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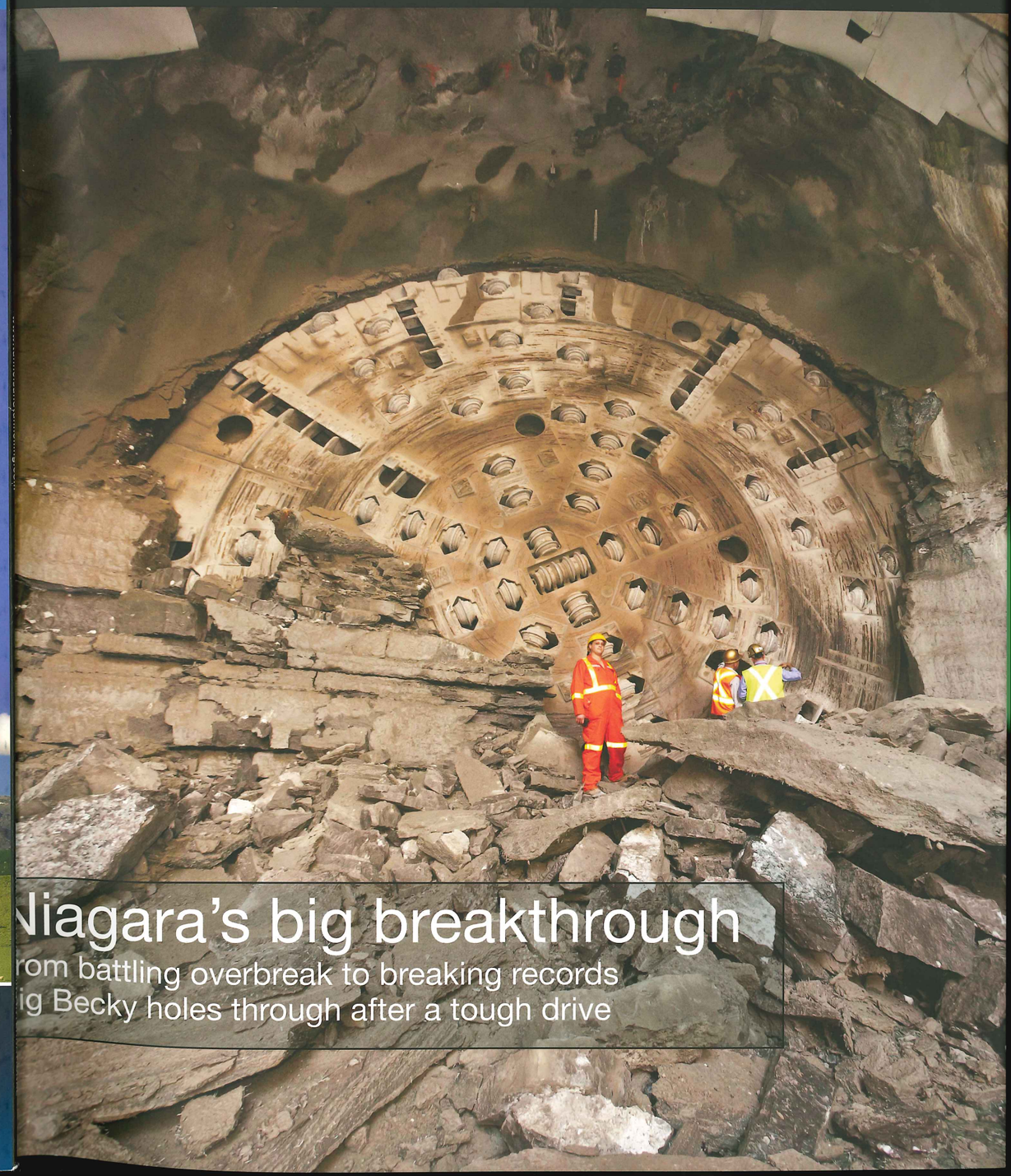
Insight: Connaught tunnel
Tunnellers set to work on the Connaught refurbishment to get it ready for Crossrail

Special report: Northeast Asia
Japan assesses earthquake tunnel damage, and Korea makes use of the underground



Niagara's big breakthrough

rom battling overbreak to breaking records
ig Becky holes through after a tough drive

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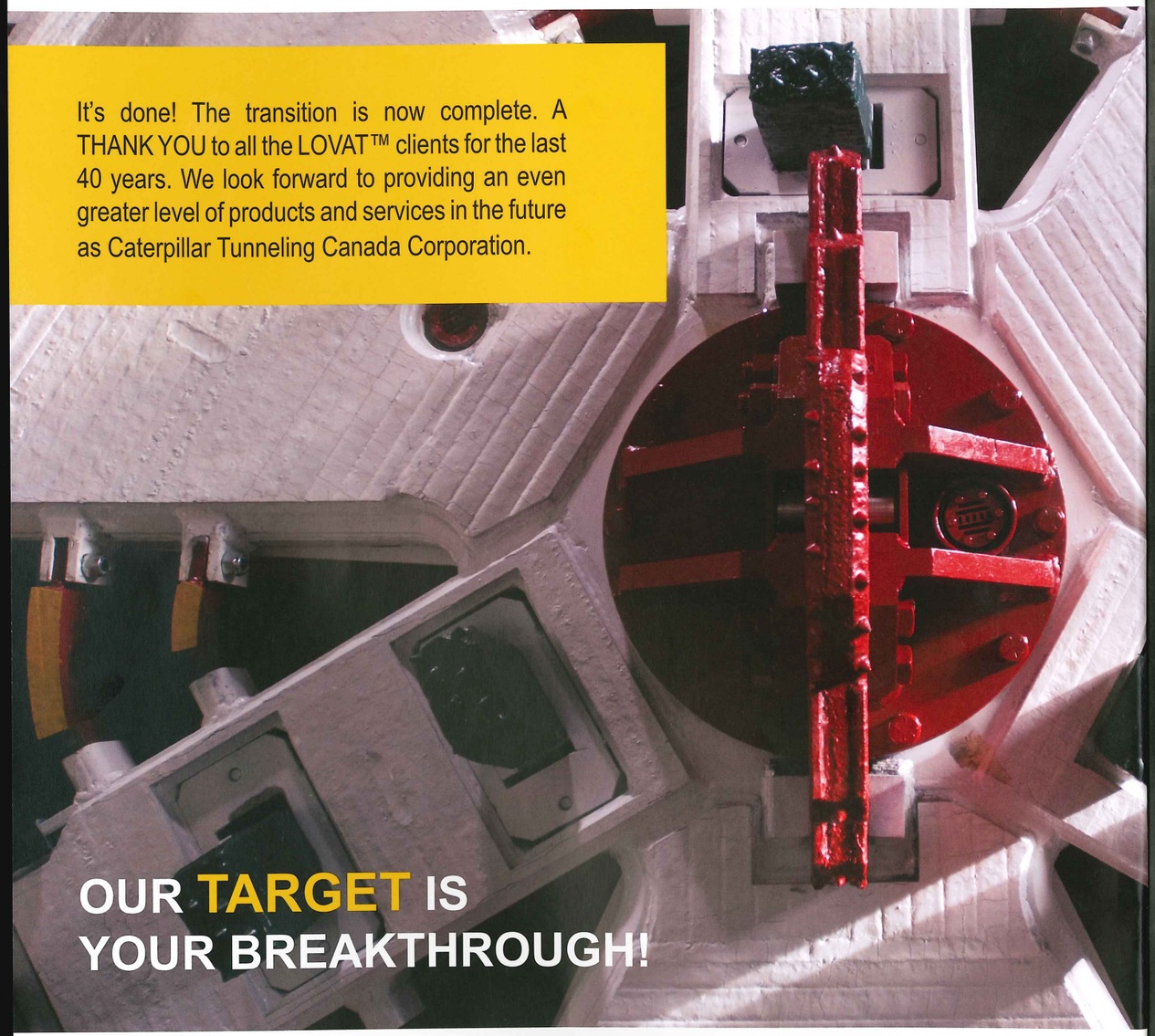

OUR TARGET IS YOUR BREAKTHROUGH!

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Standing on the shoulders of giants

Footballer Ryan Giggs and his mishandling of the fallout from his alleged love affair with reality TV non-celebrity Imogen Thomas should be a lesson to us all, as much as the growing trend for super injunctions, created by British courts, should be a warning to us.

While Giggs and other libidinous celebrities have merely been trying to cover up their misdemeanors of playing away, it should not be forgotten that super injunctions, which ban the press from even reporting their existence, have a much greater power and can be used for much more sinister ends.

The term super injunction was coined by the editor of London newspaper The Guardian Alan Rushbridger when reporting on an injunction taken by raw materials merchant Trafigura. The Trafigura injunction was taken to prevent the publication of an internal report into the 2006 Cote d'Ivoire toxic waste dump scandal. After it was referred to in a parliamentary question the injunction was amended to allow reporting of the question itself.

There is a real danger that injunctions and super injunctions will become the default position for a person or company facing possibly embarrassing or damaging publicity.

We work in an industry where often things don't go to plan; it is the nature of tunnelling that we are constantly facing the unexpected. We get it wrong and sometimes we get it very wrong. What is important is what we do next.

There is a culture of fear attached to failure. A fear that failure leads to blame and blame leads to cost and compensation. This culture must be reversed.

Transparency is the sibling of progression. It is only through studying the successes and failures of others can you truly advance the understanding of methods, materials and equipment. And the benefits are self-evident. The greater our ability to build more ambitious tunnels and the more adverse the conditions we can face, the more the industry will be called upon.

Man's greatest achievements have come off the hard work of many failed attempts. The Saturn V space rocket came after a long line of failed rockets but every failure lead to an improvement in the design and eventually culminated with man walking on the moon.

In 1881 the first exploratory tunnels were dug for the crossing of the English Channel between Great Britain and France. After numerous failed committees and two failed construction attempts, work was launched more than 100 years later in 1988 on the final and successful drives.

And holding tightly to the spirit of 'if at first you don't succeed try, try and try again' is the Hallandsas tunnel in Sweden that is making strong progress after 17 years of false starts, each time reviewing the failures of the last attempt and adjusting the plan.

If, with more powerful injunctions, we weave a larger and thicker carpet to sweep our mistakes and failures under, we will slow progress and hinder development to the detriment of the industry and all.

Sharing our successes and our failures is the only way to ensure we advance our understanding and out ability.

In the 12th Century a theologian called John of Salisbury said: "We are like dwarfs sitting on the shoulders of giants. We see more, and things that are more distant, than they did, not because our sight is superior or because we are taller than they, but because they raise us up, and by their great stature add to ours."

Jon Young

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On the cover:
The 14.4m, Big Becky breaks through after its 10.4km drive

And in the supplement:
The Herrenknecht TBM set to bore Miami's port

THREE MACHINES, TWO TUNNELS, ONE AIM: FLOOD PROTECTION IN HONG KONG.

A comprehensive flood protection program is being realized in Hong Kong in order to better control the heavy annual rains and typhoons. The program includes building huge sewage tunnels to collect the masses of rainwater and feed them safely into the sea.

The "Dragages Nishimatsu Joint Venture" relies on Herrenknecht's Double Shield technology for the construction of the "Hong Kong West Drainage Tunnel". The S-486 and S-487 sister machines with diameters of 8.28 and 7,21 meters respectively, have been driving the tunnels since April and June 2009, respectively. On January 17, 2011, breakthrough of the eleven kilometer long tunnel was achieved right on schedule. From 2012 onwards, the West Drainage Tunnel will protect the financial and business center of this huge city against flooding.

