to five months to evaluate the document, incorporate the suggestions of the experts and display the report at the community level for 35 days in places affected by the project. According to NPBCL, the project is estimated to cost NPR 34.5bn (USD 343M). Officials of MoPIT argued the project can have severe environmental impacts if not duly mitigated. The project is a complex infrastructure project with three tunnels up to 3.4km in length, cut slopes of up to 70m and 15 bridges. NPBCL, claimed that it had already got the EIA study report approved from the

MoSTE and Ministry of Forest and Soil Conservation (MoFSC).

"Some works on EIA are remaining. They can be done during land acquisition," Joshi maintained.

Yagyanath Dahal, spokesman for MoFSC, said the ministry has not issued EIA approval to the company. "We have only permitted the company to conduct EIA study," he added.

Hari Kumar Shrestha, joint secretary of MoSTE said approval of an EIA report is a must before construction of any highway.

According to Clause 18 of the Environment Protection Act, authorised officials can declare immediate closure of construction works if a developer starts construction without EIA approval from MoSTE. The Clause further says, "And the officials or the concerned company will also be penalised up to NPR 100,000 (USD 1,000) according to the degree of offence."

MoPIT secretary Tulasi Prasad Sitaula declined to comment on the issue.

Northwest Washington tunnel awarded

USA The DC Water Board of Directors has approved the construction contract to build the First Street Tunnel, a medium-term measure to address localised flooding.

Skanska/Jay Dee Joint Venture was selected based on technical score and cost proposal, DC Water stated. The USD 157M bid is for design-build, allowing for more contractor innovation and greater coordination with the contract owner. Design-build teams also assume a portion of the design responsibility.

This project consists of a 19ft (5.8m)-diameter tunnel slated for completion in 2016. The tunnel will store eight million gallons of stormwater, capturing it before it can make its way to the combined sewer system. The stormwater will be stored in the tunnel during rainstorms and pumped into the sewer system once the storms subside.

Allen Lew, chairman

of the DC Water board of directors and co-chair of the Mayor's Task Force, said: "This is a significant component to the medium-term relief from flooding in these neighbourhoods. We specifically went with a design-build contract to increase flexibility and to save time in order to meet our Task Force timelines."

Bangalore metro gets new target

India The new target for the Namma Metro, also known as Bangalore Metro, Phase One project may extend to 2015, as work on the underground stretch will be completed only by then, local news reports revealed recently.

The underground stretch is expected to take 12 months for track laying to be complete. Tunnelling work has started, while the TBM, Marg-arita, recently completed tunnelling up to Minsk Square.

Tunnelling of the remaining 220m is taking place near City Railway

station.

The first deadline of 42.3km of Phase 1 was June 2013. It was then pushed to June 2014, then December 2014. The deadline now stands at March 2015.

Tunnelling on Sungai Buloh-Kajang approaches halfway

Malaysia The tunnelling portion of the Sungai Buloh-Kajang mass rapid transit (MRT) is expected to be 50 per cent completed by year-end, said Gamuda Bhd managing director Datuk Lin Yun Ling.

Gamuda and its joint venture partner MMC Corp Bhd is responsible for the construction of the most expensive portion of the first line of the MRT valued at MYR 8.3bn (USD 2.61bn).

The joint venture also oversees the entire management of the MYR 23bn (USD 7.23bn) project.

"As of September, we are at 39 per cent completed in terms of certified progress and we are progressing about

3 per cent every month for the tunnelling portion.

"As this juncture, we are right on track and there are no cost overruns," Ling said in Kuala Lumpur on 10 October 2013.

New Dubai Metro Station opens

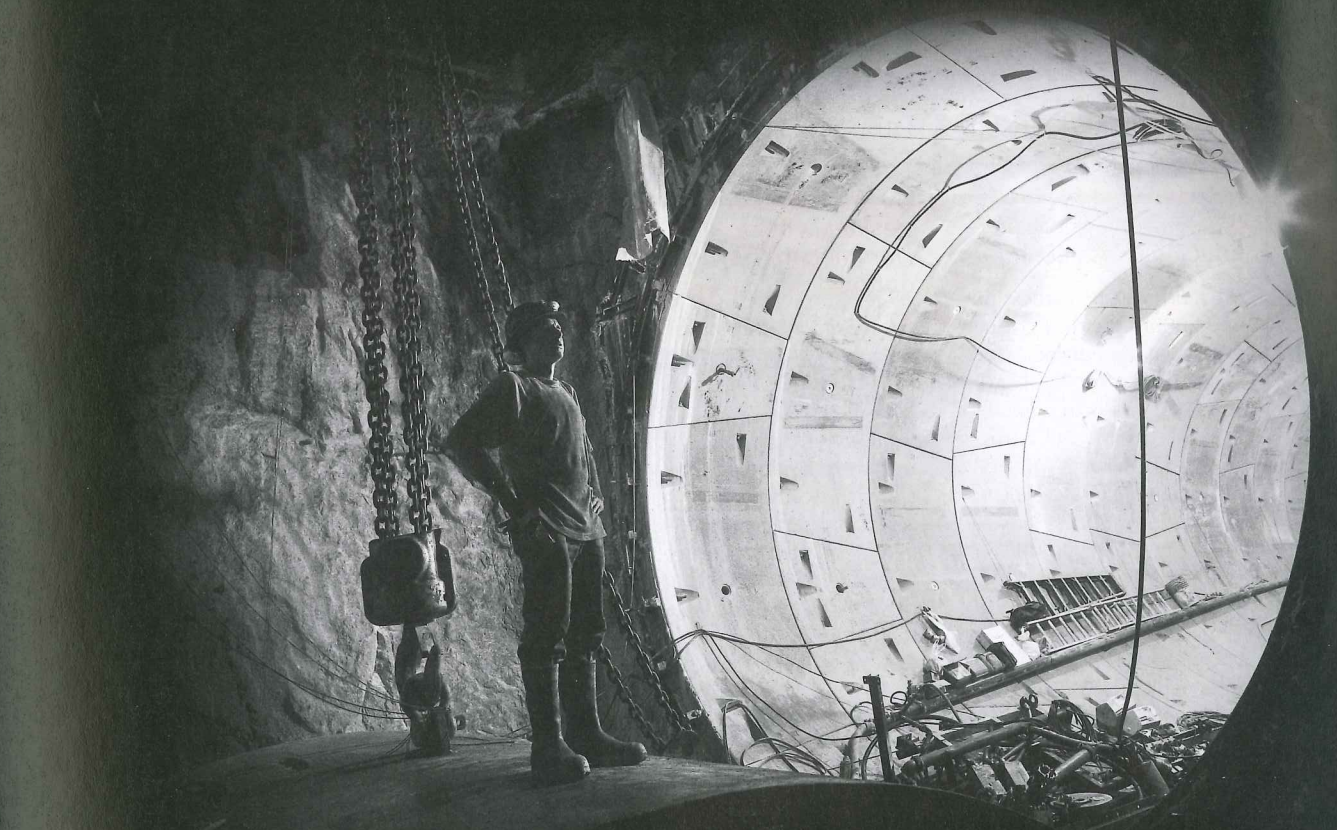
UAE Energy Station in Jebel Ali on the Dubai Metro's Red Line opened on 30 September 2013, the country's Roads and Transport Authority (RTA) announced.

Until now 28 of the 29 stations on the Red Line were operational and Energy station will be the last station to open its doors to commuters.

The station, expected to serve 2,500 passengers daily, is located between Danube and Ibn Battuta stations in the Jebel Ali industrial area.

The 52.5km-long Red Line, stretching from Jebel Ali to Rashidiya, was opened on 9 September 2009, and serves around 250,000 passengers daily.

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LTA AWARDS FOUR NEW THOMSON LINE CONTRACTS

Singapore The Land Transport Authority (LTA) has awarded four civil contracts for three Thomson Line stations and adjacent tunnels, as well as Thomson Line's Mandai Depot, it was announced last week. Construction works for the contracts are expected to start by the first quarter of next year.

Contract T203 for the construction of Woodlands station and its associated cut-and-cover tunnels has been awarded to GS Engineering & Construction Corp at a contract sum of SGD 292M (USD 236M). When completed, Woodlands station will serve as the interchange between Thomson Line and North-South Line. The design and construction of Lentor station and its associated tunnels, contract T209, has been awarded to China Railway No. 5 Engineering Group (Singapore Branch) at a contract sum of SGD 247M (USD

199.9M). Contract T210 for the design and construction of Mayflower station has been awarded to Gammon Construction Limited Singapore Branch (GPL) at a contract sum of SGD 174M (140.8M).

When completed, these Thomson Line stations will connect the northern and central parts of Singapore through Woodlands and Caldecott stations to connect with the North-South and the Circle Line respectively, bringing further convenience and connectivity to commuters working and residing in Woodlands, Lentor, Thomson and Ang Mo Kio, LTA stated. In addition, these three stations will serve as Civil Defence shelters along the Thomson Line.

The 30km long Thomson Line will enhance rail connectivity in the north-south corridors to the Central Business District and developments in the Marina Bay area.

Excavation of new 'dive-under' begins in London

Great Britain The excavation of 34,000t of earth for a new rail underpass outside Acton Main Line station has begun as part of works to prepare the route for the full arrival of Crossrail services in 2019, Crossrail stated last week.

The dive-under is needed so that trains leaving the Acton freight yard do not delay passenger trains heading towards Acton Main Line and on to central London. The new dive-under will allow the trains to access the yard without affecting passenger services, increasing capacity and reliability.

The start of excavation follows nearly two years of work to re-configure the freight yard. The work on the dive-under is being managed by Network Rail and is expected to last until 2016.

Matthew White, Crossrail's surface director said: "The dive-under at Acton is a vital part of the Crossrail works in west London, helping to ensure a fast, frequent and reliable service for passengers when full services start in 2019."

Residents back Hammersmith tunnel option

Great Britain Locals have welcomed ambitious plans to replace the Hammersmith flyover with a GBP 100M (USD 159.3M) underground tunnel, but warned against allowing developers free rein, local press announced.

The proposal could see a tunnel running beneath the existing A4 from the Hogarth roundabout to Earl's Court with north-south links.

Residents believe the tunnel is the solution to the "Jammersmith" chaos brought to west London by the emergency closure of the Hammersmith Flyover. Other possibilities include building the tunnel without the supporting link roads and a straight replacement of the existing flyover, either with or without the link roads. Local press reported that many residents spoke out in favour of "burying the flyover".

CMRL work gains pace at Mannady

India Two TBMs engaged in Chennai Metro Rail work

will soon complete work on a tunnel from Mannady to Madras High Court station, local Indian press announced.

The TBMs have to each drill a distance of 690m. So far, the two have excavated 655m and 672m respectively.

The two TBMs began tunnelling in October last year and have a target of 4.4km from Washermanpet to Chennai Central.

Tunnel completion keeps STEP on track

UAE Abu Dhabi has completed the construction of a 41km main sewer tunnel, one of the largest and longest gravity-driven sewerage networks in the world.

The eco-friendly sewer main is the major part of the city's ambitious Strategic Tunnel Enhancement Programme (STEP), costing AED 5.7bn (USD 1.6bn), which will almost triple the capacity of its sewerage network.

The STEP features three key components: 41km of deep sewer pipes, 43km of smaller diameter link sewers, and a pumping station

adjacent to the Al Wathba Independent Sewerage Treatment Plants, where the major sewer main ends.

An initiative in compliance with Abu Dhabi's Vision 2030, the project will cater to future needs arising with an increasing population.

"It is meant for the increased population of 2030; however if the population growth is slow, this system may serve until 2040 or even beyond," officials of the Abu Dhabi Sewerage Services Company (ADSSC) said on 6 October.

The company organised a ceremony to celebrate the sewer main breakthrough of the eighth TBM of the tunnel project. The final breakthrough completed the excavation of all sections of main tunnel.

The TBMs mined through mixed ground conditions of dolomitic siltstone, clay stone, mudstone, and gypsum without causing any adverse surface settlements.

With completion of the backbone of the project, the major tunnel stretching from Al Mushrif to Al Wathba, the focus has shifted to the construction of 43km long sewerage link tunnels.

About 26 per cent of the construction of sewer links is over and the rest will be completed by 2015, Alan Thomson, managing director of ADSSC, said.

The pumping station at Al Wathba, one of the biggest in the world, will replace 34 existing pumping stations across the city, he said.

The 'green' tunnel will drastically reduce the carbon footprint of Abu Dhabi's sewerage system and save AED 4.2bn (USD 1.14bn) to be spent on energy and maintenance costs in the next 25 years.

The tunnel starts at 27m underground and reaches a depth of 100m.

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Road tunnel specialist names Greek agent

Greece Road tunnel specialist, Enalos, has made an agreement with Nyx Hemera Technologies, to serve the company's agent in Greece. Enalos will distribute Hemera Technologies' tunnel lighting control system.

Nyx's Tunnel Lighting Addressable Control System (TLACS) controls tunnel luminaires and enables operators to save substantially on energy and maintenance costs, Nyx Hemera Technologies stated.

"With over 100 road tunnels, including 75 tunnels of over 500m in the Greek Trans-European Road Network, Greece has an interesting potential, especially now as tunnel operators are looking for solutions to significantly reduce their operational expenses," said Pierre Longtin, president and CEO of Nyx Hemera Technologies.

The TLACS is one of the most technologically advanced tunnel lighting control system on the market, Nyx Hemera Technologies claims. TLACS is installed in one of the longest tunnels in the world, the Kallang -

Paya Lebar Expressway in Singapore.

HS2 appoints new chairman

Great Britain Doug Oakervee, chairman of HS2, the planned high speed rail line in the UK, has announced last month that he will be standing down at the end of the year.

Oakervee's successor has been announced as current Network Rail chief executive Sir David Higgins, who will join HS2 on 1 January 2014 on a part-time basis before taking up the post full-time from March.

Doug Oakervee, a distinguished civil engineer and former chairman of Crossrail, took up the post of HS2 chairman in April last year. Oakervee has overseen the development of the detailed proposals for the new HS2 line and laid a foundation for the delivery of the rail project.

Patrick McLoughlin, secretary of State for Transport, said: "The fantastic work that Doug Oakervee has delivered as chairman of HS2 is testament to the experience and expertise that he brought to this role.

"His energy and

professionalism have ensured that the detailed proposals for Phase One of the country's first high speed line north of London will be introduced to Parliament on schedule later this year.

Oakervee said: "I believe HS2 is vital to the growth of the UK economy and will deliver the capacity our rail network sorely needs. Sir David is the right man to continue the delivery of this project. I am delighted at his appointment and am confident that alongside Alison Munro, our chief executive, he will continue to drive the scheme forward."

Higgins added: "I am delighted to be taking up this role. Working at Network Rail I know the challenges we have ahead with capacity on the railways - they are real and we need to take action now. I also know the significant benefits that improved journey times will bring not just to the north, but the UK economy as a whole.

"HS2 is the right solution. It is vital for both passengers and the economy, and will put the UK in a different league in terms of infrastructure."

News briefs

GREAT BRITAIN

The UK Government's latest business case for the HS2 high-speed rail link has slightly lowered the amount of benefit it predicts relative to the cost, HS2 announced in a statement earlier today. The Government has updated its expected benefit-cost ratio (BRC) has fallen from GBP 2.50 (USD 4.00) to GBP 2.30 (USD 3.70) in benefits for every pound spent. However, BCR is expected to increase to GBP 4.50 (USD 7.20) if rail demand continues to rise until 2049, the Government added. That fall is mainly due to a GBP 10bn (USD 16bn) rise in the scheme's projected GBP 42.6bn (USD 68.5) cost, which was added earlier this year.

CHILE

A joint venture of Eurovia subsidiary, ETF, and Colas Rail has been awarded a EUR 150M (206.5M) contract to build and maintain track and catenary on lines 3 and 6 of the Santiago metro. Line 6 is 15.3km and is expected to open in February 2017. Line 3 will be 22km long with and is due to open in June 2018.

IRAQ

The Baghdad government announced last month that the Metro Baghdad project shall be accepting bids at the start of 2014. The cost of the project is expected to reach USD 6bn. The project shall be done either by direct investment or through governmental funds.

TURKEY

The Marmaray tunnel underneath the Bosphorus Strait has been opened in Turkey, creating a new link between the Asian and European shores of Istanbul.

THREE GROUPS SHORTLISTED FOR EAST WEST LINK

Australia Three consortia have been shortlisted by the Victorian Coalition Government for Melbourne's East West Link. East West Connect, Inner Link Group and Momentum Infrastructure have been shortlisted to tender for the tunnel in Victoria, Australia.

East West Connect comprises contractors Capella Capital, Lend Lease, Acciona and Bouygues. Inner Link Group includes Cintra Infraestructuras, Retail Employees Superannuation, Samsung C&T, Ferrovial Agroman, Ghella, Transfield Services and Macquarie Capital.

While Momentum Infrastructure is formed of John Holland, Dragados Australia, Leighton Contractors, Iridium Concesiones de Infraestructuras, and The Bank of Tokyo-

Mitsubishi UFJ.

Treasurer Michael O'Brien said all short-listed bidders had strong financial credentials that would support the project moving quickly to the construction phase in 2014.

"It is exciting to see such a competitive field of international and Australian bidders," O'Brien said. "I have no doubt this competition with three shortlisted bidders will drive value for money for Victorian taxpayers."

The next step for the project will be the release of a Request for Proposal to the shortlisted bidders, which will be finalised in October.

Contracts to deliver the project will be awarded in late 2014 with completion anticipated in 2019-20.

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JV SELECTED FOR OZ WATER PLAN

Australia Melbourne Water has selected a joint venture between KBR and John Holland (JHKBRJV) to deliver engineering, procurement and construction (EPC) services for water, wastewater and drainage projects in Melbourne over the next three years, it was revealed recently.

HKBRJV is one of two joint ventures that will deliver these services as part of Melbourne Water's 2013 Water Plan capital works programme.

KBR and John Holland have collectively delivered over AUD 8bn (USD 7.5bn) worth of water infrastructure projects.

Ted Cusack, KBR's director of water, Asia Pacific, said: KBR has over 60 years of experience delivering water projects in Australia and has played a key role in many nation building infrastructure projects in the region. We look forward to working with our joint venture partner, John Holland, to deliver optimal water solutions and make a lasting contribution to the Melbourne community by providing improved facilities with a strong focus on environmental solutions."

Brendan Petersen, executive general manager for specialist engineering businesses, John Holland, added: "We are one of Australia's leading service providers of innovative solutions for the delivery and operation of water and environment infrastructure solutions. Our strength lies in our dedication to safety, our clients' needs, our people, our partners, quality and delivery performance. We look forward to working with our partner KBR to deliver value for money for the residents of Melbourne."

Two-year Waterview tunnelling process begins

New Zealand Eighteen months into its five-year construction programme, the Waterview Connection project is ready to start tunnelling, it was announced recently.

The project is ready to bore on the date set 18 months ago. The New Zealand Government stated that this puts the project on the right path for the successful completion of the Waterview Connection in early 2017.

Gerry Brownlee, transport minister, said: "The start of tunnelling marks the completion of what has been complex works to prepare the boring machine for tunnelling. Each of these work packages was a major project in itself, involving significant challenges and risks. The TBM, named Alice, will excavate twin 2.4km

tunnels under Avondale and Waterview. As Alice bores its way to Waterview and back over the next two years, it will remove 800,000cu.m of spoil and position 2404 tunnel lining rings, each comprising 10 pre-cast reinforced segments.

Esteemed former Delhi Metro MD recognised

India Delhi Metro's Principal Advisor and former Managing Director, E. Sreedharan was last month awarded the prestigious 'Order of the Rising Sun, Gold and Silver Star' by the Government of Japan.

Sreedharan received the Insignia and Certificate from Japan's Prime Minister Shinzo Abe at a ceremony at the Imperial Palace in Tokyo. After the ceremony, he was granted an audience with the Emperor of Japan.

Sreedharan was honoured for promoting friendly

relations between Japan and India through the Delhi Metro Project, which is viewed as a symbol of Indo-Japanese collaboration.

After receiving the award, Sreedharan attributed the honour to the entire Delhi Metro family and said that he has been conferred with the award because of the achievements of the Delhi Metro Rail Corporation.

During his tenure as the Managing Director of DMRC, Dr. Sreedharan has been conferred with a number of prestigious awards and recognitions such as the 'Knight of the Legion of Honour (Chevalier de la Legion d'Honneur)', France in 2005, 'Padma Shri' in 2001 and the 'Padma Vibhushan' in 2008.

Jeddah urged for tunnel intersection solution

Saudi Arabia Jeddah's mayoralty has been urged to build a tunnel at the intersection between Madinah Road and Tahlia Street, where major bottlenecks occur during peak hours.

Brigadier General Wasil Allah Al-Harbi, director of the Jeddah Traffic Department, said: "We have stationed a 24-hour patrol at this location to regulate the flow of traffic, sometimes manually, by traffic wardens. We have recently sent a recommendation to the Roads and Projects Department at Jeddah's Mayoralty that they build a tunnel under the intersection in place of the traffic light. We are still awaiting for their response," he said.

Sami Nawar, spokesman for Jeddah's Mayoralty, said: "We have received strong recommendation from the traffic department proposing that a tunnel be built at this intersection. We are currently studying the recommendation and we are seriously considering the removal of the traffic light and the construction of a

tunnel in its place to ease the flow of traffic. We will make the announcement once we conclude our study."

Preferred contractor for John Hart revealed

Canada BC Hydro announced last month that SNC-Lavalin, Inc. has been selected as the preferred contractor to design and construct the billion dollar John Hart Generating Station Replacement Project.

The replacement facility will improve power reliability and seismic safety, and make it easier for BC Hydro to protect fish habitat in an area renowned for its salmon.

After a procurement process that began in March, BC Hydro and SNC-Lavalin, who was informed of their selection last week, will now begin final discussions toward a contract signing that will likely be in early 2014.

The John Hart project will construct a replacement water intake at the John Hart Spillway Dam, replace the three 1.8-kilometre long penstocks with a 2.1km long tunnel, construct a replacement generating station beside the existing station, and a new water bypass facility. BC Hydro said it was "pleased with the calibre and depth of experience that the competing teams brought to the table."

Construction mobilisation is anticipated to get underway when the contract is signed. The project is scheduled to be complete by the end of 2018.

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The diameter of antennae of the common wasp „Vespula Vulgaris“ and the accuracy of VMT's Active Laser Target Unit.



NEW PRODUCT

profile monitoring for tunnel concrete segments

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The RST Profile Monitoring System for Tunnel Concrete Segments is a series of tilt meters, fixed to the tunnel wall on each of the precast concrete segments erected in place as tunnel lining by a Tunnel Boring Machine (TBM). Its main advantage is that it can be deployed in the tight space available around the TBM to monitor deformation. A data logging system and RST's Geoviewer software are available to provide near real time displacement and generate a graphical representation of the tunnel convergence.

Typical installation of the RST Profile Monitoring System for Tunnel Concrete Segments with an RST flexDAQ Datalogger System.





Esther Alcocer Koplowitz

FCC chairwoman receives award for growth in Latin America

Spain The chairwoman of the Spain-based infrastructure and environmental services company, FCC, has been commended for FCC's growth in Latin America, the company announced last month. Esther Alcocer Koplowitz received the Business Growth Award from the Latin American Business Council (CEAL) on behalf of FCC. The company currently holds contracts in Latin America worth EUR 2.5bn (USD 4bn), with the region accounting for 11.5 per cent of revenues, FCC announced.

Key projects include the nearly completed USD 1.8bn Panama Metro Line One.

Chief executive steps down from Laing O'Rourke amid allegations

Australia International engineering and construction group, Laing O'Rourke,

has announced that David Stewart has stepped down as chief executive officer of its Australian business, and as a member of the Group Executive Committee, with immediate effect.

In light of recent articles in the Australian media relating to business practices at Leighton Holdings, Stewart has stepped down to enable him to deal with the allegations made against Leighton during his tenure as a senior executive there.

Laing O'Rourke Group chief executive Anna Stewart commented: "I am grateful to David for taking the tough decision to step down at this time."

"His action respects the exemplary business values and ethical practices that Laing O'Rourke maintains through its relationships with our clients and stakeholders."

Meanwhile, David Savage, Leighton's former chief operating officer and head of its international business, has stepped down as a non-executive director of

UK engineering group Keller "to enable him to deal with the allegations made against Leighton during his time as a senior executive there", the company said.

The resignations follow reports by Fairfax Media that senior executives at Leighton were aware of widespread improper behaviour within the international arm.

Keller acquires South African business

South Africa International ground engineering company, Keller, has announced that it has agreed to purchase the geotechnical division of the Johannesburg-listed civil engineering and construction company, Esorfranki, for an initial consideration of GBP 31M (USD 49.4M).

Esorfranki Geotechnical is the largest ground engineering business in South Africa, offering design and build services to the mining, civil engineering and construction industries.

In addition to adding a market-leading business run by an experienced management team who will remain with the business, the acquisition will accelerate Keller's entry into selected sub-Saharan construction markets. The business will form part of the Group's EMEA division, Keller

Central bank rates	
	Rate (%)
AUD	2.50
BRL	9.50
CAD	1.00
CHF	0.25
CNY	6.00
EUR	0.25
GBP	0.50
INR	7.50
JPY	0.10
NZD	2.50
USD	0.25

Rates are taken on the 12th of each month.

announced.

The total consideration, to be paid in cash from Keller's existing facilities, will comprise an initial payment of GBP 31M (USD 49.4M), on a debt and cash free basis, together with a maximum deferred consideration of GBP 9.4M (USD 14.9M) dependent on the achievement of a certain level of profits over the three years following the acquisition.

Completion is expected by the end of November 2013 and is subject to approval by shareholders of Esorfranki at its general meeting on 18 November 2013 and the approval of the South African Reserve Bank.

Oil price



Values are taken on 12th of each month.

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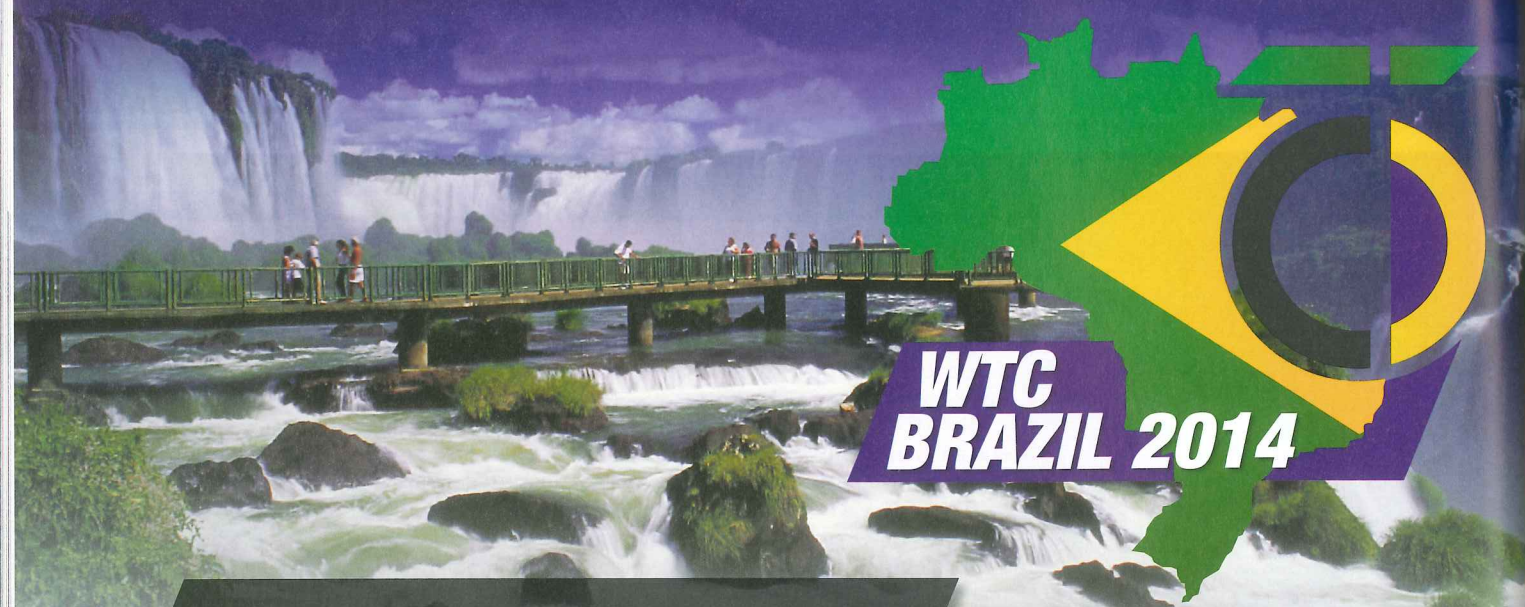
TUNNEL PLUGS FOR NYC

Last month New York Governor Andrew Cuomo toured Lower Manhattan to see some of the technologies being considered for future storm defence. The Resilient Tunnel Plug developed by ILC Dover is one example favoured by operator Metropolitan Transportation Authority (MTA).

The MTA is chasing solutions to fully prevent water incursion at the approximately 600 entry points in Lower Manhattan as well as vulnerable vent plants and openings in other flood prone areas. MTA New York City Transit is also analysing all underground tube locations to ensure that critical points where water can enter the system are protected.

An ILC Dover spokesman said of the product, "The Resilient Tunnel Plug (RTP) is a scalable technology that is intended to plug rail, automotive, or other tunnels from threats, including water. The development system was a 16.2ft (4.9m) diameter, 32ft (9.8m) long inflatable structure capable of long-term operation of 17psi. It was configured to deploy from a container mounted inside the tunnel. The inflation system pressurizes the plug rapidly and maintains its pressure over its operational life."

The Governor's Office announced, "The tunnel plug [pictured] was demonstrated inside a station. Though not designed for use inside the subway system, it is an example of the design ILC is developing for the 207th Street portal that saw flooding during Sandy. At 207 Street, early development of a 'Tensioned Curtain' (which is a derivative of the plug technology) is underway to meet that challenge. A similar prototype is being developed for a typical street stairwell entry. If successfully prototyped and tested, the MTA hopes the technology could be applied to portals and stairwell locations throughout the system"

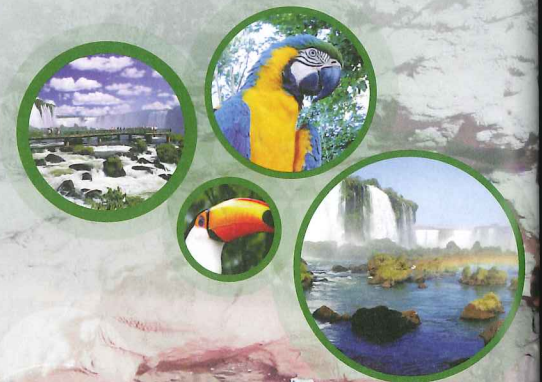


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TROPICAL WEATHERING

Maria Cecilia Sierra of Colombia-based engineering services, design and management provider *Integral* discusses the geotechnical behaviour of underground excavations in volcano-sedimentary rocks in tropical sand

THE GEOTECHNICAL behavior of volcano-sedimentary rock materials during underground construction depends largely on the weathering level, and the speed at which weathering occurs.

The rocks under study correspond to a volcanoclastic sequence composed by planar strata with thicknesses that can go from centimetres to metres, these are alternate basalts, sandstones, tuffs, agglomerates, pyroclastic flows and lahars with variations in the grain size and composition.

The tectonic activity has affected some of these rocks a great number of times, but this was especially intense during the last Tertiary period.

CHARACTERISATION OF ROCK MATERIALS

At a shallow depth the amount of fractures in the rock is low, with RQD ranging between 80 per cent and 100 per cent, depending mainly on the kind of rock and the thickness of the stratum. In the case of metric strata of agglomerate the level of fracturing is low, while in thin layers of fine tuff the fracturing is quite blocky. Generally, the persistence of secondary joints is low, except for some irregular fractures filled with quartz and locally sulfides, with weak walls probably as the result of metamorphism due to the circulation of hydrothermal waters.

In general, the ranges of some parameters of these rocks are the followings. It is important to clarify that these numbers are not representative of failure or sheared zones:

- Density (kN/m³): 24- 26
- Geological strength index GSI: 50-60
- Uniaxial compressive strength σ_c (MPa): 70-130 (basalt), 20-35 (siltstone - conglomerate) 30-60 (sandstone)
- Parameter m_i : 4 (clay stone), 15 (sand stone)
- Deformation modulus E_i (GPa): 4 - 35 (since limolita - conglomerate to sandstone)

In general, these types of rock have low density, high porosity and moderate to high elasticity module. Besides, it should be taken into account that in the Hock and Brown failure criterion, the strength values of the basalts with olivine (olivine toleite) and the hyolite (rhyolite) were not used. The rock mass quality is very good generally except where there are faults.

WEATHERING IN THE TROPICS

The weathering process is a physical, chemical and biological phenomenon induced by the flow of oxygen and water. This phenomenon is also controlled by the type of minerals and the process of formation of the rock, among others. ▶

To produce the chemical weathering the water is necessary and if it is at high temperature, the reaction speed will increase.

Chemical weathering is very intense in equatorial and tropical zones, mild in warm humid climate zones and low in extreme cold or extreme heat and low precipitation where the weathering is dominated by mechanical alteration.

Weathering processes of volcano-sedimentary rocks at the tropics are accelerated by the tropical - humid climate and the basic mineralogical composition (high olivine basalts), calcium content, high porosity (of the sandstones) and low levels of formation (level four in Goldich, 1938 and Bowen scale) also contributes to the process.