The "Lai Chi Kok Transfer Scheme" is planned for completion in 2011. Since March 2010, the "Leighton John Holland Joint Venture" has been excavating the 3.5 kilometer long tunnel with the Herrenknecht S-536 Mixshield. The 5.67 meter diameter TBM has already completed excavating work for the 2.5 kilometer branch tunnel on January 18, 2011.

In future, these tunnels will also be able to provide protection against the storm surges that occur about every 50 years. They will soon contribute significantly to Hong Kong's flood protection system.

HONG KONG I CHINA

PROJECT DATA	CONTRACTOR
S-486, S-487 **2x Double Shield TBMs** Diameter: 8,280mm, 7,210mm Cutterhead power: 3,150kW, 2,800kW Tunnel lengths: 6,640m, 4,360m Geology: granite, volcanic rock	Dragages Nishimatsu JV: Dragages Hong Kong Ltd., Nishimatsu Construction Co. Ltd.
S-536 **Mixshield** Diameter: 5,670mm Cutterhead power: 1,575kW Tunnel length: 3,484m Geology: fresh granite, granite with varying degrees of weathering	Leigthon John Holland JV: Leighton Contractors Pty. Ltd., John Holland Engineering PTY. Ltd.

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Crossrail's first six TBMs to be Herrenknecht manufactured

GREAT BRITAIN

Crossrail announced last month that six of the TBMs required for the project will be manufactured by Herrenknecht.

"To construct the 21km of twin-bored tunnel required for Crossrail, at least seven tunnel boring machines will be required," said a Crossrail spokesperson. "[The machines] will undertake ten individual tunnel drives to construct the 6m diameter rail tunnels."

A spokesperson for Herrenknecht told *T&TI* at the World Tunnel Congress last month that being given the suplly contract for Crossrail, as such a large, impressive and challenging project was more important than the number of TBMs ordered.

The first two TBMs, to be delivered in early 2012, will be launched from Royal Oak in spring on the 6.1km 'Drive X' – the Royal Oak to Farringdon western running tunnels. The second two will be delivered in mid 2012 to Limmo Peninsula for the 8.3km eastern running tunnels drive to Farringdon 'Drive Y'. The final two Herrenknecht machines will be delivered to Stepney Green in late 2012 for the 2.7km 'Drive Z' to Pudding Mill Lane.

"All of the tunnel boring machines, except for the TBM used to construct the Thames Tunnel, will be Earth Pressure Balance Machines," said the spokesperson. "These will pass through ground which is predominantly London clay, sand and gravels. The Thames Tunnel, which is predominantly constructed through chalk, will use a Slurry TBM."

The contract for the Thames Tunnel – part of the plan for the Plumstead to North Woolwich 'Drive H' of around 2.6km – had only recently been awarded as *T&TI* went to press. The TBM supplier had yet to be announced.

Many in the industry were surprised that the TBM purchases were not shared between manufacturers as for HS1.

Rail minister, Theresa Villiers said, "This is an exciting step forward for the Crossrail project, which will revolutionise rail travel in the capital."

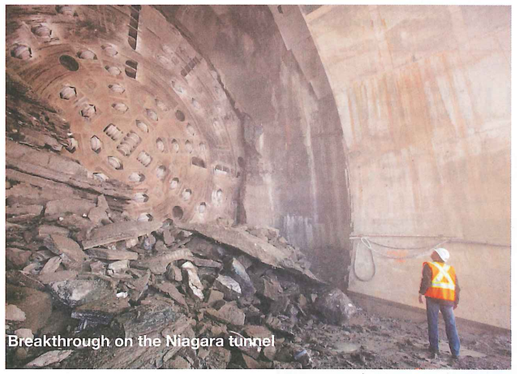
Big Becky reaches daylight

CANADA

Final breakthrough for the 14.4m diameter hard rock TBM used to bore the Niagara Tunnel near Queenston in Ontario, Canada took place last month.

While the main beam TBM has completed tunnelling, contractor Strabag still has two years of work left to complete on the 10.2km tunnel. The 12.8m- diameter finished tunnel will be fully lined with both 600mm thick continuously poured concrete and a polyolefin waterproof membrane to prevent leakage.

Immediately before Big Becky holed through the remaining rock and shotcrete of the tunnel to arrive in a 100m deep shaft,


Breakthrough on the Niagara tunnel

provincially owned client Ontario Power Generation (OPG) announced the cutterhead would be put on display in the city of Niagara as part of the project's legacy.

Big Becky was launched in summer 2006 to excavate the tunnel on behalf of OPG. This will be the third Niagara headrace.

Robert Milner wins Harding Prize 2011

GREAT BRITAIN

Robert Milner of Halcrow presented the winning paper at the BTS Harding Prize last month. Milner's paper on 'Settlement due to tunnelling on the West Ham Flood Alleviation Scheme' beat his competitors from Austria and Greece.

Runner up Spyridon Konstantis of Arup presented his paper on 'Probalistic assessment of face stability conditions for shallow tunnels in soft ground' and Andreas Feiersinger of Dr. Sauer & Partners presented his paper on 'Comparison of deformations predicted using 3D finite element analysis with deformations encountered during construction', with a focus on London's Green Park Station.

Questions from the audience followed before the judges announced the winner. See page 48 for Milner's paper.

News in brief

TTC begins Spadina subway soil testing
The Toronto Transit Commission announced that soil testing and monitoring for potentially hazardous gases has begun on the Toronto-York Spadina Subway Extension project.

Adelaide to take first water in July
The intake and outfall tunnels for Adelaide's USD 2bn desalination plant in Australia have been completed and first water is expected at the end of July, said Paul Caica, South Australia minister for water.

WTC 2014: Sao Paulo
The Brazillian bid for WTC 2014 beat tough competition from Singapore and Australia. The vote took place at WTC Helsinki last month.

John Holland to deliver Singapore DTL3 station
John Holland announced last month that it had been awarded the USD 139.69M contract to construct the Sungei Road Station and associated works.

Living and breathing with tunnels at WTC Helsinki

FINLAND

International Tunnelling Association (ITA) president In-Mo Lee kicked off proceedings at the press conference at World Tunnel Congress (WTC) Helsinki last month by looking at a new worldwide trend, to 'really breathe' and 'live life'.

"Greenfield sites on the surface can only be maintained by putting structures and infrastructure underground," said Lee. "In Seoul, we are putting as much infrastructure underground as possible to keep the surface green and improve quality of life."

Finnish Tunnelling Association (FTA) president and chair of the WTC 2011 steering committee Pekka Sarkka said that it is necessary to change this perception of dark and dusty underground environments to make them more desirable, though he and J B M (Han) Admiraal, chair of the ITA steering group of the Committee on Underground Space (ITACUS), both agreed that the public is generally enthusiastic and interested in underground development. In Britain, the popularity of the recent tours of the A3 Hindhead tunnel showed this.

Sarkka and Admiraal spoke about the need to end a '2D mentality' in city planning.

"China thinks four stories down as well as however high they go," said Admiraal. "This is a lesson to be learned. It is unique to be in Helsinki, the only city in the world to have actually thought about, reserved and planned the use of its underground space. Helsinki is to be congratulated.

"According to UN-HABITAT, some 70 per cent of the world's population will be living in cities by 2050. This means the equivalent of everyone alive on the planet today, living in cities. We have an obligation to contribute with our knowledge to help the growing problems of cities."

Admiraal hit on the need for enhanced disaster protection, as well as infrastucture. Flood defences in the form of underground sewer works, would be needed for people to continue enjoying life in the cities.

"Madrid diverted part of its M30 motorway underground and freed around 1M sqm of land that was given back to the city as green space to improve quality of life."

Strabag buys Aker Wirth shield machines for Koralm

Left: Wayss & Freytag and Granit boring Koralm Tunnel section one

AUSTRIA

Aker Wirth last month won a contract to supply the two telescopic shield machines for the 32.5km Koralm tunnel in Austria, part of the high-speed rail link between Austrian cities Graz and Klagenfurt.

Each machine has a 9.93m diameter and will be used at the approximately 20km long KAT 2 section of the tunnel, starting in October 2012.

The cutter head is driven by electric motors with an overall power rating of 4,800kW and the maximum cutting torque is 30,000kNm, according to a spokesperson for Aker Wirth.

"We have continually strengthened our technological leadership, in particular in hard rock," said Christoph Kleuters, Aker Wirth CEO.

TBM back-ups will be delivered and constructed by Switzerland-based Rowa Tunnelling Logistics.

The entire tunnelling set up is around 160m long.

Koralm will comprise two parallel single-track tunnel tubes, the only access to the work areas is by a 60m deep shaft.

News in brief

Shinagawa excavation rate smashes target
Excavation rates on the tunnel portion of the Shinagawa section of the Central Circular Route of the Tokyo Metropolitan Expressway in Japan hit 550m in April, a Metropolitan Expressway spokesperson told *T&TI* this month. This exceeded the already high target rate of 400m per month.

NSW M2 tunnel widening will pay dividends
The Norfolk tunnel in New South Wales, Australia will be widened to eight lanes, allowing three traffic lanes and one hard shoulder in each direction. "This USD 588.94M project will deliver over USD 1.82bn in returns to New South Wales," said Mark Birrell, chairman of advocacy group Infrastructure Partnerships Australia (IPA).

MTR awards Leighton
Leighton Asia announced last month that it had been awarded two contracts by MTR Corporation for construction of the new 7km-long South Island Line East in Hong Kong. Work included 1.1km of tunnels and two underground stations to be dug by cut and cover.

Fehmarnbelt elements sourced from Rodbyhavn
At a Board meeting last month, Femern recommended to the Danish Minister for Transport that Rodbyhavn, Denmark be used as the production site for tunnel elements for the Fixed Link.

Part of Alaskan Way referendum to go to voters
A judge ruled last month that part of a referendum blocking construction of the Alaskan Way replacement can go to voters of Seattle this August.

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Tunnelling gets underway on Bangalore's first metro project

INDIA

Tunnelling was launched last month on Bangalore's east-west metro line. An official launching ceremony was held at the Majestic Station work site in the centre of Bangalore that contains the TBM launch shaft and will later form the interchange station for the east-west and north-south metro lines.

Launching the TBM is a momentous achievement as it is the first to be used a South Indian state and, according to Karnataka Chief Minister Shri Yeddyurappa, it is the first slurry TBM to be used in the country.

Taiwanese contractor Continental Engineering Corporation (CEC) is carrying out the tunnelling works and Indian contractor Soma is excavating the stations. The twin bore tunnels will have an internal diameter of 5.6m and will be lined with precast segments manufactured by Ya Li, part of Far Eastern Group.

The 6.44m diameter Hitachi Zosen TBM called Helen is expected to begin boring in the next 10 days and will launch eastwards on an approximate 1km drive to Central College Station. The TBM will leap frog over the station and relaunch on the 727m drive to Vidhana Soudha Station. It will be dragged through this station and continue on the 479m drive to Cricket Stadium Station. The TBM will finally be dismantled and relaunched from the west shaft of Majestic Station and complete the 227m drive to City Railway Station.

The tunnels will bore through mixed ground with a granite rock head of up to 300MPa UCS dipping in and out of the face.