It is very common to find that after few days the surface of a cut in rock would get soft.

In the case of tunnels, the change of consistency does not occur in days but slower, although it must be taken into account for long term designs and especially when these are going to be exposed to water flow with dissolved oxygen.

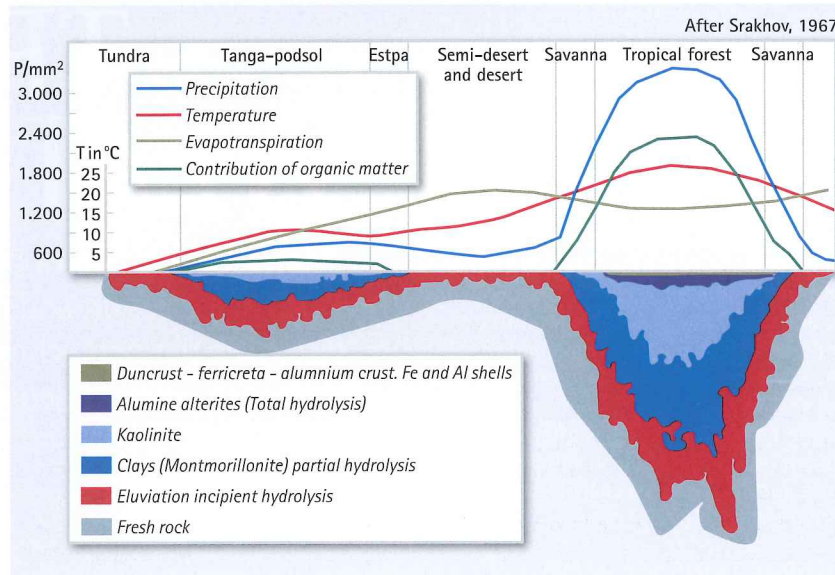
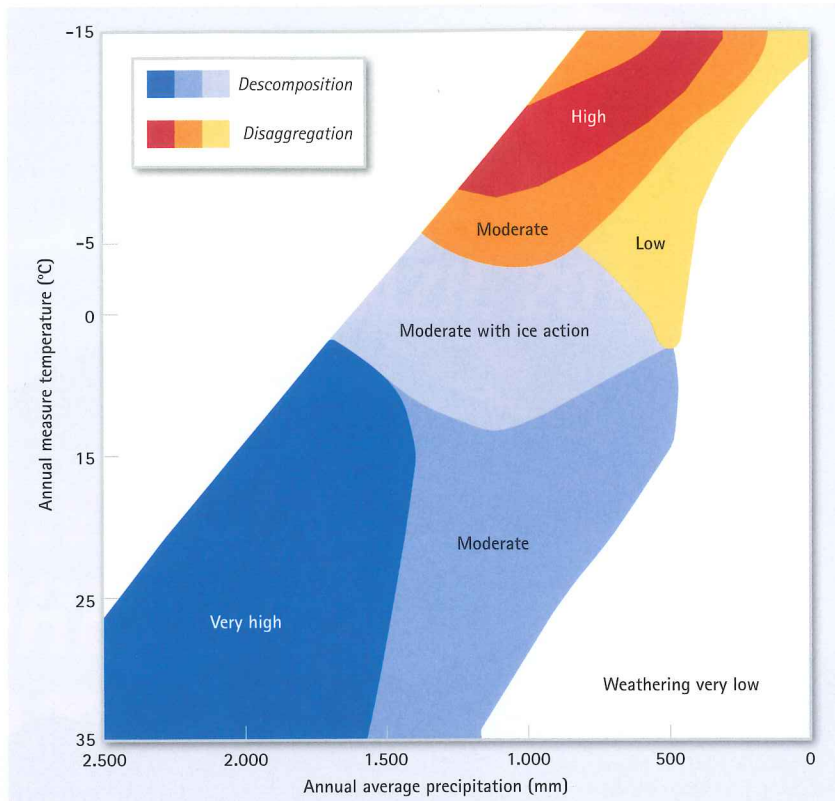
Deep water has no dissolved oxygen so therefore even though there would be saturated rocks, there is neither water flow nor oxygen, thus the process is very slow (Fletcher 2006). Therefore if the tunnel walls are kept covered, so that there is no water flow and oxygen, accelerated weathering processes can be controlled.

Although different authors report weathering speeds in metres per millions of years, it should be clear that these refer to the deepening of the weathering profile which is given in millions of years, but in this case we are referring to the surface.

In the event that the material that softens is removed and once again fresh rock is exposed, the deepening will be much higher than that reported by different authors (Dosetto et al 2011) (Riebe et al 2003, 2004).

The factors that affect the weathering of volcano-sedimentary rocks are the mineralogical composition, the climate and the water flow.

According to the chemical composition and the aggregates formed, the special conditions that produced the weathering for these rocks are:



- The basalt rich in olivine is very sensitive to hydrothermal weathering and to the effects of weathering.
- Detritic sedimentary rocks with feldspar which has high durability but is unstable in extremely hot and humid conditions due to the hydrolysis or cleavage of a molecule in the presence of water. As a result there is loss of minerals in the rock. Hydrolysis is the destruction of the original crystalline structure leading to the progressive separation of silica from other the elements, to the new formation of clay minerals and the deliverance of the metallic elements in the form of hydroxides.
- The shales with high silica content undergoes through a process of hydrolysis, that is, when is hydrated with water it becomes clay. Therefore its resistance decreases significantly. Sometimes when is slightly consolidated they are completely

Maria Cecilia Sierra

Maria is involved in geotechnical studies and designs for major hydropower projects in Colombia and the rest of Latin America



or partially undone with water.

Climate

According to the relationship climate - weathering proposed by Strachov (1967), the region in study corresponds to a moderate to very high decomposition zone, because the quantitative precipitation forecast (QPF) varies between 400 and 2000mm and the average annual temperature is between 5°C and 30°C.

Water flow

The factors that influence the ground water flow are the porosity and permeability. Therefore rocks that facilitate the flow of water are sandstones and limestones, as well as fractured zones. Sandstones have a porosity which can be between 12 per cent and 30 per cent, depending on the presence of fines and the grain size. The limestone has porosities between two per cent and 16 per cent.

Therefore it can be slightly porous, or highly porous depending on the clay content.

Variation in resistance

The shear strength of the rock varies when the test is performed with natural moisture and a saturated sample. This range of variation is different for sedimentary rocks and volcanic rocks.

So when a tunnel is excavated and the hydraulic gradient is changed the flow of water is enhanced. Now the weathering process is accelerated and there is contribution to the saturation of the rock mass. Moreover, when the tunnels are for conducting water this saturation can be facilitated from inside to outside.

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Opposite, top: Figure 1, Relationship between climate and weathering

Opposite, bottom: Figure 2, Climate and alternation mantles

CONCLUSION

In volcano-sedimentary rocks localised in the tropics the weathering process is accelerated in presence of water and oxygen flow, given specific characteristics of climate, chemical composition and porosity of the rock.

So when a tunnel is excavated the flow of water and oxygen is increased and therefore weathering and degradation processes are activated. Additional investigations and controls are required in addition to those normally carried out in the design of a tunnel.

These must consider the mineralogical composition, mechanical and chemical variation with the flow of water and oxygen, and the strength mechanic of the rock in humid and saturated conditions.

This paper is intended to impress the importance of further studies, in addition to those customarily undertaken (shear strength tests, characterisation of mass rock and stress-strain analysis, because with standard tests is not possible to anticipate change and potential problems that can appear in a tunnel in Central America, or the tropics in volcano-sedimentary rock

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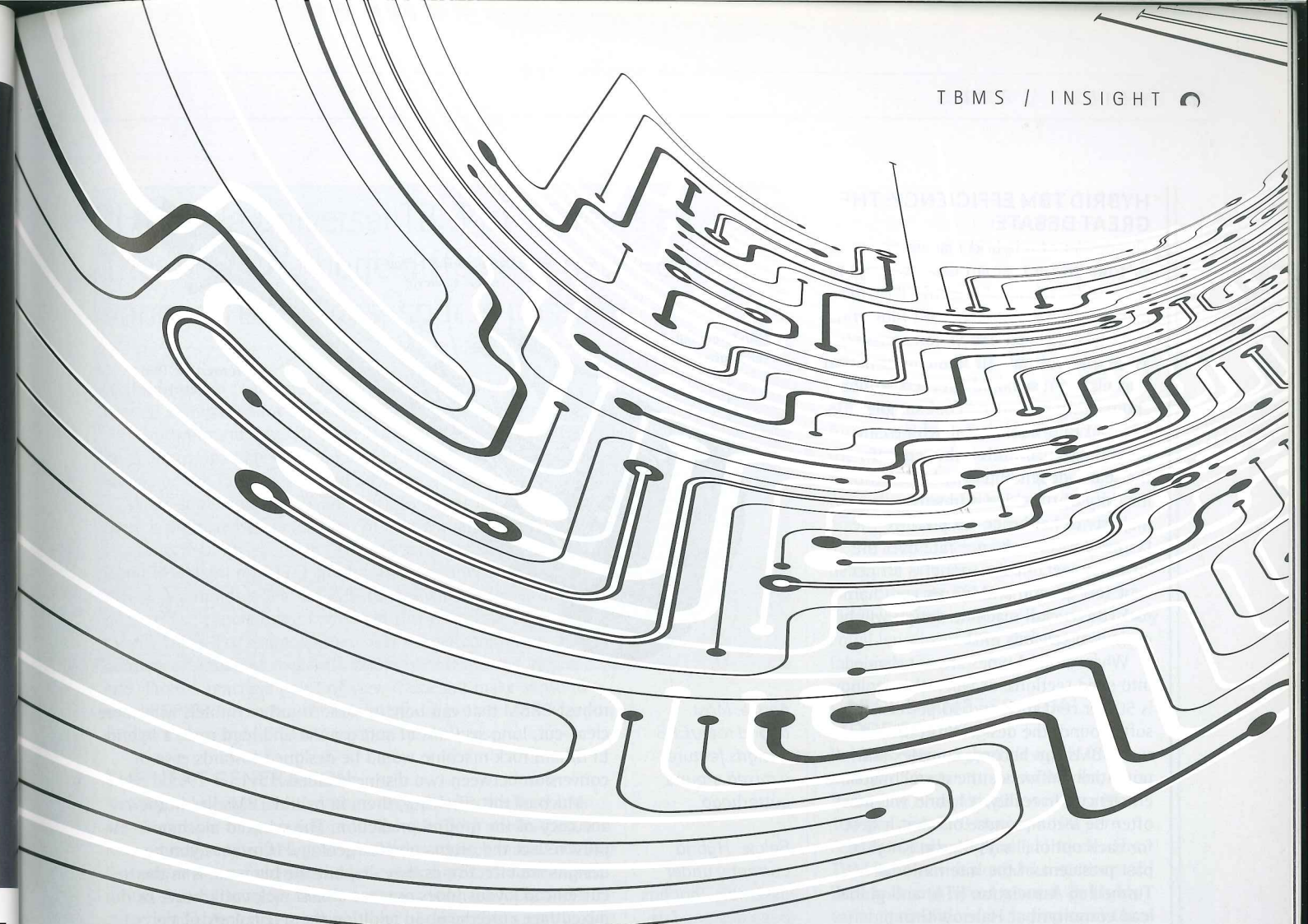
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ONE MACHINE, TWO MODES

Hybrid machines gain ground in the industry. **Desiree Willis**, technical writer for *Robbins* reports on the increase in demand, and asks why

Desiree Willis
Desiree has covered a range of topics for *Tunnels*, from project reports to TBM design



THE INDUSTRY'S use of hybrid TBMs is a trend that follows with the increasing frequency of difficult tunnel conditions in rock and soft ground. Where multiple machine types might have once been used for different sections of geology, a hybrid EPB/rock machine can excavate the entire tunnel. New designs are making this versatile take on tunnelling more efficient, even at larger diameters of 10m or more.

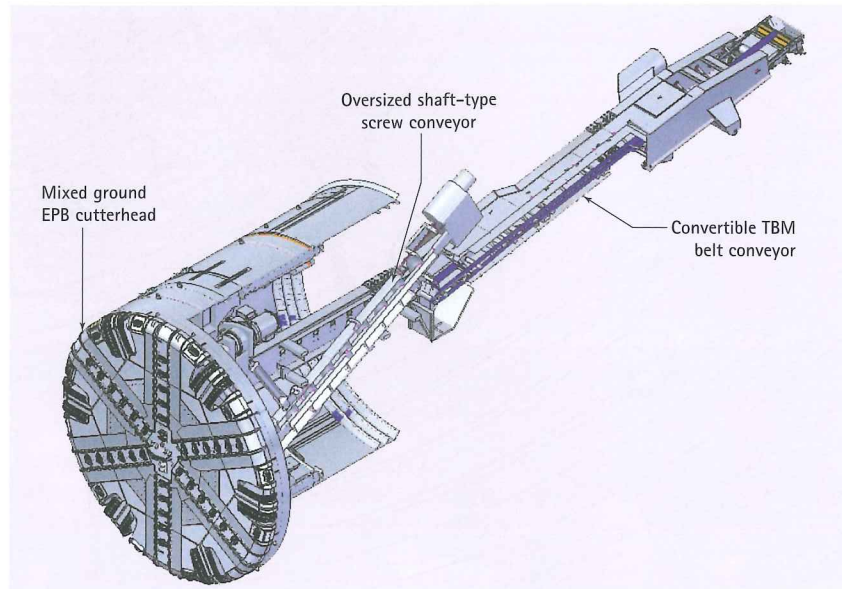
While all types of hybrid TBMs, including EPB/hard rock, EPB/slurry, and open-type/shielded hard rock designs are gaining in popularity, the EPB/hard rock machine offers some intriguing possibilities. A cross between a hard rock single shield TBM and an EPB, these TBMs bore tunnels with sections of both rock and soft ground, and utilise interchangeable cutting tools and muck removal systems to get the job done. "This type of machine allows one to use the most efficient cutting technology in a given geology," explained Doug Harding, Robbins vice president for sales. "A purely EPB machine would suffer from high EPB screw and cutterhead wear in long sections of rock, and a rock machine operating in EPB ground would have many problems in controlling the flowing ground." »

HYBRID TBM EFFICIENCY: THE GREAT DEBATE

The design of a hybrid machine must be customised for the particular geology in order to be the most effective. "Hybrid machines have the potential to lower risk and make difficult excavations possible, as long as accurate geologic information is available," says Brad Grothen, Robbins engineering manager. "For example, a hybrid EPB/hard rock machine can be optimised towards either end of the scale—depending on whether the majority of the drive is in soft soils or majority in hard rock—to produce the fastest possible advance rate over the entire project." If the tunnel is 80 per cent soft ground and 20 per cent hard rock, the overall machine design will be optimised towards EPB.

When ground types are not divided into solid sections, or when the geology is 50 per cent rock and 50 per cent soft ground, the design of EPB/hard rock TBMs can become complex and potentially influence the overall machine efficiency. "In reality, a hybrid will most often be a compromise of what is best for each option," says Martin Knights, past president of the International Tunnelling Association (ITA) and global lead consultant at Halcrow Group.

Designs for such machines do require a careful balance: in some projects with short sections of rock changing to soft ground, the design might favor a



Above: Most hybrid rock/EPB designs feature a mixed ground cutterhead

Below: Hybrid currently under assembly, that has been designed as explosion proof for a coal mine

robust EPBM that can bore in rock. In other tunnels with more clear-cut, long sections of soft ground and hard rock, a hybrid EPB/hard rock machine would be designed towards ease of conversion between two distinct modes.

Much of the efficiency, then, in hybrid TBMs lies in the accuracy of the ground prediction. The selected machine must reflect the often complex geology. "Current hybrid designs are effective as they are, but the big issue is in the cutterhead layout: does one use a hard rock cutterhead, or mixed face cutterhead. In addition the technology of the cutters themselves is moving at an exponential rate," says Steve Skelhorn, project sponsor for McNally Construction.

As for speed, Skelhorn believes that choosing the right machine type and operating in the correct mode are key.

"I think [a universal TBM is] 15 years away. There is not a huge difference between the various TBM types, so it is possible."

"Hybrid machines are the way to go. Segmentally lined rock tunnels eliminate a lot of issues in loose rock. And for projects with both ground types, it makes perfect sense. I think advance rates are comparable to standard EPBMs, as the EPB mode will always be the factor restricting advance rates."

While some contractors are quick to adopt hybrid machines, there is an increased perception of risk by many in the industry, as the technology is newer. "There is some resistance against using EPBMs in non-EPB conditions," continued Skelhorn, "There is a mindset that an EPB tunnel will be slower and will need to use concrete segments, but this is not the case with hybrid TBMs. For example, there is a tunnel coming up that consists of 3.5km of rock with 200m of soft ground at one end. From a practical point of view it doesn't make sense to use an EPBM for such a tunnel, but there is no reason why you couldn't use a hybrid EPBM in open mode."

THE NEXT GENERATION

New hybrid designs are variations on a theme: the machines are all capable of operating in EPB mode, both pressurised and non-pressurised, as well as in shielded hard rock mode. The key features of these machines include mixed ground cutterheads, robust screw conveyors, a belt conveyor for hard rock, and cutterhead drives that are capable of handling both hard rock and soft ground conditions. Mode conversion between hard rock and EPB modes typically takes up to two weeks in the tunnel, as modifications are done to the muck discharge facilities, cutterhead, and any other critical structures.

In practice, however, many contractors using hybrid EPB/rock machines avoid mode changes because of the downtime associated with it. This type of TBM is a substantial investment, and if not used properly in the ground type each mode was designed for, advance rates will be less than desired. The requirement for smooth and efficient mode changes is thus essential for these hybrid designs, leading to the next generation of mixed ground machines: those that compromise no features in hard rock or soft ground, and allow for ease of mode changes in the tunnel. New setups have been designed with this in mind, for use on large diameter TBMs in the 12 to 15m diameter range, and for tunnels in nearly equal lengths of hard rock and mixed face ground.

LARGE DIAMETER, DUAL MODE SETUP

Robbins' latest hybrid design is for a large diameter tunnel in Ankara, Turkey: It is capable of operating in 100 per cent EPB mode or 100 per cent hard rock single shield mode. The TBM has been designed for sections of hard rock and mixed ground, in highly variable conditions including sandstone, mudstone, claystone, quartzite, schist, soil, and clay. In EPB mode, the screw conveyor operates as in any typical EPB machine. The screw features a





Above: An 8m hybrid being assembled in Australia

Below: Hybrid setup designed for EPBMs in the 12 to 15m diameter range uses a hydraulic muck ring to divert muck through the screw conveyor and onto the belt conveyor, making for a swift mode conversion

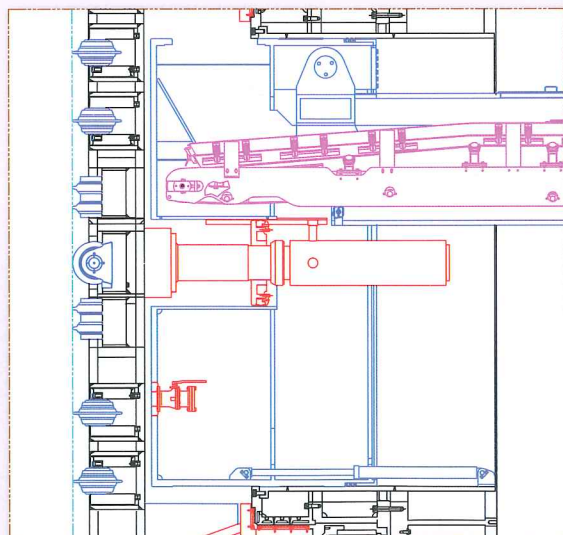
replaceable inner liner and replaceable carbide wear bits for abrasion protection. A mixed ground cutterhead is fitted with knife bits that can be switched out with disc cutters in harder conditions. Much of the cutterhead is covered in Trimay wear plate for additional abrasion protection.

A wear detection pipe on the cutterhead monitors any wear occurring to the cutterhead structure itself, while wear detection bits on the cutterhead and periphery tell the operator about tool wear, and if a gage cutter has been lost. The machine design includes a man lock for cutterhead inspection and changes, and mixing bars inside the mixing chamber.

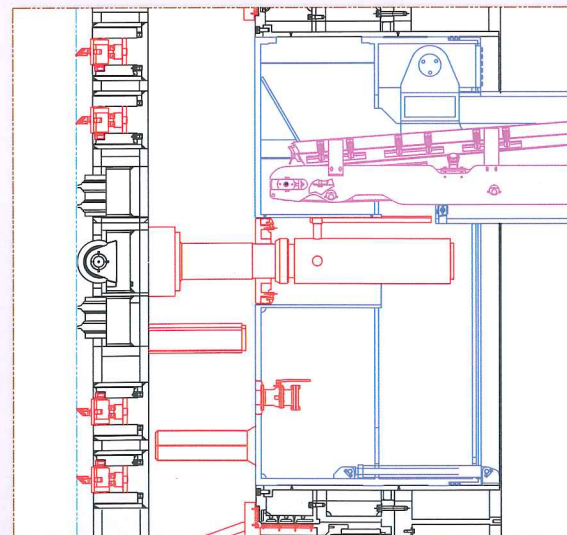
To convert to hard rock mode, the mixing bars and initial portion of the screw conveyor can be optionally retracted. Interchangeable EPB knife bits must be replaced with disc cutters on the cutterhead, and the EPB scrapers on the cutterhead must be replaced with hard rock bucket lips. Muck paddles are installed in the cutterhead to allow the muck to fall into the muck chute. A hydraulic muck ring allows a chute attached to the bulkhead to move forward and down at a diagonal angle, directing rock chips into the chute and through the screw conveyor onto the TBM belt conveyor.

OPTIMISATION TOWARDS HARD ROCK

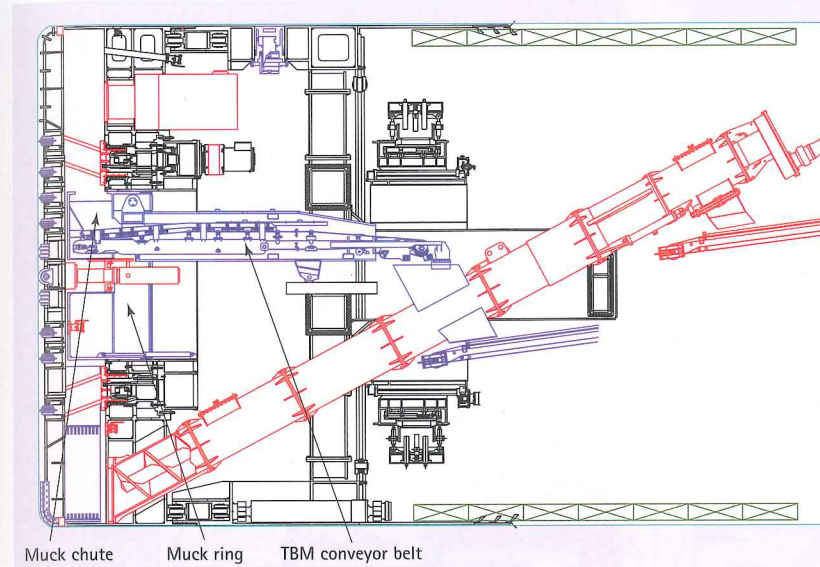
Going the other direction, a separate hybrid design has been developed for large diameter (8m and up) machines in majority hard rock tunnels. In 2013, an 8m diameter Robbins hybrid single shield/EPBM is gearing up for the Grosvenor Decline Tunnel at Australia's Anglo-American Coal Mine. The machine is being built using Onsite First Time Assembly (OFTA) in



Muck ring extended



Muck ring retracted



Muck chute Muck ring TBM conveyor belt

order to fit within a tight project schedule. The design allows operation in a decline through possibly gaseous conditions.

Two decline tunnels, at grades of 1:6 and 1:8, will be used for mine access to new coal seams. The hybrid machine will tackle mixed ground conditions ranging from sand and clay to varying grades of hard rock up to 120MPa UCS, as well as coal seams. Methane gas is expected to be present throughout the tunnel, so the machine has been designed as Explosion Proof Compliant to ERZ-1. Because of this, it was decided not to include a man lock, though one could be included. Only about 300m of ground are expected to be in EPB mode, while the rest will be bored in hard rock mode. Thus, the design was optimised towards hard rock excavation.

In EPB mode, the machine utilises a two-stage, center-mounted screw, with a replaceable inner liner and carbide bits for abrasion protection. A mixed ground cutterhead is fitted with interchangeable knife bits and Trimay wear plates for abrasion protection. To keep the mixing chamber spark-safe in the presence of methane the chamber is filled with water, foam, and other additives. To deal with the watery muck, one screw conveyor is run faster while the second screw conveyor is run slower, creating a muck plug in screw conveyor number two, which pushes the water out of the screw conveyor.

"The machine essentially uses its EPB technology to deal with any methane gas safely," says Harding. If any methane leakage is detected, an evacuation system called a 'snuffer box' will draw methane out of the end of the screw conveyor and directly into the ventilation system.

To convert to hard rock mode, a hydraulically operated muck chute is deployed around the screw. The muck is then picked up by paddles in the muck chamber to load the screw. Interchangeable EPB knife bits must be replaced with disc cutters on the cutterhead, and the EPB scrapers on the cutterhead must be replaced with hard rock bucket lips.

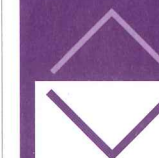
A skew ring offsets the torque of the machine in hard rock, allowing for more efficient single direction cutterhead excavation and muck pickup. Mini grippers on the rear shield allow the machine to bore 400 to 600mm forward, and then be retracted for cutter changes.

A final interesting aspect of the machine is a specially designed 'Quick Removal System'. As no ground in Australia can be left unsupported and the machine is boring a blind tunnel, it will be able to retract in one piece from its shield, leaving the shield in place. "The core of the machine is a bolted

Above: Large dual mode designs, require a larger initial investment but are versatile

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design and separates from the shield, in a process that does not require a cutting torch," said Harding. The machine will then be walked up the decline tunnel on a set of specially designed transport dollies and sent by rail to the second decline tunnel, where another shield will be waiting for machine assembly prior to launch.

ONE DIRECTION

The future use of all hybrid TBMs is predicted to increase, as more tunnels are slated for areas in mixed ground conditions. Other types of hybrids than those discussed here, such as EPB/slurry and open-type/shielded hard rock TBMs, are also increasing in popularity.

Skelhorn sees some barriers to the acceptance of hybrid rock/slurry and EPB/slurry designs however: "I think they have their place, but slurry is very expensive, and the size of the slurry plant and its requirements is tremendous. I think with advances in machine technology, we are closing the gap between slurry and EPB, and the hybrid design lends itself better to EPB conversion anyway."

Harding believes the initial investment of a hybrid EPB is offset by their versatility: "The machine may initially be expensive, but it is likely the machine will be able to be used and reused on a variety of projects afterward. It will also be able to perform better in difficult ground conditions."

When asked about the likelihood of the long-predicted 'universal TBM' able to operate in all modes and convertible from within the tunnel, attitudes are quite mixed. "There will never be a universal TBM that can equal the performance of a uni-purpose TBM," says Knights, indicating that the efficiency of such a machine would be quite low. For Skelhorn, the possibility is there, but it would require some advances in technology to make the design useable: "I think it's probably 15 years away. There is not a huge difference between the various TBM types, so it is possible. The biggest difference would be in converting such a machine for very hard rock tunnels where robust disc cutters are needed. Replacing cutterheads and cutting tools will be the biggest challenge."

For now, hybrid machine use seems destined to increase. Above all, Grothen says that effective hybrid machine design is about minimising complications: "Any job underground is not a simple one. Hybrid machines must be able to mine efficiently in the prescribed conditions while minimising cost to all involved"



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FORWARD MARCH

Bahram Salehi and Mahsa Shahandeh present their work on the validation of TBM advance rate predictions, with reference to a case study in Iran



Bahram Salehi

Bahram is a senior tunnel engineer for P.O.R Consulting, and is based in Tehran, Iran



Mahsa Shahandeh

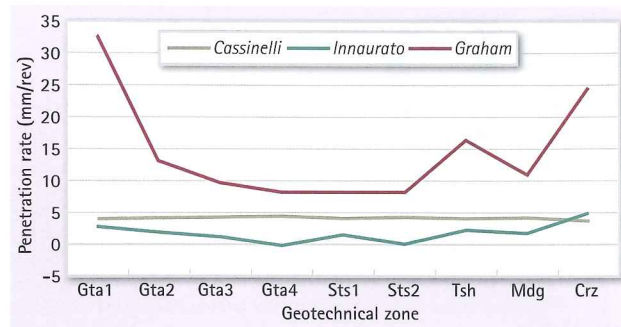
Mahsa is an MSc of rock mechanics, at Amirkabir University of Technology, Tehran



IN RECENT years different methods have been introduced to analyse and assess excavation operations of various TBM systems. These methods are divided in two groups: One, those based on mathematical equations and shear force of each cutter. Two, those based on production data and empirical relationships. This paper compares and analyses three methods: two experimental types, QTBM (Barton 1999) and Rock Mass Excavability (RME) (Bieniawski and Celada 2006), as well as using a mathematic model introduced by the Colorado School of Mines (CSM). A case study is presented featuring the 16km Karaj-Tehran water supply tunnel. This study concluded that mathematical models are not suitable because they are highly dependent on the results of special laboratory tests and are not representative of the rock mass characteristics. In jointed or non-homogeneous rock masses such as on this project, the experimental/empirical methods, are more credible as they are based on field data. QTBM considers less the effect of boring machine characteristics and joint filling factor. According to our analyses, and the conditions of the Karaj - Tehran water supply tunnel project, the RME method is more valid than the other approaches.

TBMs have a good reputation for high advance rate. Since 1990, usage of mechanised tunnel methods has increased. Hence, prediction capability of operations and performances in these machines, especially in long length projects, has received much attention. Peter Tarkoy in 1987 developed an empirical relationship between hardness and TBM penetration rate. Cassinelli et al. (1982) used a rock structure rating (RSR) system for evaluation of TBM performance. Nelson (1983) studied TBM performance at several tunnelling projects mainly in sedimentary rock formations, comparing the instantaneous penetration rate achieved in different rock properties. Aeberli and Wanner (1978) studied the effects of schistosity on TBM performance. Barton (1999, 2000) reviewed a wide range of TBM tunnels to establish databases required to estimate penetration rate, advance rate and utilisation of the TBM.

For this purpose, Barton slightly



Above: Figure 1, Comparing the results taken from a calculated penetration rate in CSM methodology

modified the Q rock classification system and produced a new equation, defined as QTBM which is used in this paper. The CSM has developed a semi-theoretical model, based on the measurement and evaluation of cutting forces on an individual cutter (Ozdemir, 1977). Rostami and Ozdemir (1993a, 1993b) improved this model theoretically by estimating cutting forces as a function of intact rock properties, including uniaxial compressive and tensile strength of rock, and cutter geometry. The disadvantage of this model was that it did not quantitatively consider rock mass properties, including planes of weakness, fracture orientations and rock brittleness. Yagiz (2001, 2002) modified the CSM model by adding brittleness of intact rock and fracture properties of rock masses as indices for this the model. The Norwegian Institute of Technology (NTNU) has developed a comprehensive empirical performance prediction model which considers intact rock and rock mass properties as well as machine parameters (Lislerud, 1988; Bruland, 1999).

In this model, the machine specifications along with laboratory measured indices, (drilling rate index, brittleness index, and cutter life index), and rock fracture data, are used to estimate the penetration rate (Norwegian Institute of Technology, 1995).

Rostami, Ozdemir and Nilson compared CSM and NTNU (also known as NTH) method for hard rock TBM Tunneling (Rostami and et al, 1996). Based on the results, the CSM model can be used to estimate the basic penetration and provide the ability to improve machine design and the NTH model can be applied to adjust the CSM estimate and incorporate the effects of discontinuities and rock mass.

In 2006 Bieniawski et al introduced the Rock Mass Excavability (RME) Index at the ITA Congress in Korea. Its purpose is to evaluate rock mass excavability in terms of TBM performance and to serve as a tool for choosing the type of TBM most appropriate for tunnel construction

in given rock mass conditions.

In this method specific correlations between the RME and the average rate of advance (ARA) were developed for double shield TBMs, based on data from tunnels constructed in Spain and in Ethiopia.

In addition, specific correlations between RMR and the ARA were proposed for open and single shield TBMs.

In this paper, the authors analysed the validity of three methods: QTBM, RME and a mathematical model introduced by CSM. In addition, the prediction capability of advance rate on the Karaj – Tehran water supply tunnel was assessed. Because consumption of drinking and industrial water will increase in future decades, many projects including this tunnel have been designed and are being implemented. This 16km long tunnel was excavated by a 4.56m diameter TBM which supplies 16m³/sec water from Amir-Kabir dam to Tehran refinery (treatment system) no.6.

EXPERIMENTAL MODELS

Q classification is on base drill and blast tunneling and introduced by Barton. After some field research, he developed the tunnel quality index model as follows after some field researches. Also, Barton (1999) developed a prediction model by means of some other parameters to estimate the advance rate of tunnel boring machines:

$$Eq\ 1: Q_{TBM} = \frac{RQD_o}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \times \frac{\sigma_c}{F_{10}} \times \frac{20}{CLI} \times \frac{q}{20} \times \frac{\sigma_\theta}{5}$$

where:

RQD_o: rock quality designation index in direction of tunnel excavation.