Project manager for CEC Russell Brown said the first 140m of the drive would be among the most testing, as the shallow tunnels with an overburden of just 1.5 diameters will pass under fragile buildings. Settlement will be reduced by using a thick slurry developed by Ian Morrisson of Mudtech.

Helen will be followed on its drives by its sister TBM Margarita with a four-week and 50-100m long stagger.

Above: The TBM was the first to be used in a South Indian state

British Tunnelling Society Annual Dinner 2011

GREAT BRITAIN

As the collective hangover of the *T&TI* editorial team begins to vanish, and we delicately peel business cards out of eyelids and discover receipts in pockets we didn't know we had, the memory of the 2011 BTS Annual Dinner returns.

The British 'tunnelling elite' as Sandi Toksvig – the comedian, writer and broadcaster chosen as the after dinner speaker – put it, gathered last month for the traditional dinner at the Brewery on Chiswell Street in London.

Speaking after the meal, society chairman Bob Ibell praised the past work of the BTS given its 40th anniversary this year, and looked to the future, making a special mention of the recently founded BTS Young Members and the unprecedented opportunity for continuous tunnel work in the UK.

T&TI covered the formation of the BTS in 1971 and has been the official magazine of the British Tunnelling Society and tunnellers worldwide ever since.

As always the editorial team was there in force and would again like to thank our friends in the industry for helping us to prop up the bar, again, as always.

Kandahar prison break claims expertise

AFGHANISTAN

Taliban spokesman Zabiullah Mujahid announced last month that the tunnel used for the breakout at Sarposa Prison, just outside Kandahar, Afghanistan on 24 April benefited from expert consultancy.

Tunnel works began in a house to the southwest of the prison some five months ago and emerged in the correct prison cell for the escape, said Mujahid.

The tunnel opening was 1m in diameter. From the cell it dropped immediately down 1.5m before running to the compound some 360m away.

According to Mujahid, muck disposal posed a particular problem, "We had proper digging equipment. There was so much earth from the tunnel that we carried it away gradually and sold it in the market."

"The house where the tunnel was found was searched by security forces two-and-a-half months ago," said Afghan justice minister Habibullah Ghaleb. "Earth or soil dug out of the tunnel must have been moved and should not have been missed by security forces."

Around 470 of the 1,200 prisoners escaped during the operation. Three militants within the prison were aware of the plan and woke prisoners a handful at a time to make their escape. Prison officials said they became aware of the tunnel at 4am, after the breakout had taken place.

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Land Transport Authority awards DTL3 contracts

SINGAPORE

The Singapore Land Transport Authority (LTA) awarded two contracts for construction work on the Downtown Line Stage Three project on 29 April. The contracts, C931 and C936, were valued at SGD 188M (USD 152.91M) and SGD 177.58M (USD 144.43M).

Contract 931, awarded to Hyundai Engineering & Construction Co., covered construction of MacPherson station and associated tunnelling works. MacPherson station will link DTL3 to the Circle Line. Contract 936 was awarded to Sato Kogyo for construction of Bencoolen station. Work was scheduled to commence in Q2 2011 with completion in 2017.

"Hyundai has extensive experience building rail projects in Singapore and Korea," said an LTA spokesperson. "They have worked on several rail projects including the construction of several North East Line stations."

Above: MacPherson Station will provide a connection between the Circle Line and the Downtown Line.

Final breakthrough at A Luoi on Vietnam's longest tunnel

VIETNAM

Cavico announced last month that its subsidiary, Cavico Bridge and Tunnel, had broken through the final section of the main headrace tunnel on the A Luoi hydropower project.

Excavation of the 8.7 mile (14km), 21.3ft (6.49m) diameter tunnel was a major part of the USD 53M contract.

Cavico was awarded a contract to excavate a 12km long, 5m wide headrace tunnel in July 2007. The company was also contracted to excavate four sub-tunnels, a surge tank, a vertical shaft and a service access road.

"We are very pleased to complete the tunnel construction at the A Luoi plant," said Hung Manh Tran, Cavico's executive vice president. "This achievement is the result of many months of dedication and hard work by Cavico's employees. "Additionally, this breakthrough represents a major step toward completing our role in the A Luoi project."

Marti to construct safety gallery on Milchbuck road tunnel

SWITZERLAND

Marti announced last month that it had been awarded the CHF 25M (USD 28.22M) contract to build the safety gallery of the Milchbuck road tunnel, near the University of Zurich in Switzerland, with work set to begin this month. Construction should take nearly three years, finishing in 2013.

The project is part of works in progress since 2003 to make the heavily used tunnel comply with modern safety standards. The safety gallery will run for 1,380m, parallel to the main tunnel and lie between six and 40m below the surface.

Marti will use two excavation methods, said a spokesperson. "A TBM with a diameter of 4.15m will make its way from the north through a solid rock section of approximately 1km.

"From the South, the approximately 400m-long, loose rock section is being excavated beneath a jet grouted umbrella.

"Beneath the reinforced crown, the working face is being mined metre by metre with a tunnel excavator and the resulting roof supported with steel arches and shotcrete."

Five cross connections to the main tunnel will be excavated after the primary works.

News in brief

Roadheader work wraps up on Airport Link
The last of 17 roadheaders has finished excavation on Brisbane's Airport Link. With more than 10km of the 15km of tunnelling completed only two TBMs remain on site. Brisconnections reports the remaining excavation is 70 per cent completed, and anticipates both of the machines will finish their 2.5km drives this year.

Mexican army spots smuggling tunnel
Troops in San Luis Rio Colorado, Mexico, found the start of a tunnel being constructed to cross under the border with the U.S., on 5 May. The tunnel measured approximately 5m deep and 1.9m in diameter.

Channel Tunnel could house 75km ElecLink
Groupe Eurotunnel and STAR Capital Partners have established a joint venture to develop an electricity interconnector between the UK and France. The project, estimated to cost EUR 250M (USD 353M), would see twin 100mm diameter, High Voltage Direct Current cables run hrough the Channel Tunnel's service tunnel.

DOT distributes Florida's high-speed rail funds
Some USD 2bn has been reassigned to 15 states and Amtrak for 22 high-speed rail projects. Florida's republican governor, Rick Scott, turned the money down. The U.S. Department of Transportation (DOT) awarded the largest sum, USD 795M, for upgrades in the Northeast corridor. California, which is leading the way for the nation's first 220-mph high-speed rail system. The project will receive another USD 300M.

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Lemminkainen awarded Helsinki's Koivusaari excavation project

FINLAND

Finnish contractor Lemminkainen announced last month that it was awarded the EUR 22M (USD 32.75M) construction contact for the Koivusaari section of the Helsinki West Metro in Finland. The contract covered excavation of the Koivusaari station and Katajaharju shaft as well as a 2km tunnel from the shaft to the border of the neighbouring city, Espoo, on Helsinki's western border.

The metro will be partially built under the sea. The plan included an emphasis on technically challenging dredging works for the foundation and construction of a blasted rock embankment in the sea.

Rock quality in bordering Otaniemi, a southeastern district of Espoo, varies generally between good and poor (Q-classification) with limited zones of very poor rock, according to a spokesperson for Poyry, a designer on the West Metro project.

"This challenging project provides an excellent opportunity for us to combine Lemminkainen's strengths in both rock engineering and foundation engineering," said Risto Kupila, vice president, rock engineering, at Lemminkainen.

Excavation was scheduled to begin in June. The metro tunnel and station should be completed in early 2012.

Above: Lanismetro woking on the Helsinki West Metro. Photo copyright Lanismetro

News in brief

Seattle starts U-Link extension excavation
Two Herrenknecht TBMs have been launched to mine twin bore tunnels for the University Link light rail extension from the University of Washington to Seattle's downtown. The USD 2bn project will see a third Hitachi-Zosen TBM complete another leg of the 3.15-mile (5km) extension. Excavation rates of 44ft (13.4m) to 50ft (15.2m) per day are expected on average.

South Australia sets price on suburban tunnel
As part of its Bowden Urban Village project just outside Adelaide, a transportation oriented development, the South Australia government estimates the 1km tunnel and underground station would cost approximately AUD 418M (USD 442.6). The project would require both state and federal support in order to move forward.

Fehmarnbelt soil documented

DENMARK

Government-owned planning body for the Fehmarnbelt Fixed Link, Femern, announced last month that the soil documentation for the link project had been completed.

"There are no geological or geotechnical obstacles to constructing a fixed link in the area," said Jens Kammer, geotechnical manager at Femern.

"The result of our studies is largely as we had expected based on the previous feasibility studies of the 1990s. However, we have now ascertained that the clay layers close to the coastal regions have been disturbed more by the glaciers of the ice age than previously assumed."

"By the Danish coast, this so-called palaeogenic layer of clay is placed so deeply that it will not be affected by the pending construction work. However, by the German coast, earthworks will occur in the palaeogenic clay layer because the layer is very close to the seabed in this area.

"To obtain further geotechnical information and practical experience with work in this specific type of clay layer, Femern has established a special test field off the German coast. Experiments to measure and observe movements in the earth under various conditions of stress are currently conducted here, and will be continued in the coming years.

"The geotechnical knowledge that we have today is sufficiently detailed for experts to create a full picture of the geological conditions of Fehmarnbelt. Therefore, any interested construction companies can begin to work on the available data even now, so they are well prepared when the construction work is put out to tender in the coming years."

The full report was made available by Femern at the project's webiste: http://www.femern.com/Home/Publications

Algeria East-West Highway project breakthrough

ALGERIA

Cavico last month announced that it had broken through on one of the tunnels in the T1 section of the Algeria East-West Highway project. The drive stretches for 1.19miles (1.92km) with a 31.17ft (9.5m) width.

Cavico won the USD 2.4M contract to supply skilled workers in July 2007 and has since sent around 500 workers to the project. The contract is based on monthly completion rates and man hours worked. The overall design-build contract for the 248-mile (399.12km) east section of the highway was awarded in September 2006 to the Cojaal JV of Itochu, Kajima, Taisei, Hazama and Nishimatsu.

Following the announcement, Cavico said it will begin to work on the second tunnel, which should be completed in 2012.

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Leighton finalises strategic India subsidiary sale

INDIA

Leighton Holdings last month announced that it had finalised the sale of a 35 per cent stake of the operations of its subsidiary, Leighton India, to Welspun Group. The deal was announced in December.

"We will build a strategic partnership with Welspun that can capitalise on the enormous opportunities that are emerging in the Indian infrastructure sector," said David Stewart, Leighton Holdings chief executive. "The strategic partnership combines Leighton's international construction capability and Welspun's significant local market knowledge, a pipeline of construction work and preparedness to invest in infrastructure projects.

"For Leighton, partnering with a local partner clearly provides greater access to the market and is a strategic move which aims to capitalise on the many concessions based projects - which have similar characteristics to PPP's - and infrastructure opportunities that are emerging in India. The Indian government is planning to spend USD 1000bn on infrastructure projects during the XII Plan between 2012 and 2017, which should offer a wide range of projects for the new partnership."

Putzmeister partnership begins in Spain

SPAIN

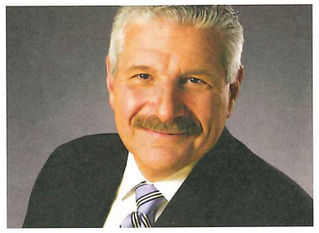
Shotcreting equipment supplier Putzmeister announced last month that it had reached an agreement with GHH & Mine Master, a distributor of drilling and earth removal equipment, for the distribution and service of drilling jumbos, bolting rigs and load haul dumpers. Putzmeister said this would complement its business.