J_r/J_a: value related to discontinuities, joints and sheets of rocks which participate in most excavation trends.

J_w/SRF: the same Q value (unchanged)

Sigma: equivalent factor of rock mass strength

F: average cutter load, in tnf

CLI: cutter life index

q: quartz in percent.

σ_θ: induced biaxial stress on tunnel face (approx MPa) in the same zone, normalised to an approximate depth of 100m (=5MPa), (Barton, 1999).

The NTNU model was developed by Norwegian University of Science and Technology from the 1970s.

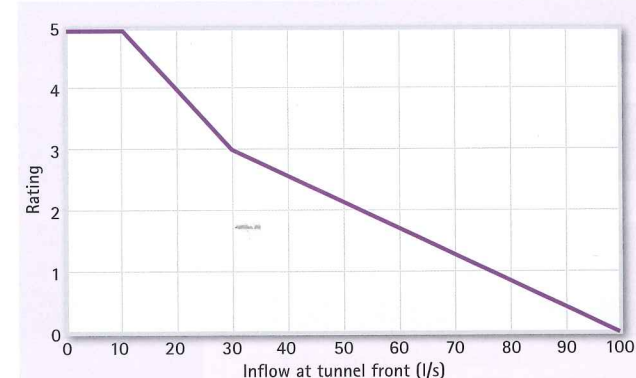
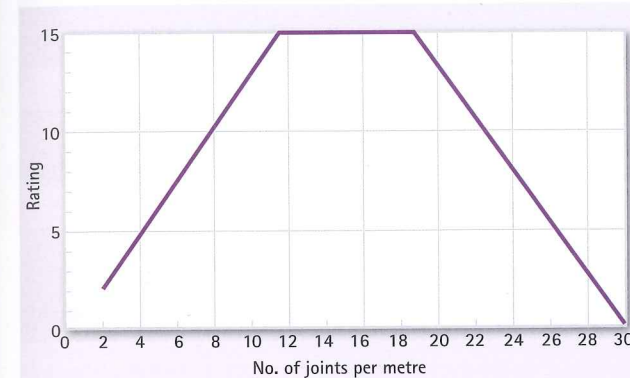
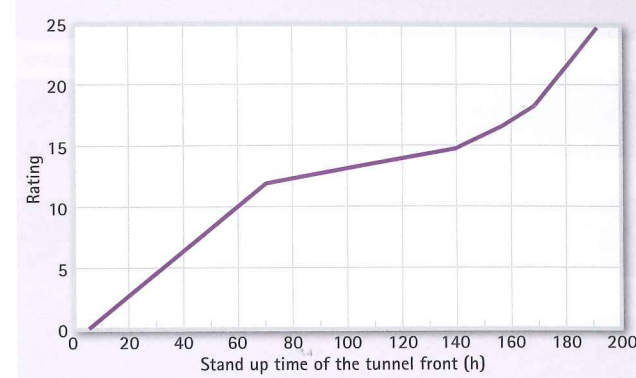
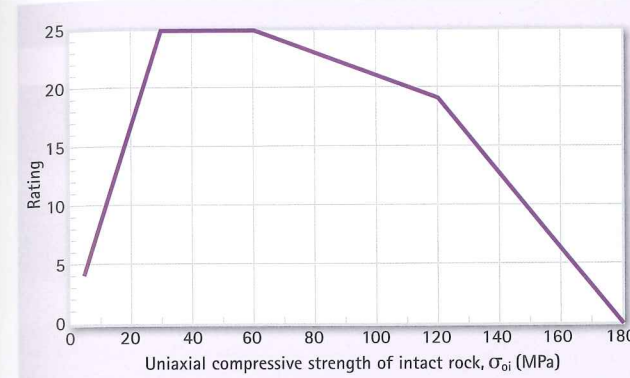
In 1995, Palmstrom introduced the RMI system to explain the conditions of rock mass. Based on this model, the penetration speed is estimated with a combination of the characters of rock drillability and rock mass joint as well as machine factors.

The purpose of the RME index, first presented in 2006, is to evaluate rock mass excavability in terms of TBM performance and to serve as a tool for choosing the type of TBM most appropriate for tunnel construction in given rock mass conditions.

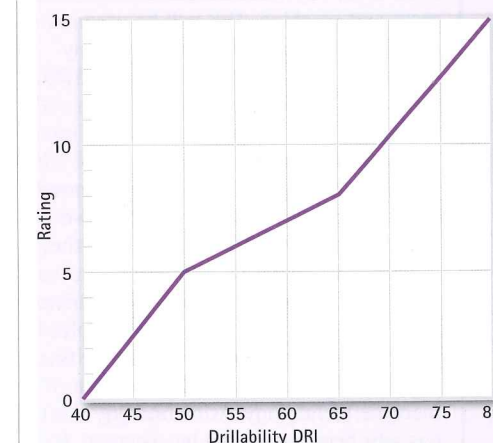
MATHEMATICAL MODELS

CSM introduced a mathematical model by the Earth Mechanics Institute (EMI) for advance estimation and penetrating rates based on 25 years of theory, experimental and operational studies.

In the late 1970s, work by Ozdemir and subsequently by Rostami and Ozdemir (1993) modified the model based on extensive theoretical analysis of rock failure under the action of TBM cutters. An empirical modified CSM model has been developed to describe rock fractures, brittleness and



All: Figure 2, Graphs for determination of the ratings for RME input parameters



to quantify their effect on TBM performance. Incorporating these adjustment factors into the existing CSM model basic penetration rate has led to a more accurate TBM performance prediction for given rock conditions (Yagiz, 2002).

This model is based on the forces applied to disc cutters for a certain penetration, advancing force momentum and the necessary power of cutter head. To estimate the amount of forces applied in disc, shearing tests must be carried on a real scale and accurately. This type of test contains all controlling parameters. Some of these parameters are: rock strength, rock brittleness, disc cutter details, spaced joints, continuity and joint gradients (slopes).

VALIDATION STUDY ON METHODS

CSM Methodology

One of the most sensitive parameters of the CSM model is the penetration force of each disc cutter. This parameter can be estimated by laboratory testing. If it is not determined accurately, the results of calculation will be wrong. The Colorado School of Mine has proposed many equations to calculate the penetration rate, the most important of which are the Cassinelli equation (Eq 2), the Innaurato equation (Eq 3) and the Graham equation (Eq 4).

Eq 2: $P = 0.0059 RSR + 1.59$

Eq 3: $P = \sigma_c^{-0.437} - 0.047 RSR + 3.15$

Eq 4: $P = \frac{3940FN}{UCS}$

where:

RSR: Rock structure rating

σ_c: Uniaxial pressure strength of rock (MPa)

P: penetrating rate in Innaurato and Cassinelli equations in m/h and for Graham equation mm/Rev

FN: penetration force of any disc in kN

UCS: rock pressure strength in kPa

Table 1. The Ratings for RME Input Parameters (Bieniawski et al. 2008)

Uniaxial compressive strength of instant rock [0 - 25 points]										
σ_c (MPa)	<5	5-30	30-90	90-180	>1800					
Rating	4	14	25	14	0					
Drillability [0 - 15 points]										
DRI	>80	80-65	65-50	50-40	<40					
Brazil	15	10	7	3	0					
Discontinuities in front of the tunnel face [0 - 30 points]										
Homogeneity	Number of joints per meter					Orientation with respect to tunnel axis				
Homogeneous	Mixed	0-4	4-8	8-15	15-30	>30	Perpendicular	Oblique	Parallel	
Rating	10	0	2	7	15	10	0	5	3	0
Stand-up time [0 - 25 points]										
Hours	<5	5-24	24-96	96-192	>192					
Rating	0	2	10	15	25					
Groundwater inflow [0 - 5 points]										
Litres/sec	>100	70-100	30-70	10-30	<10					
Brazil	0	1	2	4	5					

Source: Authors

methodology. This equation considers simultaneously the characteristics of rock mass and machine. This will be used to calculate Karaj-Tehran water supply tunnel project.

The CSM model evaluates the utilisation of any region without considering time. Furthermore, the standard values that have been presented based on the data bank have extensive ranges. This reduces the accuracy of the calculations. Also, the section in the CSM model that is used for performance calculation, cannot estimate accurately for the time being, because, the results of field studies are dependent on the machine technology, As technology has advanced the model has become outdated. The model is therefore not able to make accurate predictions.

QTBM Methodology

This method by Barton (1999) involves six parameters shared by two models designed to undertake any conventional (Q) and TBM excavation (QTBM) except the index of Rock Quality. The RQD index in QTBM model, as opposed to earlier model must be measured on direction of the tunnel axis. The RQD parameter can be measured through drilling with a diamond bit and by using equation 5.

$$Eq\ 5: RQD = \frac{\sum \text{Length of core pieces} > 10\text{cm length}}{\text{Total length of core run}} \times 100$$

The SIGMA parameter can be

calculated with the related UCS and tension strength of rock (or 150) and Q. The numerical value of the SIGMA parameter is closely related to the angle between discontinuity and tunnel axis. A parallel or semi-parallel structure with the tunnel axis (perpendicular to face) not only can alleviate the penetration rate (PR) but also decreases the utilisation (U) rate. Since, longer sections of rock need to be supported, the operations on the face are harshly crushed and fall. Also, the presence of the synchronous jointed structure that is normal in tunnel axis (parallel to face) will influence positively on PR, U and advance rate (AR). This structure shows a better stability in boring the rock with TBM.

Table 2. Capability of AR prediction models for consideration of effective parameters (Oraee and Salehi, 2013)

Parameters	Mathematical models	Expert mental models
Shearing force	Yes	No
Material, form and pattern of cutting tools	Yes	Indirect
Forces applied to cutting tools	Yes	Little
Machine Designing parameters	Yes	Little
Depending on technological level	No	Much
Fault recognition ability and design modification	Yes	No
Rock strength	Yes	Yes
Rock Quality index	Little	Yes
Geological conditions	Indirect	Yes
Jointed conditions	Indirect	Yes
Utilisation	Yes	Yes
Sensitive to operator	No	Some case
Depend to experimental data	Yes	Some case

Source: Authors

Table 3. Scoring the influences factors in excavating

Parameters	Q_{TBM}	NTNU	RME
Geotechnical and Tunnel Parameters			
Rocks pressure strength	5	1	10
Rock tensile strength	2	0	0
Groundwater conditions	10	0	10
Number of discontinuities	10	5	10
Discontinuities orientation	5	5	10
Discontinuities filling	2	5	0
Discontinuities spacing	2	5	5
Discontinuity general condition (roughness, alteration...)	5	2	1
Type of rock mass	5	1	5
Porosity and brittleness	5	0	5
Tunnel diameter	5	5	10
Stand up time	5	0	10
Abrasive minerals	10	5	0
Machine Parameters			
Cutting tool properties	2	5	0
Estimation of cutting tool effective life	0	10	0
Correction of constant coefficient	0	10	10
Tunnel section morphology	5	5	5
Maintenance operation	2	10	5
Man power operation	10	0	10
Dependency on critical factors	2	10	10
Utilisation (performance/productivity)	10	10	5
Adaptability to modern technology	5	2	10
TBM type	5	0	10
Sum	112	96	141

Source: Authors

The Cutter Life Index (CLI) depends on the rock condition in addition to the alloy materials applied. The presence of abrasive minerals such as quartz increases cutter wear and reduce its life. This index is presented in estimating figures by cutting tools manufacturers. However, exact measurements are necessary to test abrasion and drillability (Salehi, 2007).

It is evident that there is a direct correlation between the strength of rock mass and vertical stresses. Barton has included the σ_θ in the equation in order to consider the bidimensional mode of stress. It must be noted, considering the value of parameter σ_θ in 100m depths or the equivalent by tangential stress is generalised and less precise. So, it must be considered when using numerical value of σ_θ .

In the Q_{TBM} model, utilisation of machine at the any is dependent on the tunnel diameter, CLI, rock mass quartz content and porosity. Indeed, the QTBM model knows the self support of the tunnel as well as excavation capability impressed by four mentioned parameters. Utilisation is exercised in reducing factor form. In other words, U is considered as a negative exponent of special time range.

NTNU Methodology

This method uses parameters such as joint characteristics, rock mass strength, cutter thrust, and also contributes to the AR. However, this method considers equivalent value of parameters as well, rather than using their numerical values.

In this model, the joint characteristics of rock mass are introduced by six parameters. In the NTNU model, the classification of joints was based on their spacing and all parameters such as joint condition and drilling rate index (DRI) as computed by joint equivalent factor.

In the NTNU model the base penetration rate can be computed by using the numerical value of joint and cutter thrust equivalent factors. The data bank in this method shows some parameters such as the cutting tool spacing and diameter with constant values. Therefore, in cases where the parameters of a project differs from the data bank, correction coefficients are used. By applying the correction coefficient the pure or operational penetration rate is calculated.

Performance of a machine is expressed by the time of the service and the length of drive within a selected time range.

RME Methodology

Since RME introduction in 2006, continued improvements were made to the RME index as more case histories were collected for double shield TBMs and new data obtained for open TBMs and single shield TBMs from tunnels constructed in Germany, Switzerland and Spain. As a result, the score for σ_{ci} has changed from 0-15 points to 0-25 and for the discontinuities has decreased from 0-40 to 0-30 points, as shown in Table 1 (page 34) and Figure 2 (page 33). Note that the graphs enable more accurate determination of the RME values than the Table 1 (Bieniawski et al, 2008).

The RME is calculated using five input parameters having these initial ratings:

- Uniaxial compressive strength of intact rock material, σ_{ci} : 0 - 15 rating points;
- DRI: 0 - 15 points;
- Number of discontinuities present at tunnel face, their orientation with respect to tunnel axis and homogeneity at tunnel face: 0 - 40 points;
- Stand up time of the tunnel front: 0 - 25 points; and
- Water inflow at tunnel front: 0 - 5 points.

Table 4. Geotechnical zones in the Karaj-Tehran Water Tunnel (Oraee, et al. 2010)

Crz	Mdg	Tsh	Sts		Gta				Parameter
			2	1	4	3	2	1	
520	750	1410	3670	620	3280	1200	2300	2230	Zone Length (m)
Crushed Zone	Mudstone, Tuff, Siltstone		Conglomerate, Mudstone, Tuff		Clay, Schist, Tuff		Tuff, Conglomerate		Rock Type
-	2.8	2.6	2.55	2.6	2.6	2.6	2.6	2.6	Density (t/m ³)
300	100	150	250	150	500	350	350	200	Over Burden (m)
0.45	1.9	1.14	4.7	2.71	7.1	2.83	1.8	0.85	C (Mpa)
25.1	63.7	51.3	56.1	57.7	53.9	50.8	44.4	43.7	ϕ (degree)
-	15-20	5-10	17-25	10-15	12-18	10-15	10-15	5-10	E (Gpa)
<25	70-85	50-70	75-100	50-75	90-100	50-75	30-60	25-50	ROD
<30	90	60	120	120	120	100	75	30	UCS (MPa)
0-5	20-30	20-30	20-30	20-30	10-20	10-20	10-20	10-20	Q
78	48	63	43	43	42	45	55	80	DRI
22	67	55	73	57	80	62	57	52	RMR

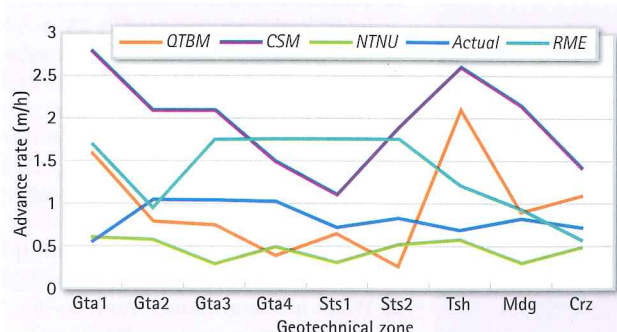
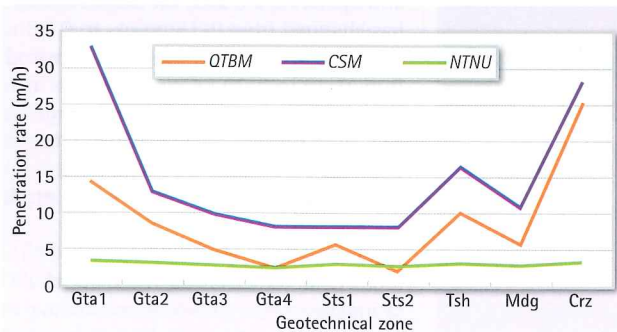
Source: Authors

The sum of the ratings of the above parameters varies between 0 - 100 rating points and it is expected that the higher the RME value, the easier and more productive the excavation of the tunnel.