The new understanding will begin with the distribution of GHH & Mine Master machinery in Spain via Putzmeister, where its Underground Concreting Division is headquartered in Madrid. A spokesperson for Putzmeister said that it might be the starting point for a possible global cooperation.

"Through this mutual complementation of the product range the companies broaden the product offering around the tunnelling process," said the spokesperson. "This results in synergy effects for customers of the Iberian Peninsular. Equipment and service solutions for all working stages can now be obtained from one source."

Aecom appoints new chairman of board

USA



Aecom announced last month that John Dionisio will succeed Richard Newman as chairman of the board of directors, effective from 1 October. Dionisio joined Aecom in 1971 and has been Aecom president and CEO since 2005, the latter being a role he will retain in his new position.

"On behalf of the Aecom Board of Directors, I am pleased to announce John's appointment as chairman," said Newman. "As our president and CEO, he has successfully advanced Aecom's growth strategy - significantly expanding our service offerings and markets, growing our global footprint and delivering superior business results."

During Dionisio's tenure as president, Aecom reported a period of growth. It increased annual gross revenue from USD 2.4bn to approximately USD 7bn and increased its workforce from nearly 28,000 to approximately 45,000 employees.

News in brief

Tutor Perini sees reduced Q1 results
Revenues from construction operations were USD 615.3M for the first quarter of 2011, as compared to USD 865.1M for the first quarter of 2010. Net income was USD 6.9M for the first quarter of 2011, as compared to USD 20.9M for the first quarter of 2010.

Leighton director
The Board of Leighton Holdings Limited announced last month that Dr Frank Stieler, currently chairman of the Executive Board of Hochtief has been appointed as a non-executive director of the Company

Lemminkainen enjoys bumper Q1 results
Q1 net sales were up 14 per cent and amounted to EUR 316.3M (USD 454.62M). The order book at the end of Q1 amounted to EUR 1.48bn (USD 2.12bn). Year on year growth stood at 14 per cent.

Becker joins Atlas Copco
Scott Becker has been appointed to the Baltimore surface drilling equipment sales team at Atlas Copco. Becker has worked in the construction equipment industry since 1995, and five years in the drilling sector. "This made him a perfect fit," said Atlas Copco branch manager Edward Hullet.

PB adds to Los Angeles office

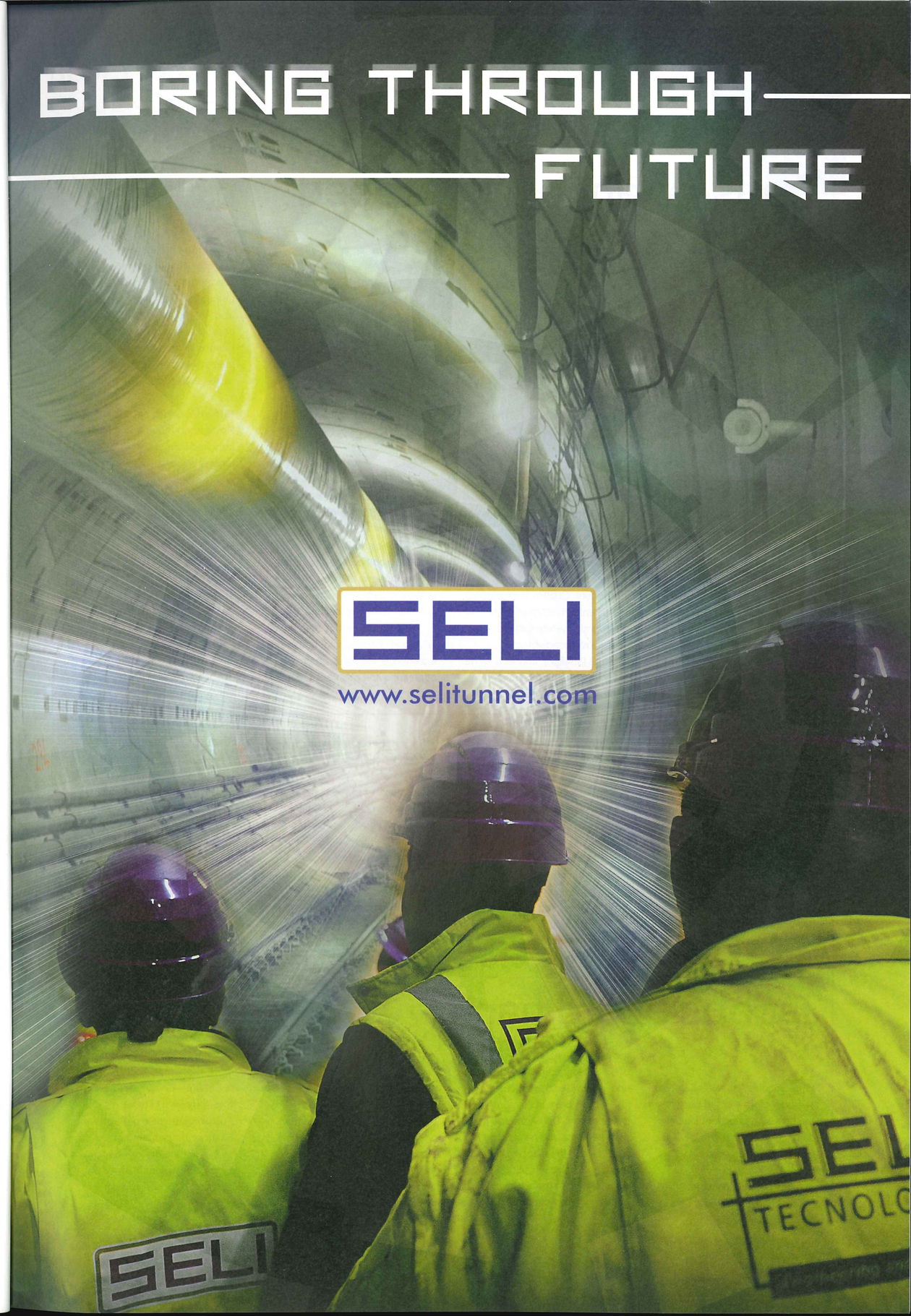
USA

Parsons Brinckerhoff announced last month that it had made two new hires at its Los Angeles office.

Dirk Braxton, a lead mechanical engineer, and Douglas Conyers, a senior supervising engineer joined Parsons last month.

Braxton will be responsible for mechanical designs for the Los Angeles Metro's Westside Subway Extension project. He has been working with the Metropolitan Transportation Authority in New York City for 23 years, most recently serving as a project mechanical engineer within the Parsons Capital Program Management department.

Conyers has 25 years of experience in the design of transportation infrastructure and has worked on numerous transit and airport projects throughout Southern California. He will be responsible for design work on a segment of the new Exposition Light Rail project in Los Angeles.



Trans-Atlantic high-speed rail agreement signed…

USA

United Kingdom Trade & Investment and the California High-Speed Rail Authority (CHSRA) board signed a cooperative agreement last month to exchange high-speed rail planning, design and operation information.

The UK is the ninth country with which CHSRA has this type of partnership. The others are South Korea, Belgium, China, France, Germany, Italy, Japan and Spain.

Curt Pringle, chairman of the CHSRA board of directors said, "This gives us an opportunity to look to their real-world experience and the economic advantages they enjoy as a result of their system as we continue pursuing California's project, the first true high-speed rail in the United States."

The agreement will help UK companies benefit from California's high-speed rail project, said Lord Steven Green, Minister of State for UK Trade & Investment. CHSRA is developing an 800-mile (1287.5km) high-speed train system that will operate at speeds of up to 220mph (354kph), connecting the state's major urban centers, including the Bay Area, Fresno, Los Angeles and San Diego.

"British companies have much to offer in terms of their expertise in the low carbon infrastructure and high speed rail sectors."

The authority said agreements have been beneficial for gathering experience, feedback on proposed operations and maintenance plans and impact mitigation efforts.

Above: The agreement will see cooperation on HSR planning

…As Parsons hires HSR executive

USA

Kevin Thibault joined Parsons as vice president and market development manager for state transportation programs in the United States last month.

He will be responsible for developing Parsons' relationships in strategic markets as well as other transportation initiatives.

Prior to joining Parsons Thibault was the executive director for the Florida Rail Enterprise, a unit within the Florida Department of Transportation responsible for implementing the state's high-speed rail program.

"We are excited that Kevin has joined the Parsons team," said Tom Barron, president of Parsons. "He is a well-respected professional whose proven leadership skills and experience in Florida will help us strengthen our business throughout the country."

Thibault is a registered professional engineer in Florida and Massachusetts. He holds a degree in civil engineering from the University of Massachusetts Dartmouth in North Dartmouth, Massachusetts, US.

Jacobs board names CEO

AUSTRALIA

The Jacobs Associates board of directors elected current executive vice president Daniel Adams as president and CEO, positions currently held by William Edgerton.

Adams will be the sixth president of Jacobs Associates in the firm's 57-year history. The bulk of his 22-year career has been in underground construction.

"For this point in the company's development, Dan Adams is the right person at the helm, and I'm glad to pass the baton to him at this time," Edgerton said. "His commitment to the advancement of the underground industry will be critical to Jacobs Associates' continued success over the coming years."

Edgerton will assume the position of the board's chairman.

Adams joined Jacobs Associates in November 1995, was elected to the board in 2000 and has served as executive vice president since 2010.

News in brief

Leighton movement
Leighton Holdings announced last month that Dr Herbert Lutkestratkotter had resigned from the board of the company as a result of his retirement as chairman of the executive board of Leighton's major shareholder, Hochtief.

Poyry's Swiss expansion
Poyry announced that it had acquired Paul Keller Ingenieure, a specialised engineering consultancy company for the provision of electrical engineering and consultancy services.

FCC Q1 profit report
FCC reported a profit of EUR 40.5M (USD 58.17M) in Q1 2011, an improvement of 9.8 per cent on the same period in the previous year.

Shorter, easier winter leaves Strabag strong
Strabag generated an output volume of EUR 2.31bn USD 3.32bn in the first quarter of 2011, which corresponded to an increase of 26 per cent. CEO Hans Peter Haselsteiner said the less severe winter this year meant construction began earlier than in 2010.

Devico staffing and capacity growth
Devico announced last month that it had increased the number of technicians it employs. "We have the capacity to take new projects and is ready to support the Scandinavian mining industry with their expertise in cost effective exploration drilling," said a Devico spokesperson.

Bilfinger Berger sees future opportunities
Following the sale of Valemus, Bilfinger Berger announced that it has the opportunity for future investment in its services business segment.