To prevent errors in the prediction, this approach avoids calculating the ARA from the PR which normally varies between 6 and 60mm/min (Bieniawski and et al, 2008); this is so because while PR can be accurately measured in the TBM controls, the actual daily ARA depends on a number of factors which

Below, top: Figure 3, Penetration rate calculations of the Karaj - Tehran tunnel project

Below, bottom: Figure 4, Advance rate calculations of the Karaj - Tehran tunnel project



constitute uncertainties. They are, for example, the mechanical condition of the machine, the excavation strategy adopted by the TBM crew and the percentage of TBM utilization exclusively dedicated to excavation. ARA is closer to the average speed concept of the TBM than the peak output in a day.

In RME method it is possible to predict ARA by classifying types of TBMs and uni-axial compressive strength of the rock material. It is evident that a TBM working in a rock mass having $\sigma_{ci} = 20\text{MPa}$ will obtain much higher advance than one working in terrain with $\sigma_{ci} = 130\text{MPa}$.

For this reason, and based on research and tunneling data, it was decided that the most meaningful correlations between RME and ARAT for the common TBM types are when two ranges of the uniaxial compressive strength of intact rock are selected: the strength σ_{ci} greater or lesser than 45MPa.

COMPARISON OF THE METHODS

The capability of advance rate (AR) prediction models for consideration of effective parameters is shown in Table 2 (page 34). Careful quantifying of some parameters (especially in utilisation like effect of labour force) is subjective. Clear quantification is required to achieve accurate advance rate prediction.

QTBM method, involves the CLI index as the only parameter reflecting machine characteristics, shown in Table 3 (page 35). This is a two-dimensional factor and is expressed by the geological properties in excavation area. So, to introduce the capability and operation of the TBM cannot be a good decision. In the Barton method, the factors which are effective in operation and affected by geological conditions and manpower operations, have been ignored. Geological conditions are the only parameters that have been included except for joint filling. This defect is seen in an earlier version of the rock quality index (Q).

Parameters in the QTBM method are estimated by observation and use of tables and equations. The CLI parameter is necessary to estimate by complicated tests (Abrasion value steel (AVS) and Sievers' J- value (SJ)).

Table 5. Time required advancing at any geotechnical area

Parameter	Geotechnical area						Tsh	Mdg	Crz
	Crz			Gta					
	1	2	3	4	1	2			
length of area (m)	2230	2300	1200	3280	620	3670	1410	750	520
	Q_{TBM}								
Time of execution (month)	2.33	4.8	2.67	13.67	1.6	23.53	1.13	1.4	.8
	CSM								
Time of execution (month)	1.33	1.83	1	3.64	1	3.22	1	0.6	.62
	NTNU								
Time of execution (month)	6.17	6.73	6.67	10.93	3.47	11.77	4.13	4.17	1.73
	RME								
Time of execution (month)	2.35	4.38	1.23	3.33	0.63	3.72	2.06	1.46	1.64
	Actual								
Time of execution (month)	6.73	3.93	2.07	5.70	1.55	7.98	3.66	1.63	1.30

Source: Authors

The NTNU model shows that the boring machine features are of greater importance. The most important parameters of this model are computed in an indirect way and through equivalent factors and correction coefficients. However, these coefficients and rates are limited and the effects of ground water conditions were ignored. Also, the thrust factor and DRI have great effect in this method. However, the numerical value of this index is determined indirectly resulting in considerable variation in the calculated results.

The RME method has the best score for including both influence factors as geotechnical and machine parameters (see Table 3, page 35). Parameters in the RME method can be estimated by site investigation (joint properties and ground water conditions) and basic laboratory testing methods (USC). The DRI parameter is necessary for accurate estimation using standard ISRM tests.

In the RME method, the effect of geological conditions is of more importance than the features of TBM system. In this method machine parameters are involved as correction factors. In other words, after assessment of the theoretical advance rate, the machine parameters and performance are affected by three factors (tunnel diameter, crew efficiency, and team adaptation to the terrain).

CASE STUDY

The Karaj - Tehran water supply project, with the length of 16km, is under construction by a TBM. It is a double shield

type machine with a 4.566m diameter. According to geological characteristics of this region, the whole excavation area has been divided into nine zones (Table 4, opposite). Figures 3 and 4 (page 36) show the results obtained for PR, AR as well as the real operation during one year (RME method does not deal with penetration rate). The construction time of project is shown in Table 5 (below).

The values produced by CSM are higher than by the two other models. In CSM, the utilisation has been calculated on the data bank basis, and also according to time periods required for excavation and other services. It should be noted that all the models (except the RME) are using old data available in data banks and if these are not updated, this limits the prediction capability. So, the numbers obtained with the CSM model are restricted in value.

The AR as calculated by QTBM method shows different values at different geological areas. This is acceptable, while NTNU presents a similar AR for all nine regions.

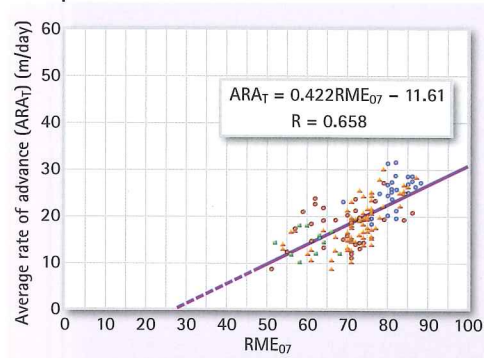
Table 6. Difference between actual and predicted value for advance rate (%).

Meth-od	Gta1	Gta2	Gta3	Gta4	Sts1	Sts2	Tsh	Mdg	Crz	Average
Q_{TBM}	65.47	30.58	38.10	156.70	9.89	215.93	67.26	8.73	35.06	69.75
CSM	80.27	50.26	50.68	31.55	35.06	56.77	73.56	61.79	48.98	54.32
NTNU	7.91	83.27	245.24	105.36	138.10	57.97	20.61	173.81	42.86	97.24
RME	67.44	11.31	40.77	41.55	59.47	53.39	43.66	10.64	27.06	39.48

Source: Authors

Acknowledgement

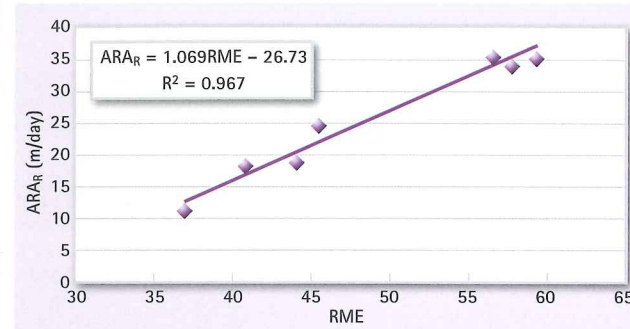
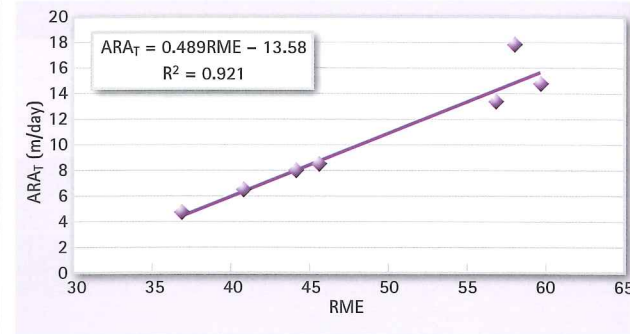
The authors would like to express great appreciation to Professor Bieniawski for his salient and constructive suggestions during the planning and development of this research work, and who spent his precious time for reviewing and making comments on this work. We would also like to thank the Hara Institute for unsparingly providing the information and data from the Karaj - Tehran water supplying tunnelling project.



All: Figure 5, Correlation between the Average Rate of Advance (ARA) and Rock Mass Excavability Index (RME): left, the original correlation by Bieniawski et al. (2008), right, the results from this investigation - on the above ARA (theoretical), on the below ARA (real)

Finally, Figure 5 (page 37) summarises the best results of the correlation obtained during this investigation between the ARA and the RME index, plotted with the original correlation by Bieniawski et al. (2008). Note that ARA (theoretical and real) is expressed in meters per day (m/d).

The results are also tabulated for convenience in Table 7 (below). A significant conclusion becomes apparent that the present correlation is markedly better, with R2 over 0.9, by comparison with the original correlation of R2 just below 0.7. This means that once the RME is determined on a given tunnelling project, the site-related correlation should be calibrated for the best R2



which can then be used with much confidence for reliable prediction of future rates of TBM advance at that project.

CONCLUSIONS

In the CSM model, construction time in the Karaj-Tehran Water supply tunnel project was estimated at 15 months (Table 5). The CSM model is also necessary for some essential tests that should be conducted to identify the cutter thrust and determine the initial PR. But these kinds of tests could not be conducted in the present project. This model considers the geological characteristics in an indirect mode and by using laboratory findings. It is evident that inaccurate quantities of parameters such as cutter thrust produce a less credible result. Furthermore, the CSM model estimates the performance process for all regions independent from time interval (as opposed to Barton model). It is one of the weaknesses of CSM. Generally, the PR as obtained from this model can be relied on if the required tests have been conducted carefully

Table 7. Summary of TBM Advance Data for the Karaj-Tehran Water Tunnel

Crz	Mdg	Tsh	Sts		Gta				Parameter
			2	1	4	3	2	1	
520	750	1410	3670	620	3280	1200	2300	2230	Zone Length (m)
Crushed Zone	Mudstone, Tuff, Silt-stone		Conglomerate, Mudstone, Tuff		Clay, Schist, Tuff		Tuff, Conglomerate		Rock Type
22	67	55	73	57	80	62	57	52	RMR
<30	90	60	120	120	120	100	75	30	UCS(MPa)
4.75	6.5	8.6	13.55	13.55	13.51	14.8	7.94	17.94	ARAT (m/d)
11.24	18.38	20.4	35.25	35.25	35.13	34.97	18.77	33.94	ARAR (m/d)
13.33	15.33	12.83	15.33	13.33	19.17	19.33	19.5	11.05	Actual TBM advance (m/d)
37	40.9	45.7	56.9	56.9	56.8	59.7	44.2	58	Rock Mass Excavability Index (RME)

Source: Authors

and completely. Among the experimental methods, the NTNU model requires accurate values of DRI and the equivalent factor of cutter thrust. Also, the calculation complications will be intensified because engineering judgment differs as well as different correction factors. Wherein carry out tests is possible to assess the drill ability, bit wear index, equivalent cutter thrust and etc, NTNU method will produce more accurate the results. Because this method considers not only the ground condition but also the characteristics of boring machines. Certainly, the NTNU method cannot find a reliable answer exclusively. Because, a number of influencing factors are not considered, such as ground water conditions and tunnel self support. The required time for execution of the project was estimated 56 months (Table 5, page 37).

Factors of QTBM model except CLI do not require intricate tests. As for equation 1, it is observed that this index has been applied inversely to the first power. Hence, approximating this factor with specific limits will not provide gross changes in the results. With its extended data bank based on rock mass quality (Q) and repeated use of it in both mining and civil projects, it is possible to assess accurately the geological factors. The time to implement the project has been calculated at about 52 months by using the Barton model. This method considers less to effect of boring machine specification and joint filling factor.

In the RME method all parameters were assessed by site investigation and standard laboratory tests. The RME

method introduced in 2006 utilised the experience with the RMR classification system, because one of the RME input parameters, the stand up time, is determined from the RMR. To prevent errors in prediction, this approach avoids calculating the ARA from the PR.

Moreover, with the RME, one considers a TBM type (open, single or double shield). This feature makes this method more useful in construction issues. Using the RME, the required time for execution of the project was estimated at 21 months, which was the closest result to actual data out of all the methods.

It was concluded that for projects with various joint structures, where tests of drill ability, and abrasion were not implemented, RME is the most suitable method. The data that is available from the Karaj-Tehran water supply tunnel conform more to the RME method capabilities. Furthermore the results showed in Figure 5 and Table 7 confirm the credibility of the RME method

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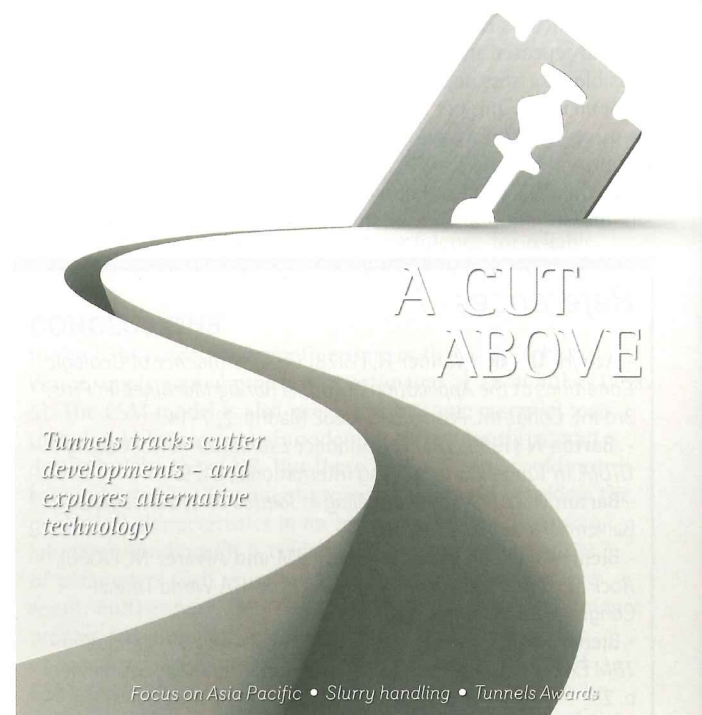
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The quality of photos in the 2013 Tunnels Photo Competition has surpassed previous years. The judges eventually picked their favourites...

THE 2013 PHOTO competition was the toughest to judge to date. The quality of entries was second to none.

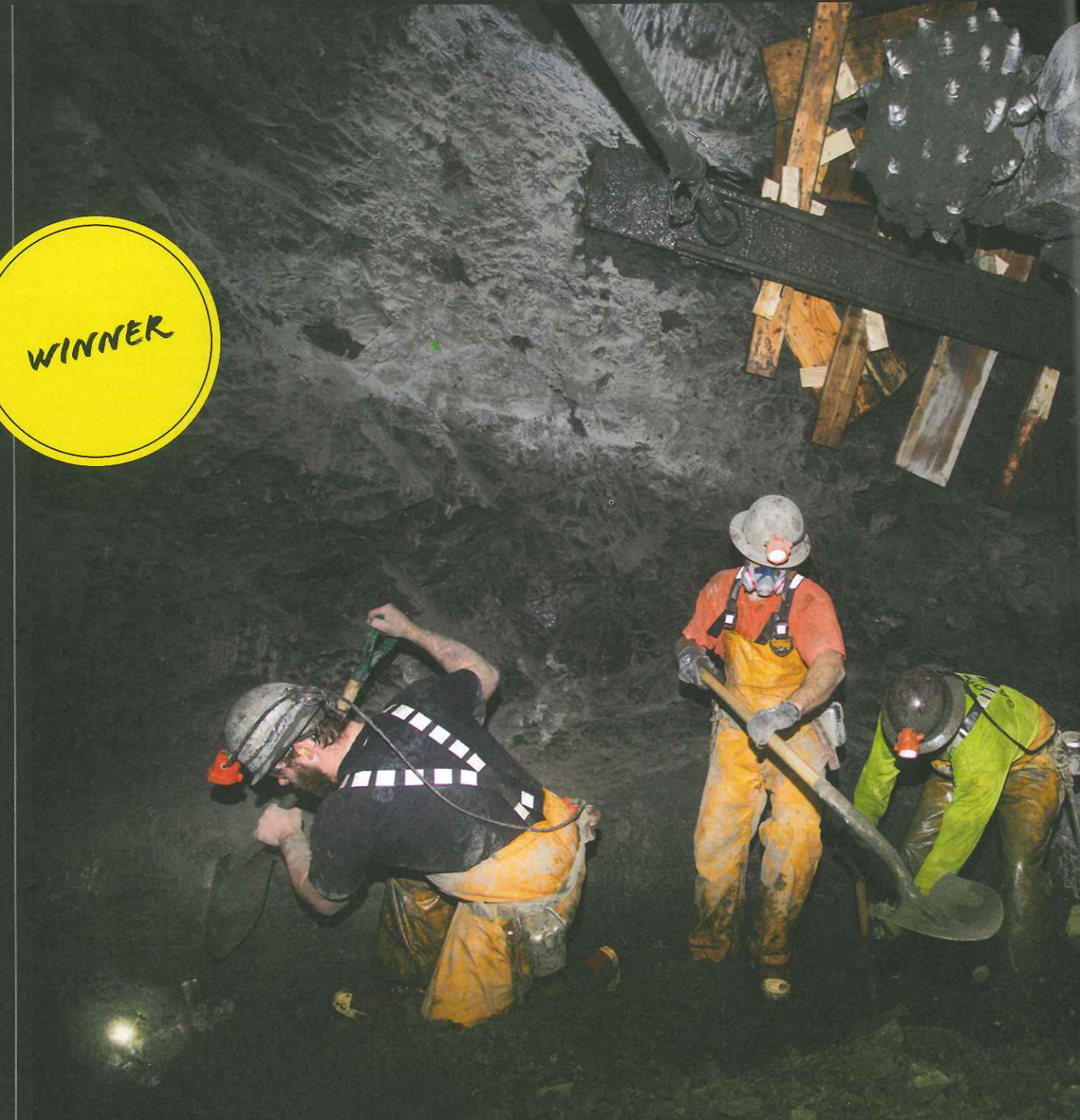
Photographer Nick Kozak, one of the judges, says "we were looking for reasons not to give the award with many of these entries".