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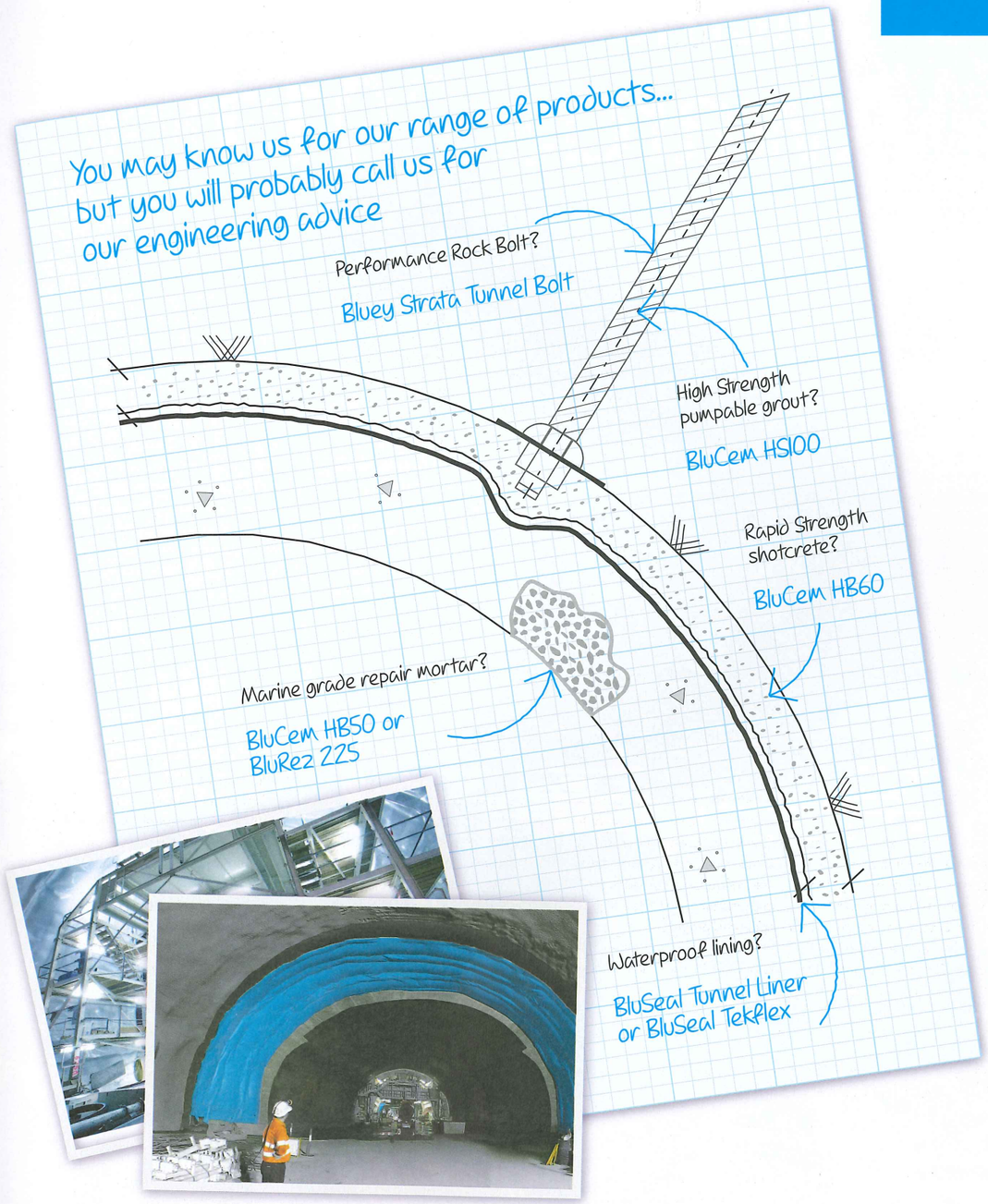

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T&T International Awards 2011

We are proud to announce the launch of the *T&T* International Awards 2011, which promises to champion the industry's best efforts, greatest achievements and most impressive recoveries.

The awards aim to identify and applaud those that go above and beyond the call of duty to meet the testing demands of clients, budgets, schedule, geology and scope.

It is our pledge that these awards will not be a backslapping exercise for sponsors and supporters but instead will stand as a testament to the true achievements of tunnellers and an opportunity for others to learn from them.

The entry criteria will be published on our website: www.tunnelsandtunnelling.com along with a complete list of the judging panels.

Over the coming months we will be seeking entries that demonstrate ground breaking achievements, as well as innovative use of new and existing technologies, methods, equipment and practices.

The judging panels are in the process of being pulled together from the most experienced professionals and unbiased representatives of committees, societies and institutions.

The event will be held on Wednesday 7 December 2011 in Berlin, Germany. Shortlisted entries will be announced on 1 November and the list published in the November issue of *T&TI*.

A special awards supplement will be printed and distributed in Berlin and with the December issue of *T&TI*. The supplement will announce the award winners and also take a look at all of the shortlisted submissions.

All award entries are completely free of charge.

We hope you get involved by nominating your projects and colleagues for awards, by supporting the event and by joining us in Berlin!

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The awards

Category One: OVERCOMING ADVERSITY

- **Foresight Award:**

For the early identification and mitigation of a problem in design or construction

- **Endurance Award:**

For completing a project in the face of numerous or persistent challenges

- **Tour de Force Award:**

For successfully overcoming the greatest single challenge

Category Two: SUSTAINABILITY

- **Investor in Tunnellers Award:**

For services to the education of tunnellers

- **Preservation Award:**

For tunnelling with the lowest impact on the environment through design or construction methods

- **Lifetime Service to the Industry Medal:**

For devotion and selfless service to tunnelling

Category Three: INNOVATION

- **Innovative use of Materials:**

For the successful use of materials in unusual deployments

- **Innovative use of Equipment:**

For the successful use of equipment in unconventional deployments

- **Innovative use of Instrumentation:**

For the successful unusual use of instrumentation in site investigation, surveying or monitoring

Don't forget...

...to enter the 2011 *T&T* Photo Competition!

With the launch of the *T&T* International Awards 2011 the photo competition has been given an extension with entries being accepted until 1st October.

The final three shortlisted entries will be given a seat at the *T&T* table in Berlin and the winner will be presented with an all singing and all dancing digital SLR.

So get snapping and send in the image that best captures the tunnelling spirit.

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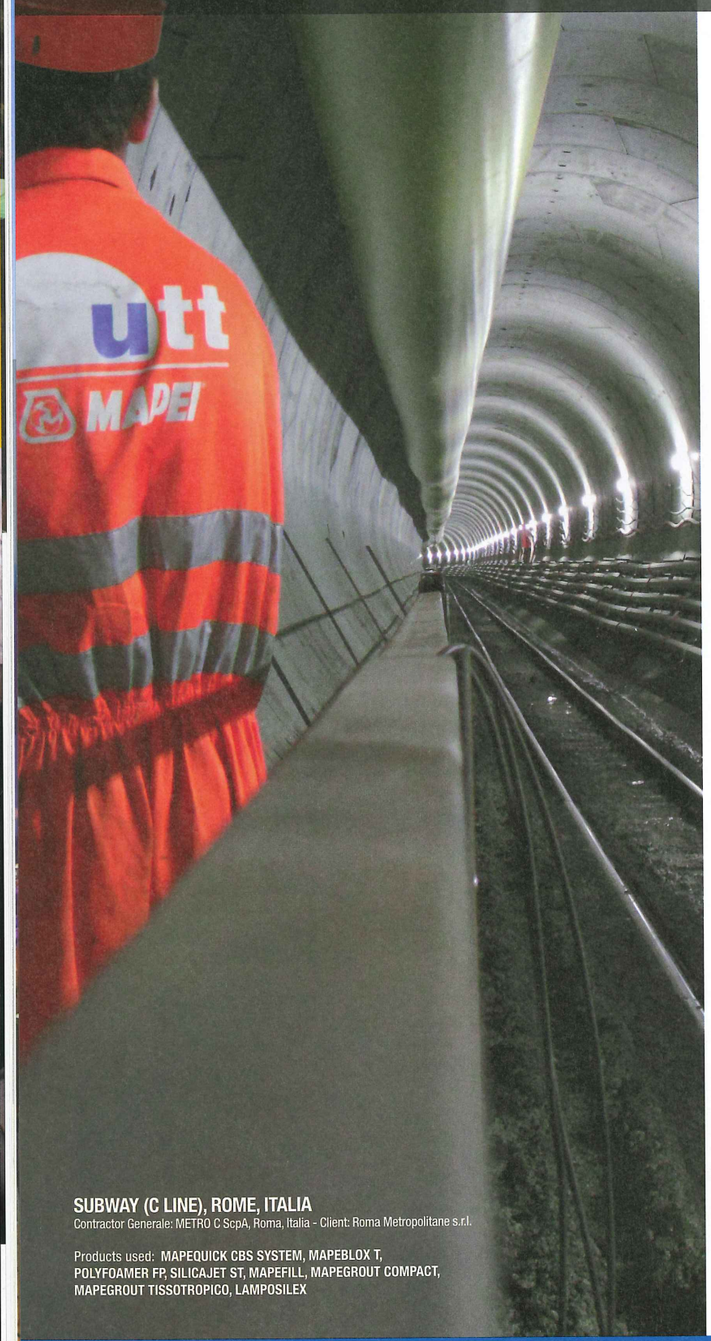
Underground Construction



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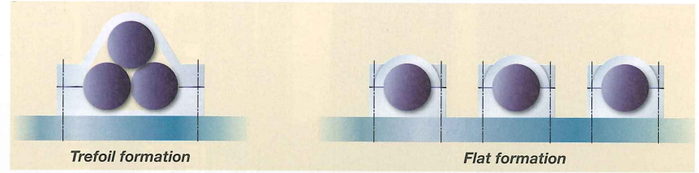
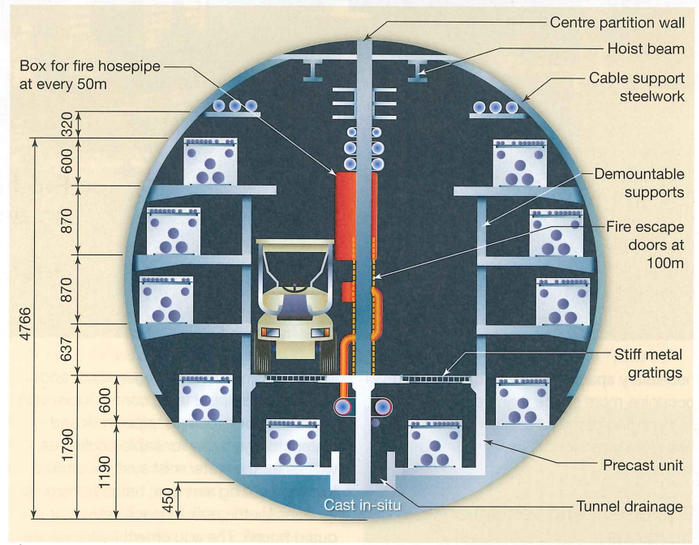
Singapore's cable tunnels

Contractors hoping to construct Singapore's planned cable tunnels are going to face highly variable ground conditions, very hard rock and some deep bores. Leslie Pakianathan of designer Mott MacDonald describes the plans and challenges

In order to renew the existing aged extra high voltage (EHV) transmission cable network as well as expand and enhance the power supplies to the central and southern parts of Singapore, SP PowerAssets is embarking on a major tunnel infrastructure construction programme. The tunnels will enable progressive installation of EHV cables and facilitate future maintenance or replacement of the cables with relative ease. The tunnels are of 6m internal diameter and approximately 35km long. They are planned for a 100-year design life with provision for 10 EHV circuit cables will enter and exit at the termination points as well at various shaft locations along the route to maximise usage of the tunnels.





Top: **Figure 1, transmission cable formations for a typical circuit;** Above: **Figure 2, typical cross section of the cable tunnel**

Tunnel design

Tunnel and shaft layout arrangements have been developed to accommodate the different types of cables and circuit configurations. The internal space is sized to accommodate both oil-filled and XLPE (cross linked polyethylene) cables and joints within the tunnel.