The winning photo needed to give an insight into the grandeur and complexity of tunnelling. To demonstrate what it means to work underground.

While a number of the entries showed a great talent for photography and an understanding of tunnelling, there could only be one winner



WINNER



1

1. This skilfully captured moment showcases tunnelling for what it really is, a relationship between man, machine and earth. This was the only entry that showed the gruelling nature of working underground. Capturing movement in low light shows Robin Scheswohl's talent



2



3

2. Another entry by Robin Scheswohl again puts the men in the foreground. A great composition and use of lines

3. This photo by Derek Paulson shows the grit and dirt of tunnelling. It also shows the challenges of poor lighting

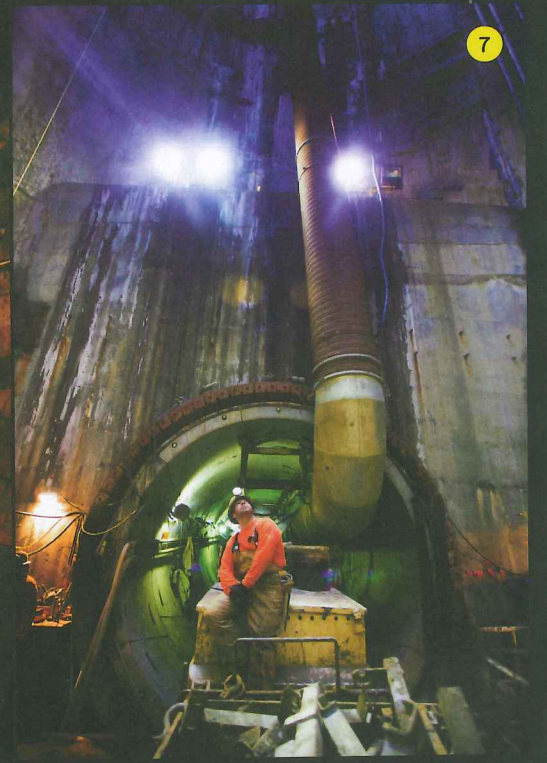


4. Andrés Moreno Sánchez's photo shows the scale and drama of mega tunnelling. The colours and geometry of the image are captivating. The judges felt this photo shows the enormity of a deep tunnel project and was a very close runner up.

5. A second entry from Andrés Moreno Sánchez shows a talent for capturing the grandeur of deep tunnelling

6. Descending into hell, Kyle White's fiery photo caught the judges' eye. There is a sense of mystery that draws you in.

7. Robin Scheswohl's beautifully colourful photo paints a serene picture of a sewer project



RUNNER UP



8

8. Sudipto Das's image is in many ways a classic tunnelling shot, but it is an exceptional example. The rich gray of the tunnel and the lighting draws you in. The two figures are perfectly composed, one under the light in silhouette and the other in the dark lit by his high vis.



11

9. Andras Nemeth's ethereal shot captures a peaceful moment. The image appears almost painted

10. A brilliantly composed shot by Robin Scheswohl. The vanishing point positioned in the middle of the action

11. The 2011 winner Katherine Du Tiel returned with another clever use of lighting, giving an unusual take on a classic shot



9



10

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Ensuring the correct lifting strategy is vital to the success of any tunnelling project, reports technical journalist **Bernadette Ballantyne**



FROM PLACEMENT of TBMs to the removal of muck generated by the excavators, lifting forms a vital part of any tunnelling project. "The importance of the lifting equipment cannot be underestimated," says Steve Chorley, field service Director at TBM manufacturer Robbins. "It is the key to a successful assembly, and failure to provide the right lifting equipment or correctly rated lifting equipment can often end in disastrous results," he says, adding that employing highly skilled personnel is just as important. ▶



Bernadette Ballantyne
Bernadette is the editor of *Tunnels'* sister publication *Underground Utilities*

WHAT GOES UP



The most challenging components to lift are usually the shields themselves. "To reduce the assembly time contractors would prefer to leave as much equipment installed inside the shields. This can alter the centre of gravity making the lift more challenging," explains Chorley.

WORLD'S LARGEST

Perhaps the most challenging lift undertaken recently was the erection of the largest diameter TBM in action in the world, a 17.5m-diameter, 7,000t beast known as Bertha. The machine is currently boring the Alaskan Way Viaduct Replacement Scheme (SR99) in Seattle, replacing the original earthquake damaged structure. Manufactured in Japan by Hitachi Zosen, the machine was delivered to the contractor Seattle Tunnel Partners, a JV of Dragados USA and Tutor Perini, in April. "The target was to design and manufacture the TBM in as big blocks as physically possible to save disassembly time in factory and assembly time at the jobsite and to mitigate the lack of room besides the launch pit that did not allow us to stage a huge amount of small components on it," says Juan Luis Magro, construction and equipment manager for Dragados USA. This meant delivery of 41 components the heaviest of which weighed in at nearly 850t.

From the beginning this required some heavy duty lifting equipment. TBM manufacture was carried out at the Sakai Works in Osaka, Japan which is a former vessels factory, and had direct access to maritime transportation. "Our launch pit is adjacent to the water



Above, right: The TBM for the Alaskan Way Viaduct Replacement Scheme was manufactured in Sakai, Japan

Above, left: Australia-based Melrose crane in use on site

as well, right besides the Elliot Bay. Since we knew there are heavy lift shipping and loading means available in the market, we designed and set the construction of the launch pit accordingly," says Magro.

Therefore the assembly and disassembly in Japan was performed using 'Mushashi', a 3,700t floating crane owned by Fukada Salvage and Marine Works. The 'Fairpartner' vessel, a heavy-lift cargo type J1800, owned by Netherlands based Jumbo Maritime then shipped the TBM from Osaka to Seattle. This featured 2x900t floating crane to self-load TBM components from barges and offload without additional cranes at Port of Seattle. Local firm Barnhart Crane & Rigging then employed self-propelled module transporters known as Goldhofer trailers, to haul TBM components from the Fairpartner vessel to the staging area besides the launch pit approximately 500 yards (457m) away. These had to be carefully placed to ensure that they were sitting in correct sequence for lifting into the 80ft (24m) deep launch pit. Barnhart supplied a 1,200t Modular Lifting Tower for lifting the largest of the components and used a Demag 1800 crawler to erect the MLT gantry as well as to lower the smaller TBM components. "The 1,200t MLT gantry was set specifically for TBM assembly and was removed upon termination. Then a 63t gantry crane manufactured by Spain's GH took over the top of the shaft, to lower segments down to launch pit," says Magro. These then also loaded the segments on to rubber tired vehicles supplied by Metalliance of France which moved the segments to the rear of the TBM known as the back-up where they were then offloaded and transported to the ring assembly area. Muck will be conveyed by means of a tunnel and overland conveyor belt system of 2,800t per hour capacity, supplied by Germany's H+E Logistik. This material will then be placed on top of barges that will haul it to a nearby abandoned quarry in Port Ludlow, Washington.

HEAVY DUTY

Given the scale of the job and the complexity of the lift it is not surprising that Magro lists the coordination as being the biggest challenge for the team. "The technical front was well covered by our very own team of engineers and those of our subcontractors and suppliers. However, getting every third party involved understanding the complexity of the operation and

ultimately, being on the same page was the real deal of this amazing operation and in the end, it worked pretty well," says Magro.

As a result Magro says that the TBM hauling and assembly has been performed in record time, ahead of schedule without impacting any of the project neighbours. The final piece, the cutterhead, was lifted in on 31 May. For the lifting team the next major activity will be removal of the machine from the North Portal, which has limited dimensions of 70ft by 100ft (21.3m by 30.5m). Magro says the removal strategy is still under discussion. "It is still a work in progress, although the TBM was designed and built to be removed in blocks smaller than those of the assembly," he says. "Ultimately, a large crawler or hydraulic crane will be necessary on top of the extraction shaft to lift up the TBM pieces taken apart at the bottom and upended by means of a small gantry and/or sliding and tipping over system to be installed down there."

If the team do decide to use a crawler crane they will be in good company as large crawler cranes are a common site on tunnelling projects. In Germany in June a Liebherr LR1600/2 was used to lift the segments of a tunnel boring machines from the barge on which it arrived along the River Spree, into the 20m deep launch shaft where it was assembled. Supplied by Riga Mainz the machine when complete weighed in at 700t with the heaviest component 135t and is now being used to bore a new 2km connecting tunnel for Berlin's underground system.

Crawlers too feature on London's Crossrail project where contractor Dragados Sisk is responsible for construction of the eastern running tunnels on the huge GBP 14.8bn (USD 23bn) link. The scheme connects Abbeywood in the east with Heathrow airport in the west and involves 42km of underground tunnels along with extensive work to build new stations. Most of the Crossrail TBMs were driven into the bore from launch pits but as part of its contract Dragados Sisk had to launch two 6.2m diameter, 586t TBMs from the 40m deep Limmo Shaft. Lifting of both machines was achieved using a Liebherr LR11350 crawler supplied by Weldex Crane Hire. It was rigged in a week and configured on a 48m boom with a 42m derrick mast with 300t of counterweight. The first TBM named Elizabeth was lifted at a radius of 21m with an additional 350t of counterweight. The second machine (Victoria) was lifted at a 31m radius with an additional 600t of counterweight.

The contractor has also used gantry cranes extensively on its sections of the project and it sourced these from Spain's GH. Three of these are at the Limmo Shaft, two of 32t capacity and one at 18t, two 32t gantries are used on other sites and a further four are being used at the precast concrete segment factory in Chatham. Two of these are 20t capacity and two are 10t. These segments are sailed from the Chatham site where a Liebherr LR 1140 lifts them onto one of four purpose built barges, these then sail to the Limmo Wharf dock where a gantry unloads them. For this section of the project muck removal is achieved using a vertical HAC (high angled conveyor) which uses two belts to squeeze the muck between them until it is lifted out onto waiting conveyors.

Another company supplying gantry cranes to Crossrail is UK overhead crane and hoist specialist Street Crane. It currently has 10 gantries in use on the scheme including a 40t Goliath crane which was used to build the new western ticket hall at

850t

The heaviest component to be lifted for Bertha, the Alaskan Way Viaduct Replacement Scheme TBM

Tottenham Court Road. This crane is a double girder box beam design with twin custom built TVX hoists, each capable of lifting 20t. The crane has a total height of lift of 37m with a maximum normal speed of 15m per minute and a minimum 1.5m per minute. Hoist speed can be boosted to 23m per minute for light loads of 2t or less. Large ground beams, 1.5m deep, were cast 31m apart on which the rails for the Goliath crane legs run. The crane spans the beams and has an additional 5.1m cantilever at one end so that spoil skips can be offloaded onto awaiting trucks that are outside the protected excavation area.

Sales director for Street Crane Chris Lindley-Smith says that there are a few important considerations to be taken into account when using gantry cranes for underground work. "You have to make sure that the hoist unit has true vertical lift. Lowering something down a vertical path, the hook path has to stay constant. With a lot of wire rope hoists you find that the hook moves laterally as it is raised and lowered so you have to use a specific design to make sure that the path stays central. You also have to make sure that the speeds are correct."

SIZE AND STAMINA

The duty class of the crane is also important. "You have to make sure that the hoist is of the correct duty and the motor is of the correct duty. A crane being used 24 hours a day for lifting operations has to be a higher duty class than a maintenance crane in a turbine hall that is used twice a year, otherwise it will just wear out," he says.

For heavy lifting mobile cranes rope length and weight is a vital technical consideration. Gregg Melrose is founder of Sydney based Melrose Cranes and Rigging. He says that this is often overlooked. "A lot of people forget to consider how long the winch rope is. Sometimes you have to use a bigger crane than necessary because of the winch rope length. For example a contractor might decide that they can lift their load with a 300 tonner but that machine has 350m of rope on the drum and the lift needs 450m of rope, so you have to use a 400t machine. For deep shafts that rope length is the main consideration."

Melrose is currently sharpening his pencil to tender for lifting services on a major tunnelling project set to start in Sydney in 2014. The AUD 8.3bn (USD 7.65bn) North West Rail Link was awarded to the Theiss/John Holland/Dragados joint venture in June and involves construction of 15km twin bore

"You have to make sure the hoist unit has true vertical lift"

tunnels using double shield hard rock gripper TBMs starting construction at either end of the bore. "On a job like this you generally need something like a 450/500t mobile hydraulic to put the TBMs down the hole. Then you might use a 220t or 200t mobile to service the shaft afterwards with equipment and generators," says Melrose.

The firm has several large machines with such capacities including all terrains such as the Grove GMK7450, the Demag 500AT as well as a 600t Terex CC2800-1 crawler crane. At the same time Melrose anticipates that the job will need service support from smaller Franna Cranes, also known as pick and carry cranes. These 18t-25t machines were developed in Australia in 1980 and named after creator Francis and his daughter Anna, the company is now owned by Terex.

Tunnelling projects are nothing new for Melrose which recently worked with other Australian lift specialists Kennards Lift & Shift and A Noble and Sons to lift a TBM from underwater in Botany Bay. The 98t Herrenknecht machine had to be lifted at six points to ensure the integrity of the machine joints. "The engineer told us how many points he wanted it to be lifted along the length so we had to work out how to achieve equalisation at all of those points. There are a few ways to do that. Our friends at Kennards had the modular bar at the top with the right rating, and we had the small bars so a combination was put together using our experience," explains Melrose.

Back in the UK Ainscough Crane Hire special project manager Bob MacGrain also says that rope length is critical when lifting down into tunnels, and says that the self weight of this can be considerable. "Even if you have got enough rope then you need to take into account that if you are working close to the crane capacity the self weight of the rope can be considerable (up to 10t). As you start lowering the TBM you are paying out more and more rope which is hanging below the boom head which means that the safe load indicator adds it on to the load on the crane. If you are near the maximum lift capacity at the start of the lift you could find that part way down the hole the crane has reached its safe working limit from the added load of the rope as it pays out."

Contractors must also be careful with their hoist drum, and MacGrain says that in the past some lifts have struggled with the top layers of wire cutting into the spool. "When you are lifting a very heavy load the top layer of rope will be under a lot of tension. What can happen is that as you are lowering off, the top



Above: The self weight of wire rope can be a significant factor in lifting work in underground construction

Opposite: Excavator being lowered on a worksite

layer can cut down through the slack layers beneath. It is a well known issue in the wind industry where taking redundant turbines off high towers can cause exactly that problem. "I have known situations in the past where the hoist rope has cut in so badly that it will neither go out or in," he says. However he says that modern spooling systems do address this problem. "Ideally when you stow the rope back onto the drum you need enough weight to make it coil tightly which the self weight of the hook block should do for you, but if you are using a very light hook block because it is a relatively light lift, then the rope on the drum is not going to be tight."

And of course what goes in must come out again. Extraction of the machines, particularly in built up areas can be even more difficult than placing them in the first place. Rope length again can affect the choice of machine. "I am considering a situation at the moment where a 550t crane could remove a TBM but it only has a single hoist drum and it is very neat for available rope length, it would have to run all the rope off to reach the criteria that we need," says MacGrain. "So I have stepped up to a 600t crane because it can run



two hoist winches simultaneously to an equalised hook block so instead of having 10 falls of rope off of one hoist drum I am running five falls off two separate drums," he says. As each drum has 900m of rope, this solution becomes much more comfortable, however the downside is that the manufacturers say that for the equalised hook blocks the operator should be able to see them during lifting to ensure that the blocks don't go out of synchronisation. This is not always easy in a deep shaft.

Technical considerations aside, contractors have a large range of lifting devices at their disposal from a mature industry well used to underground work. Many tunnelling projects manage to use everything from gantries and crawlers to mobiles, tower and barge cranes in some combination. Experts say that the determining factors in planning the lifting strategy are largely site specific with constraints on land, noise, ground conditions, access and the size and shape of components all influencing the final methodology.

CONTRACTOR PERSPECTIVE AT TOTTENHAM COURT ROAD

Upgrading Tottenham Court Road station, part of the UK's London Underground system, epitomises some of the biggest challenges that face both the lifting sector and the tunnelling industry. The site footprint is tiny given the scale of the work, cranes are shared by an array of construction teams working on what is effectively six projects in one location, tunnelling equipment and construction materials must be lifted into tight shafts or new station boxes held open with an array of props to limit ground movement creating unusual and limited spaces for lifting operations. Above ground the space for cranes is minimal, competition for lifting gear is fierce and the programme is tight.

At peak construction in August 2012 there were two tower cranes and five crawlers being used at the site supplied by the contractor along with the likes of hire companies Weldex, AGD, HTC Plant and Ainscough, and manufactured by Kobelco, IHI and Woolf. "We could have used a third tower crane," explains Colin Dunkerton, appointed manager for cranes, Taylor Woodrow BAM Nuttall. "But given the tight site and the load bearing capacity of the excavation support structures around the new ticket hall, we decided to stick with two."

The two tower cranes were chosen instead of crawlers for two key reasons – site space and the load bearing capacity of the access road. "One of the big

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issues was that we were doing top down construction (to build the new Crossrail ticket hall) and the loadings on that road are 72t, so anything of the capacity with the radius to work in the ticket hall we wouldn't have had the capacity to get it over the building so that is why we opted for the tower cranes," says Dunkerton. The largest of these was a 320B Woolf (Germany's Wolffkran) with luffing jib. Set up over a weekend the crane had a concrete slab foundation supported by four cored piles. "We would have needed a very big crawler to get the reach that we needed. The 320B was on a 50m radius with 6.6t capacity," says Buck. Given the site constraints and the scale of the work it is not surprising that the team cite the logistics as being one of the biggest challenges. "We had to have daily logistics meetings," says Dave Harper, tunnelling section manager for the Taylor Woodrow BAM Nuttall joint venture. "We had one area in front of the tower crane and every section that wanted to bring in materials or equipment landed there. If they wanted to park an arctic they had to book a time."

Added to the complexity was that many of the 100 truck movements to the site arrived at night to reduce congestion on what is one of the busiest cosmopolitan areas in the world – London's Oxford Street. "Tunnelling was 24/7 so we had to keep Dave [Harper] going and at the same time resource the rest of the site," says Dunkerton. This meant providing steel reinforcement, concrete, temporary props, shuttering materials, to the underground construction teams while also ensuring that muck could be removed swiftly. "Analysing hook time and how to keep people productive when you are sharing the tower crane between a number of operations, had to be balanced with trucks coming in and out," says Dunkerton. Not easy.

Coupled with this the team also had some unique technical work to undertake which required some lateral thinking when it came to lifting solutions. One neat innovation was the use of a monorail hung from the excavated primary lining of the new Central Line Interchange tunnel. This was used to winch in new 8m long composite steel and concrete beams that would form the base of two new overbridges to carry passengers over the existing Central Line to a new additional staircase. But before undertaking this activity Dave Harper's team had to reinforce the ground with a series of horizontal piles to support an existing brick sewer running above the Central Line. "Over a weekend we slid the beams in over the tunnel and then opened to traffic on the Monday morning. Two bridges had gone in over the westbound platform and none of the drivers could tell," says Harper.

With the tower cranes, three medium sized lattice boom crawlers and a 40t gantry crane also service the site. Unlike the tower cranes which were removed in February and June once the main station boxes had been created, the crawlers remain on site today servicing the ongoing connection tunnel works and fit out activities. A 120t IHI CCH1200 crane supplied by AGD Equipment sits in the centre of the site, a Weldex supplied Kobelco CKE 1100t sits to the north of the site and an 80t crawler manufactured by IHI and owned by BAM Nuttall Plant services the Crossrail escalator decline.

One of the most challenging aspects of the work was tunnelling of the new concourse tunnels that connect the new ticket hall to the existing Northern Line. The IHI 120t crawler was used to lift the 22t excavator machine into the box where the sidewall drift method of sprayed concrete lining is being used to construct the connecting tunnels, passageways and escape tunnels. "This was the first time sidewall drift had been used in London since the [1994] Heathrow Tunnel collapse," says Harper. As a result the team was conservative in its progress, advancing just 1m at a time and spraying a fibre reinforced concrete lining varying between 350 and 600mm

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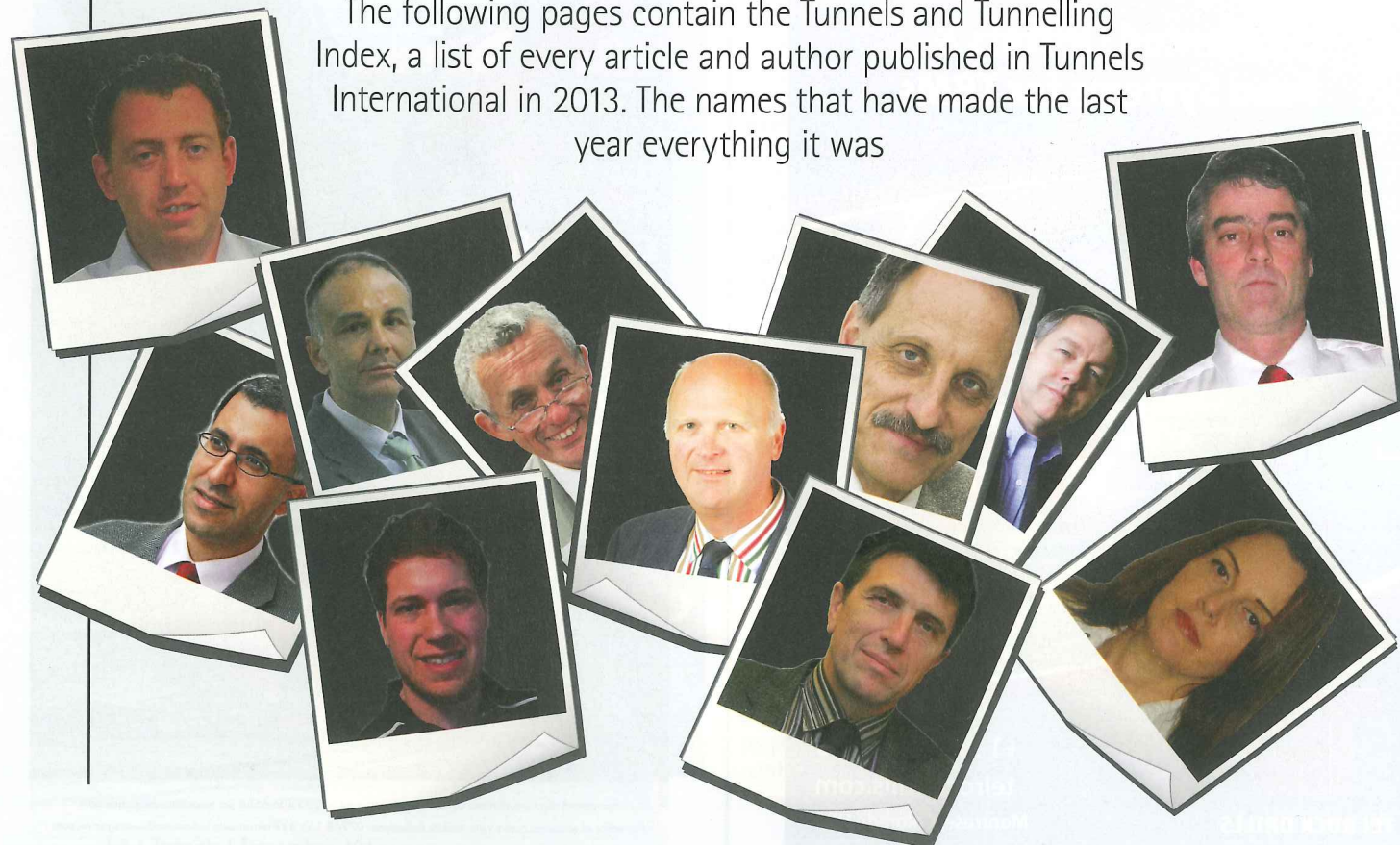
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What's on

2013

Southern Railway Link Conference
Koralmbahn and Semmering tunnels
21 November 2013
Leoben, Austria
The Southern Railway SESSION is a forum to present experiences and discuss case studies to the above tunnels major projects and other projects along the Southern Railway.
www.suedbahntagung.at/index.php

Stuva Conference
27-29 November 2013
Stuttgart, Germany
The bi-annual conferecy of the Stuva organisation heads to Stuttgart.
www.stuva.de/en

2014

Middle East Rail
4-5 February 2014
Dubai, UAE
With 82 exhibitors and attendance from nearly every regional rail operator in 2013, Middle East Rail conference and expo had more than 2,500 attendees. It's designed to help operators build and operate brand new rail infrastructure, as well as upgrading legacy networks. The event brings together rail developers, transport operators, government, contractors and suppliers to talk strategy, technology and innovation.
www.terrapiinn.com/exhibition/middle-east-rail

CONEXPO
4-8 March 2014
Las Vegas, USA
Held every three years, the exposition showcases the latest construction equipment, products, services and technologies. The show will be held at the Las Vegas convention centre.
www.conexpoconagg.com

Eurasia Rail
6-8 March 2014
Istanbul, Turkey
The Fourth International Rolling Stock, Infrastructure and Logistics Exposition features a tunnel construction section in 2014.
www.eurasiarail.eu

ISTSS
12-14 March 2014
Marseille, France
The Sixth International Symposium on Tunnel Safety and Security in Marseille, France will discuss current best practice and emerging demands and trends as well as research.
www.istss.se

World Urban Forum Seven
5-11 April 2014
Medellin, Colombia
The show for the UN-Habitat organisation. The United Nations Human Settlements Programme, UN-HABITAT, is the United Nations agency for human settlements. It is mandated by the UN General Assembly to promote socially and environmentally sustainable towns and cities with the goal of providing adequate shelter for all. This year the show visits Colombia.
www.unhabitat.org

InnoTrans
23-26 September 2014
Berlin, Germany
An international platform for buyers and sellers of passenger and freight transport technology, InnoTrans focuses on railway technology. The Tunnel Construction segment will be accompanied by International Tunnel Forum featuring a series of international discussions
www.innotrans.de

2015

World Tunnel Congress 2015
22-28 May 2015
Dubrovnik, Croatia
The jewel of the tunnelling calendar heads to the Dalmatian Coast for the technical event of 2015 as WTC returns to Europe. Many details are yet to be confirmed.
wtc2015.com

British Tunnelling Society

The BTS has a membership of almost 700 individual and 60 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. Events are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month.

Port Mann Tunnel
21 November 2013
Contingencies for a high pressure EPB tunnel under a river, presented by Steve Skelhorn.

National grid cable tunnels
19 December 2013
A report on the project, which comprises 33km of 3m and 4m diameter tunnels across London. John Tounson, National Grid Stephen Meadowcroft, Costain will present an overview of the business case for the project and details of the progress made.

Concrete & Materials Engineering and its role in underground construction
16 January 2014
This presentation will explain the fundamentals use of concrete in underground construction and highlight the demanding requirements involved with building tunnel linings. The requirements of the Client, Designer and Contractor will be discussed and examples of concrete engineering and development on projects will be illustrated. Charles Allen, CA Consult, Martin Rimes, MVB JV, and Richard Sutherden, AECOM.

World Tunnel Congress 2014
9-15 May 2014
Iguassu Falls, Brazil
Organised by the Brazilian Tunnelling Committee (CBT) of the ABMS (the Brazilian Association of Soil Mechanics and Geotechnical Engineering), as well as the International Tunnelling Association (ITA), and focusing on "Tunnels for Better Living", WTC 2014 will discuss and illustrate the importance of tunnels.
www.wtc2014.com.br

North American Tunneling Conference
22-25 June 2014
Los Angeles, California
The US Underground Construction Association (UCA)'s biennial tunnelling conferece takes place in Los Angeles, California in 2014.
www.smenet.org

Contact us

Jon Young



Editorial

Editor

Jon Young
Tel: +44 20 7406 6622
jyoung@tunnelsonline.info

Deputy Editor

Alex Conacher
Tel: +44 20 7406 6616
aconacher@tunnelsonline.info

Americas Editor

Nicole Robinson
Tel: +1 612 940 2780
nrobinson@tunnelsonline.info

Regular Contributors

Maurice Jones, Adrian Greenman,
Bernadette Ballantyne, Partick Reynolds,
Rhian Owen

Nicole Robinson



Production

Design/Editorial Production

David Cooper

Production Controller

Loraine Lee
Tel: +44 20 8269 7799
Fax: +44 20 8269 7840
llee@progressivemediagroup.com

Jim Moore



Head Office

World Market Intelligence
John Carpenter House
7 Carmelite Street
London EC4Y 0BS
United Kingdom

Tel: +44 20 7406 6622
Fax: +44 20 7936 6813

www.tunnelsonline.info
editor@tunnelsonline.info

Sales

Head of Sales

Jim Moore
Tel: +44 20 7406 6584
jmoore@tunnelsonline.info

European Sales

Randolf Krings
Tel: +49 611 5324 416
Fax: +49 611 5324 519
t&t@emcmedia.de

Classified & Recruitment

Tom Willard
Tel: +44 20 7406 6599
twillard@tunnelsonline.info

BTS - Editorial Advisory Board

Editorial Advisory Board Chairman:

Myles O'Reilly ME, PhD, CEng, FICE
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Tunnels & Tunnelling Customer Services.
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Tel: +44 (0) 845 155 1845 (local rate)
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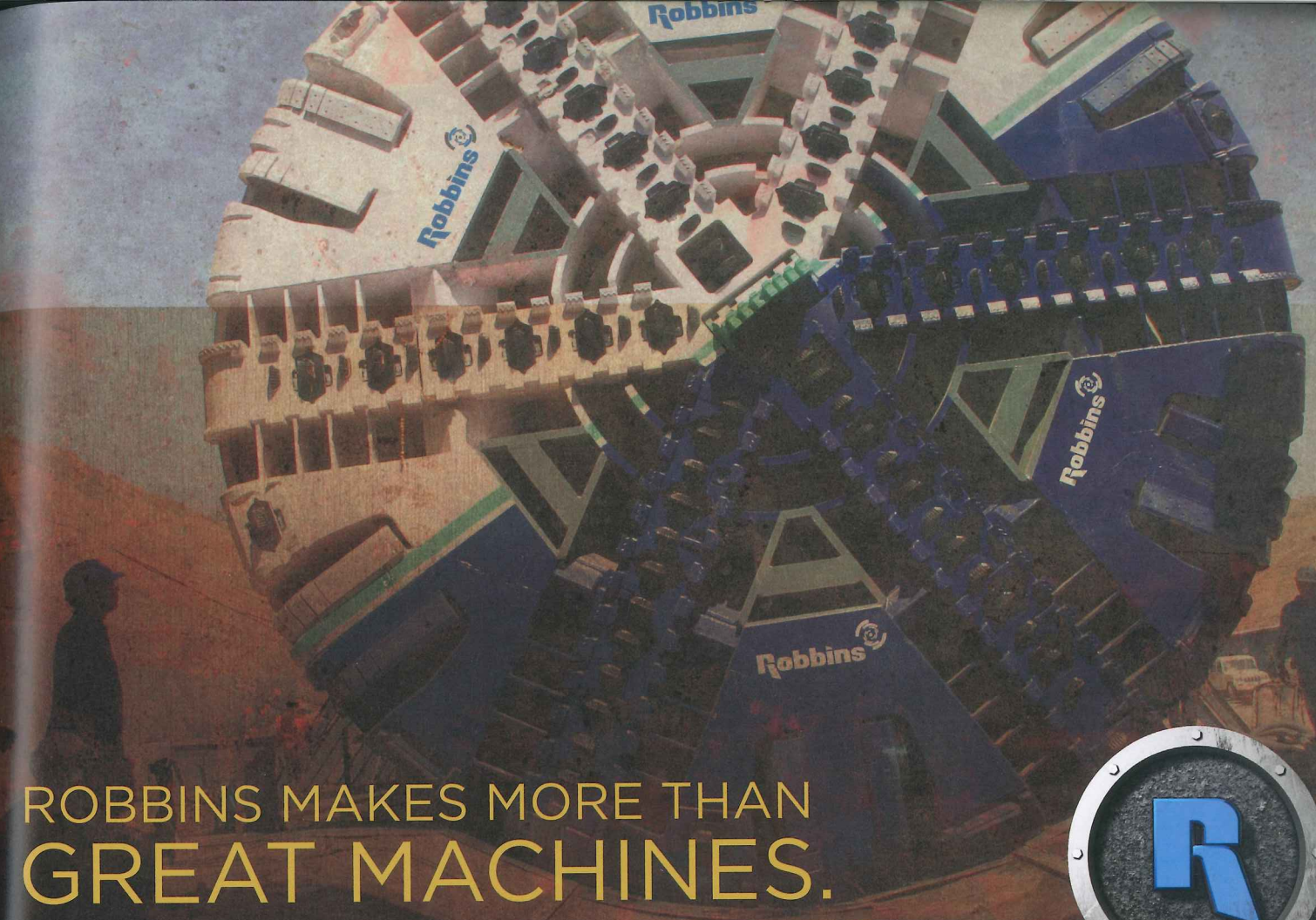
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