The cable tunnel itself is separated along its entire length into two fire rated compartments together with fire rated emergency escape doors at 100m intervals. The partitioning continues all the way up the shaft and into the shaft top buildings. This will prevent any potential fault in a circuit in one compartment affecting circuits in the other compartment, which could result in major supply interruption. The need for segregation of circuits and the provision of emergency escapes in the long tunnel is a key consideration in designing the cable layout. The tunnel diameter is determined such that it can accommodate the required number of cable circuits, provide space for a maintenance vehicle in one compartment and accommodate all mechanical and electrical (M&E) services. The maintenance vehicle is meant for four passengers and transportation of tools and minor spares. It is battery-powered and will run on top of the walls of the invert cable trough guided on either side by fixed guide plates.

EHV power transmission cables could be installed in flat or trefoil formation in the tunnel (see figure 1). Flat formation with the

necessary spacing between cables occupies more space than trefoil formation. In the sizing of the tunnel, consideration has been given for the installation of both formations.

Equipment and ventilation buildings

Ventilation is supplied to the cable tunnel by fans housed in equipment buildings located in between two ventilation buildings approximately 6km apart. The tunnel ventilation system has been designed to remove heat and smoke from the tunnel under all operating conditions, including fire emergency. The equipment building also accommodates a 22kV substation and switchgear for the power supply of tunnel M&E equipment; standby generator and underground diesel tank; control room with SCADA screen; pumps, pipe work and water storage tanks for cable cooling as well as for the water mist system; cooling towers; building services; battery charging facilities for the maintenance vehicle and a guard house. The equipment buildings are typically two storeys high with two basements and serve as main access locations for inspection and maintenance.

The ventilation buildings on the other hand are smaller in scale and complexity to the equipment buildings and act mainly as exhaust or air supply points. However, at the intermediate locations these also provide entry or exit for a maximum of four EHV circuits.

Shafts

The shafts typically have a 14m internal diameter. Their layout is complicated by the need for fire rated partitioning of the ventilation system. The shafts require four separate ventilation compartments, plus another separate section for access to the tunnel by both staircase and lift as well as the necessary framework to support the power cables. All low voltage power cables and pipes to the tunnel are routed through the shafts. During the construction stage the shafts act as launching and receiving points for the TBMs.

Alignment

The tunnel routes are selected on the basis of achieving the most direct route possible between the EHV cable termination points while complying with the requirements of the agencies and authorities. The tunnel alignment is located within road reserves as far as possible taking into account any existing obstruction and allowing for future underground infrastructure along the same corridor. Where this was not possible and the route has to be located outside the road reserves, wayleaves from third parties are required although acquisition of private land is avoided.

The main difficulty in the route selection lies in locating suitable sites for the permanent shafts and buildings and in negotiating tight bends along the route. A minimum radius of 150m has been adopted in the design of the tunnel alignment though the cables themselves can negotiate approximately 5m radius bends. The shafts cannot be located in all cases along the line of the tunnels because of land constraints. In such situation off-line shafts are being proposed.

The vertical alignment of the tunnel is also controlled by constraints similar to the horizontal alignment. These place the tunnels at depth and mostly in rock.

Implementation

The site investigations for the tunnels were carried out in 2009 and advanced engineering consultancy contracts were awarded as two parcels in October 2010. The first parcel of 18.5km long north-south cable tunnel and shafts are being designed by Mott MacDonald Singapore while the 16.5km long east-west tunnels are under a consortium of Worley Parsons and Aecom. Planning approvals for the cable tunnels have been obtained.

The construction works are proposed to be let as design-and-construct contracts and will be divided into a number of contract packages to meet programme requirements and allow for wider participation by contractors. The M&E works will be combined with the civil works contract packages to ensure better coordination during detailed design and construction. The supply and installation of EHV transmission cables will be let out as separate contracts. All contractors were required to go through a prequalification exercise on 29 April.

North-south cable tunnel

The north-south cable tunnels will form an extension to the existing 1.8km long twin tunnels between Senoko Power Station and Gambas Avenue. The Senoko Power Station is one of the three major power stations in Singapore. In total five new 230kV circuits will enter the new tunnel from the existing tunnels to transmit electricity to the load centres in central Singapore. The 18.5km long tunnel will terminate at a T-junction with the east-west cable tunnel at the May shaft in the south.

Six permanent shafts along the tunnel route spaced at a distance of 2.2km to 4.5km apart have been proposed. In addition to the permanent shaft sites, two other sites are being explored to facilitate the location of temporary shafts to aid the tunnel construction.

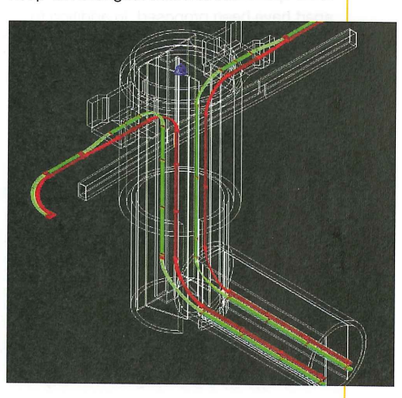
The investigation has established that the proposed route for the NS cable tunnels passes through three distinct geological formations known as the Bukit Timah Granite (BTG), Jurong Formation and Old Alluvium, with the majority of the tunnel in the BTG.

The thickness of the weathered, residual soil layer in the BTG varies between 12m and more than 64m. The ground investigation verified that the rock head levels are much lower in some areas than previously anticipated. The rock mass, classified as weathering grades GIII to GI, was encountered at between 47.18mRL to 110.63mRL and was shown by rock coring, borehole televiewer and geophysical surveys to have extremely variable characteristics. The fracture spacing varies from very close to massive and the orientation and dip of the natural fractures in the rock also varies considerably. Laboratory testing established that the BTG ranges in strength from weak to very strong, but samples were generally strong.

Old Alluvium was encountered in the southern-most 1,200m of the proposed route. It exhibits great spatial variation, particularly with respect to particle size distribution, but appears to have a relatively uniform thickness of weathered material.

The risks related to the tunnelling operations include, high face pressures in deep tunnels, highly variable geology, geological faults and open joints, high rock strength, very high abrasivity, weak ground in some local areas, mixed face conditions and corestones, high pressure groundwater, hot geothermal groundwater in a local area, unfilled boreholes and potential damage to adjacent properties and utilities from ground settlement.

In order to meet the project schedule and to control ground surface settlements, closed face TBM excavation is expected for this route. There are enough TBMs to keep drive lengths below 3km.



Top left: Singapore's skyline along the waterfront; Right: Typical cross section of ventilation shaft and adit

Above: **Singapore's population had reached 5,076,700 in 2010**

It is considered that a one pass lining system consisting of precast concrete gasketted segments will be the suitable in respect of both programme and waterproofing. Particular attention is paid in the selection of gaskets to prevent water ingress into the completed tunnel.

East-west cable tunnel

The 16.5km long east-west cable tunnel extends from Ayer Rajah Substation to Paya Lebar 400kV Substation. The initial section from Ayer Raja is critical to bring the power to a substation at Rangoon which is under construction at present. Seven permanent shafts along the tunnel route spaced at between 1.8km to 3.9km apart have been proposed. In addition to the seven permanent shaft sites, two other sites have been safeguarded for temporary shafts to aid the tunnel construction.

The tunnel route alignment is underlain by a variety of geological formations, ranging from the Jurong Formation in the west, through BTG in the central zone, a second area of Jurong Formation, the Kallang Formation and then Old Alluvium to the east. The Jurong Formation is a variable rock of interbedded sandstones, siltstones and mudstones and has been weathered to considerable depths.

The bedrock is expected to be reasonably good for tunnelling, although rapidly varying rock strengths are likely. The most important unit of the Kallang Formation is the Marine Clay, with a maximum thickness of 35m, although 10m to 15m is more common. The clay is soft to very soft. This material is difficult for tunnelling, but is within the capabilities of modern closed face TBMs of the EPB type. Careful monitoring and balance of the ground and groundwater pressures will be required in order to avoid any adverse ground movements.

The Old Alluvium is very extensive in the east of Singapore and has a thickness up to 185m. The formation is variable, but consists predominantly of dense silty sand. This is generally expected to be a good tunnelling material for an EPB machine, though it exhibits high abrasivity which could cause a very high degree of wear of the machine's cutterhead, cutting tools and screw conveyor.

Three major considerations, geology, gradient and other structures, dictate the choice of vertical alignment. The tunnel has, where possible, been maintained in one type of geological formation for the length of each proposed TBM drive, in order to minimise the complexity of manufacture and operation of these machines. However, mixed ground TBM drives are expected to be unavoidable at certain sections of the route. Gradients between 0.25 per cent and 2.5 per cent have been assumed to be most suitable for permanent drainage and for ease of construction of the tunnel drives using rail mounted transport. Vertical clearances of 5m in soft ground and 2m in rock are expected to be adequate where the crossing of other tunnels or structures is substantially perpendicular. The result of the above considerations is a vertical alignment ranging from approximately 25m below ground level to as deep as 60m in some locations.

From the consideration of geology, lengths of drives, availability of worksites, construction techniques and construction periods, it has been determined that the civil works should be formed into three separate contract packages with tunnel lengths of between 4.5km to 6.5km for each contract package.

Each contract package will consist of two TBM drives carried out simultaneously. While there are some differences in contract length, it is possible to classify one of the contracts as rock tunnel only, one as soft ground tunnel only, while for the third contract mixed tunnelling conditions probably cannot be avoided.

Reference

G D Mainwaring, Y K Lam, L W Weng and Y K Chong, R G Ramanathan, "Planning of High Voltage Cable Tunnels for PowerGrid Ltd, Singapore", Proceedings of the Underground Singapore 2001 Conference, 2001

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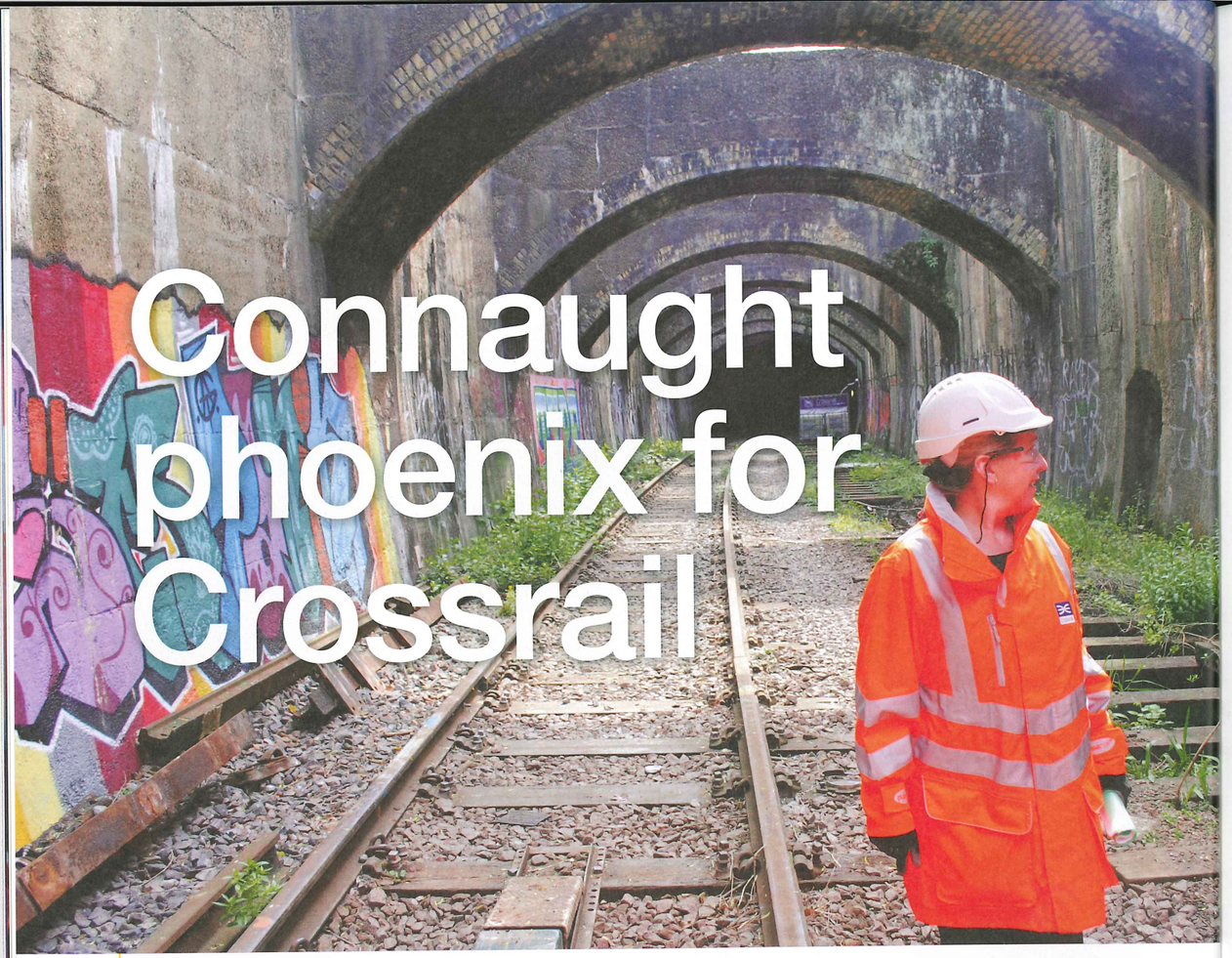
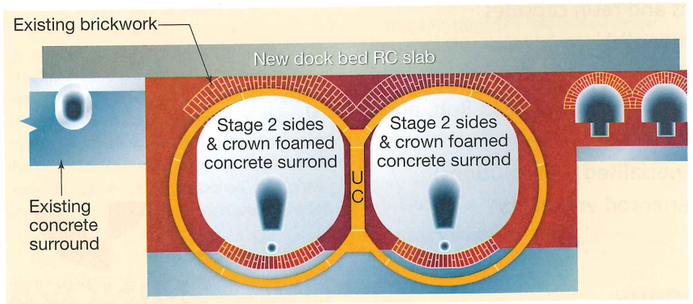


Crossrail has been revealing the Connaught Tunnel in London's Docklands to representatives of the media and stakeholders prior to work beginning on its modification. The project design involves some unusual refurbishment methods to enlarge the existing tunnel and preserve some Victorian features as Maurice Jones reports

In April the contract C315 for refurbishment of the tunnel (formerly known as the Silvertown Tunnel) was awarded to Vinci Construction UK at a value of about GBP 35M (USD 56.9M), beating a JV of Hochtief Construction, J Murphy & Sons and BAM Nuttall; and another Volker Fitzpatrick and Barhale.

The Connaught was built as a 600m-long twin-bore, brick-lined railway tunnel. Some rail and ceramic insulators are still present from the third-rail electrified track for the North London Line to North Woolwich that closed in 2006 when the Docklands Light Railway Stratford Extension took over passenger duties in the area. In relation to current surface features it runs under the Connaught Passage waterway between the Royal Victoria and Royal Albert Docks.



Site investigation

Capita Symonds engineering geologist Sophie Norgate has been working with Oli Mills from specialist contractor Soil Mechanics and Crossrail engineers on extensive site investigations, including cored boring in the brick and concrete invert of the existing tunnels, verification of the state of the existing lining and reference

Above: Project manager Linda Miller beneath brick arches near the west portal of the tunnel; **Left:** Figure 1 – Planned refurbishment of the twin bores to excavate the invert and enlarge the bore within temporary foam concrete. Note also the position of parallel service tunnels to be investigated.

surveying before the main construction work begins. The tunnel is adjacent to a busy highway bridge over the dock area, and also London's City Airport, which lies between two dock basins. It was agreed that the surface should be extensively monitored for movement. One other investigation task that remained was to check on the condition of apparent service tunnels alongside the main tunnels, revealed only on original construction sections. Others to be carried out by Vinci included checking for the presence of unexploded World War II bombs, and asbestos in the structure and ground fill.

A recent visit was led by Linda Miller, project manager on the site for Crossrail, an American tunnelling engineer with experience on Boston's enormous 'Big Dig' highway project, and a former US Army helicopter pilot. The site manager for Vinci is Richard Wall-Morris.

Victorian railway

The original tunnel was constructed for steam rail in 1878 by cut-and-cover methods. The docks were constructed simultaneously, including the Connaught Passage over the tunnel. This led to problems in 1935 when it was found that the larger ships that were then using the old docks had started to scrape the top of the tunnel structure (following dredging), leading to fears of inundation through structural damage. In order to preserve the Connaught Tunnel the central, underwater, length of brickwork lining was replaced with a full circle of cast-iron bolted segment rings. Another structural hazard occurred in the blitz of WW II when a bomb penetrated the tunnel lining. This was repaired with concrete and the patch can still be seen.

Other features of the existing structure include refuge 'manholes', and two circular ventilation shafts at each end of the twin bores. At the surface the two shafts have brick structures around them.

The new section needs to be larger to accommodate Crossrail trains and overhead power catenaries. In order to accomplish this the invert of the tunnel will be lowered and the weaker sections, including the cast-iron lining, replaced. About 100m of tunnel wall will be removed and replaced with pre-cast concrete lining in a 'binocular' section (see figure 1, left). The brick arches at both ends near the tunnel portals will be preserved and repaired as they have been found to be generally sound and of architectural merit.

In order to reinforce the central, underwater length of tunnel, a large concrete slab will be laid in the passage floor between the docks to protect and stabilise the tunnel structure. Vinci will first dredge a wide channel in the Connaught Passage just west of the Connaught Bridge Road to allow the placement of a one-metre-thick, reinforced-concrete slab of 1,000m³. This will necessitate the use of marine pontoons and divers to tremie the concrete into place.

Once the concrete slab is secure the cast-iron lining will be removed, one ring at a time, for installation of new support. During this stage of construction the remaining brick-lined tunnel will be first structurally grouted to ensure ground stability, and then filled with low-strength, foam concrete to maintain lining integrity. Excavation of twin bores to the new necessary sectional dimensions will take place through the foam concrete by small-scale methods. The actual excavation method has not yet been decided but Miller revealed that rotary cutterheads, probably mounted on mini-excavators, are likely to figure highly in the work rather than manual methods. The pre-cast concrete segmental rings will then be installed as excavation progress allows.

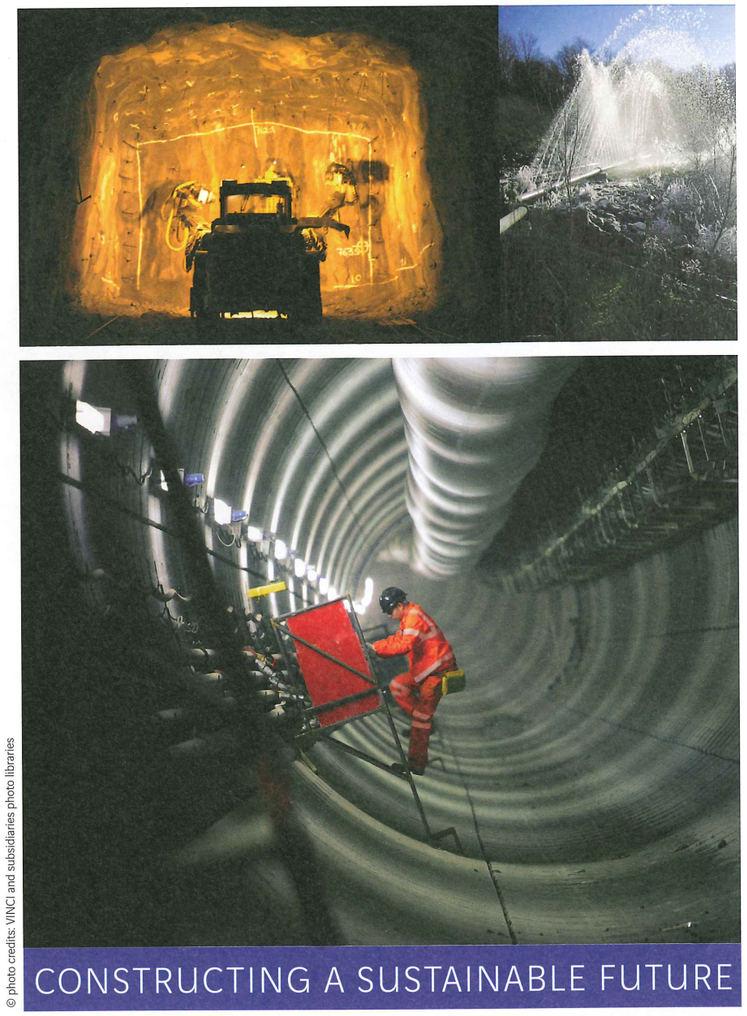
Water handling

When in use the railway tunnel has had to have continuous pumping of drainage water employing a Victorian octagonal pump house on the surface. Water will also feature during construction, although the final waterproofing solution has not been decided yet.

Wall-Morris told *T&TI* that current thinking was to connect a central sump and pumping chamber in the tunnel with the surface at the existing pumphouse that will be retained and upgraded. The connection will be made by employing pipe jacking or directional drilling. Drain water would then be removed via this route.

One current feature of the Connaught Tunnel that amused Miller is that one graffiti artist, in additional to the usual 'tags,' has adorned a refuge hole with the slogan "I ♥ [love] tunnels."

Any connection with the purchase of a can of white spray paint by the *T&TI* editorial staff is purely coincidental!



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Complexities of conveyance

Robbins technical writer Desiree Willis argues why continuous conveyors work in tough TBM-driven tunnels

Muck removal: It's one aspect of TBM tunnelling that is often overlooked, yet crucial for efficient advance. "Muck removal is always critical for any TBM to advance at high rates, whether it is in soft ground or hard rock. You may have the highest powered machine out there, but if you cannot remove the muck it goes nowhere," says Dan Martz, project manager for the contractor JV of Shea/Traylor.

The process, however, can be quite complex when the tunnel is located in an urban area, when space is limited and when conveyed materials vary widely. Continuous conveyors have made it possible to achieve higher rates even in these difficult setups, using advancements such as variable frequency drives, space-saving vertical belts and specially designed systems for soft ground.

Case studies, beginning at a massive 1970s tunnelling project in Chicago, highlight how conveyor systems have improved over the years. Recent and ongoing tunnelling projects in California and New York detail the use of today's conveyor systems in complex ground conditions and urban environments.

Better, faster, safer

The use of continuous conveyors in difficult conditions has produced great successes on modern projects. Conveyors were used on a number of record-setting tunnels at Chicago's Tunnel and Reservoir Plan (TARP) in Illinois, USA—a project that began in the 1970s and involved more than 20 TBMs over two decades. "I was one of the Project Engineers at the Chicago TARP Tunnels in the late 1990s," says Richard Redmond, now operating Redmond Construction Engineering, a construction management and cost estimating company. "The project utilized a horizontal conveyor, through 14

Above: Belt cassettes, like those on the Robbins conveyor system at East Side Access, are designed with electric rather than hydraulic winches for constant torque and PLC control

curves of 300m radius, dumping onto a specially designed vertical conveyor, and then running onto radial stacker conveyors to spread the material on site. Challenges included the installation of booster drives every 760m, and training the belt through so many curves."

Martz, then working for Affholder, was also part of tunnelling at TARP. "I worked in Chicago for many years seeing the start of conveyor systems and watching their progress. The Little Calumet tunnel was set up for high production, with a high-powered TBM, 19-inch disc cutters, and high-capacity muck removal. When you mine 300m per week, and 1,600m in a month, something is working pretty well and it is not a result you can achieve with muck cars," he says.

During tunnelling, muck was removed using a side-mounted belt conveyor that emptied onto a vertical belt with a 700t/h capacity. The Little Calumet project, excavated in limestone with curves down to 305m radius, still holds world records for best day (99.1m) and best week (562m) in the 5m to 6m diameter range.

Earlier successes such as those at TARP have inspired a host of improvements for the use of conveyors in difficult project schemes. "A good conveyor requires good maintenance, including maintaining the belt alignment, greasing, and belt splicing. We can manage our belts much better today using data logging, real-time monitoring and cameras," Martz says.

Left: California's UNWI tunnels used a 5.8km long Robbins conveyor system, resulting in both TBM and conveyor system availability of above 90 per cent

Variable frequency, greater efficiency

Variable frequency drives (VFDs) have many advantages over hydraulic couplings, an earlier form of drive motor still used on short tunnels. VFDs actively set the speed and torque that a drive contributes to the conveyor in both single and multiple-drive setups. In this way, a controlled start-up is possible and belt tension is kept low to reduce stress, allowing belting to better negotiate tunnel curves.

The drive systems are also lower in cost because they use AC three-phase motors, which require less maintenance compared to earlier DC motors. Newer systems are also digitised, so a separate frequency motor is not needed to control the torque supplied by each drive. "One of the most important factors in maximising conveyor availability is maintaining the drive motors. This is much easier to do with variable frequency drives," Redmond says.

Since their power output is controlled, VFDs are also more energy efficient than their hydraulic coupling counterparts. "Old scoop tube hydraulic couplers required a balancing act through adding or deleting oil. Later fluid couplers came with this parameter preset, but they still didn't allow us to utilize torque and speed at different RPMs during startup," Martz says.

Because they are digitised, VFDs also allow monitoring and maintenance using Programmable Logic Controllers (PLCs) from the operator's cabin or a location on the surface. PLCs have dramatically decreased downtime and increased safety of long, complex conveyor systems. When combined with Emergency (E-stop) pull cord systems, the crew can identify problems in real time, as well as the exact section of conveyor that has tripped a switch. E-stop pull cords automatically halt a conveyor belt, while magnetic impulse belt-slip and whisker-type belt run-off switches provide additional protection at conveyor discharge points.

Curved drives

Curved tunnel paths are one of the most common challenges for continuous conveyors. Self-adjusting curve idlers, patented by Robbins, help to solve the problem by pivoting to accommodate changing load tensions around curves. The pivoting action is also favourable because it does not unnecessarily alter the carrying capacity of the conveyor or the belt tension. Recent decreases in the weight of the carrying idler assembly have also improved worker safety by making the curve idlers easier to lift, while reducing installation time.

New materials

New belt materials are also making curved systems safer and more efficient. A new type of fabric, known as straight warp belting, is thinner and lighter without reducing strength or durability. The belting is able to move through small radiuses at a variety of working tensions. In addition, the fabric is resistant to string formation, a process that occurs as the edges wear and begin to fray. Minimisation of edge wear tempers the risk of strings catching on pull cords, and reduces the chance of worker injury.

Going vertical

New advancements for limited space projects, including J-Type vertical belt conveyors that are loaded using a vertical receiving hopper and feature a small vertical drive section, are capable of reducing the footprint both in the shaft and at the surface compared with conventional S-type designs. Vertical belt cassettes further reduce the space normally taken up by horizontal belt cassettes by as much as 170 per cent.

Moving rock under New York City

New York City's East Side Access Project has been in the works for over 30 years and is needed to relieve heavy traffic congestion between the densely populated boroughs of Queens and Manhattan. The project was revisited in earnest in 2006, when contracts for two parallel TBM tunnels below Manhattan were awarded. A total of eight TBM headings, drilled by two TBMs, connect the boroughs via an existing submersed tube below the East River. The setup utilizes continuous conveyors drawing from multiple headings, hauling muck up a shaft and across a six-lane highway.

Excavation with a 6.7m diameter Robbins TBM began in December 2007 and was completed in July 2010, while a Double Shield TBM of the same diameter completed tunnelling more recently. Geology has consisted of competent Manhattan schist up to 200 MPa UCS. Current operations at the project, as of April 2011, included drilling and blasting of large station caverns below Manhattan's Grand Central Station.

"This job is really logistically unique. Not only is it a massive undertaking—we also have up to 11 different headings happening at one time," says Don Hickey, Project Manager for the Dragados/Judlau JV (project contractor). "There are two TBMs, two road headers, drill and blast operations, concrete operations, and shotcrete final lining, all happening out of one major shaft."

The muck removal system for the project is equally complex, consisting of every type of commonly used belt conveyor. During TBM tunnelling, the conveyor system was in its longest iteration, stretching over 4.8km in length. Two extensible straight warp fabric belt conveyors (914mm in width) travelled behind each TBM operating in the tunnels, and dumped via a crown-mounted cross conveyor onto a single 1,863m fixed-length conveyor mounted inside the submersed tube.

From the tunnel, muck is transported up the 23m deep Queens shaft using a fixed-length, steel cable vertical conveyor. Once the muck has reached the top of the shaft, it is transferred to a storage area using three overland conveyors and a radial stacker. The second overland conveyor, 37m in length, is a completely enclosed box truss that crosses Northern Boulevard, a major thoroughfare in Manhattan. Once the muck reaches the storage area, it is transferred to a radial stacker, which can rotate through 60 degrees to deposit muck in kidney-shaped piles.

Though the conveyors are no longer handling muck from behind the TBMs, they are still in heavy use and being loaded at multiple points. "The conveyors have worked well; we still have a lot of material for them to remove," Hickey says. "They have been running since mid-2007 and will be running to the end of 2012—that's about five years of life required on this one job,"

Throughout the project's excavation, the conveyor system has averaged over 90 per cent availability.

"We have removed 2,300 to 3,000 cu m of muck a day with this conveyor system when the TBMs were running—it's the only way we could keep this project on schedule," Hickey explains.

"This belt has seen a lot of different types of material, from TBMs, road headers, and crushed drill and blast material. It has handled all of it well, though dealing with fines has been a challenge. We are using cleaning apparatus to make sure running material is removed and not returned back into the system."

Above: A Robbins fabric belt conveyor with sealed transfer points conveys clay and sand mixed with an additive in Sacramento, California

Sacramento's soft ground

While continuous conveyors have been tried and tested in hard rock, their entrance on the soft ground scene has been much more recent. The design of such systems must take into account the differences in material between soft ground and hard rock, including belt cleaning, sealed transfer points and other elements.

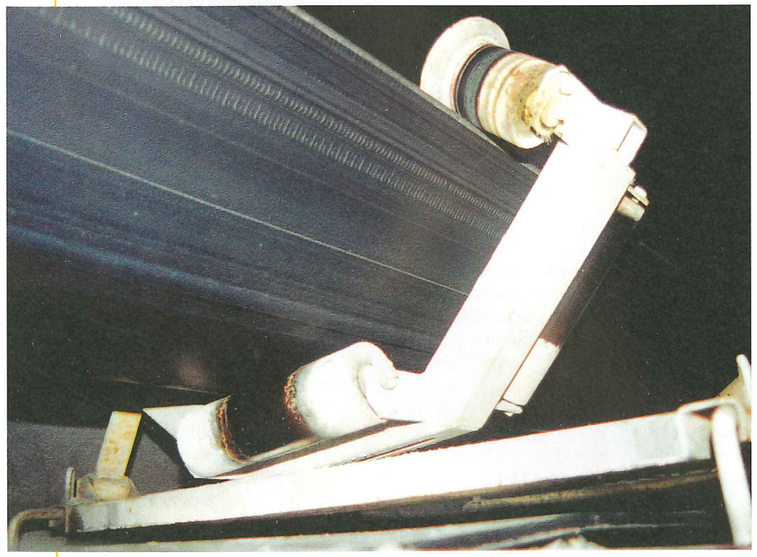
"Probably the most challenging job I've worked on was the Lower Northwest Interceptor, a short river crossing job in Sacramento," Martz says. "The EPB TBM was launched at six per cent down grade, mined 300m through a vertical curve, and then up at six per cent for another 300m to hole through. The tunnel went under the Sacramento River, through several different types of soil, clays, and sand. The conveyor was a big part of what allowed us to do the job safely and efficiently."

That project—one of the first to use a continuous conveyor for soft ground TBM tunnelling was completed in 2005. The Robbins conveyors, even with their steep inclines and declines, achieved system availability above 90 per cent for the entire project duration.

A more recent adaptation of this setup, also in Sacramento, took place at the Upper Northwest Interceptor (UNWI) project in 2009. The 5.8km long tunnel was excavated using a 4.25m diameter Robbins TBM and continuous conveyor through running sand and silt. The contractor, the Traylor/Shea JV, opted for a continuous conveyor system spanning the length of the tunnel, with custom adaptations for varying ground conditions and water inflows.

Design features included sealed transfer points and receiving hoppers. Urethane rubber was used to seal the points and minimise spillage. Additives mixed with the wet ground, such as foam and bentonite, ensured a smooth consistency of muck flow on the conveyor and eliminated clumping, which can contribute to muck fallback and spillage. Cutterhead design aided in injection of the additives, with four independent foam injection points to mitigate the risk of clogged lines.

During TBM operation, an extensible fabric-belt conveyor was constructed behind the TBM and over the top of the back-up system in the crown of the tunnel. The muck was discharged from the screw conveyor onto the belt conveyor at the front of the back-up system. From there, the conveyor system was elevated over top of the back-up system and into the crown of the tunnel. As the conveyor travelled through radiuses down to 400m, Robbins self-adjusting curve idlers transferred the load and enabled the system to run through curves. A tripper assembly, located at the open cut in the tunnel, redirected the conveyor up through the open cut at a 12 degree incline for discharging onto a stacker conveyor. The system was powered by a 150kW variable frequency main drive, as well as two 150kW booster drives.



Left: Hazardous belt strings can be minimised with new materials such as straight warp belting, which is string formation resistant and aids conveyors on curved tunnel drives; Bottom, left: Robbins self-adjusting curve idlers allow for curved conveyor drives by pivoting to accommodate changing load tensions

By machine breakthrough, the conveyor had operated at well over 90 per cent availability for the duration of the drive. The 210m weekly advances, as well as daily advance rates of up to 50.3m, are believed to be records for EPBMs in the 4m to 5m diameter range.

Continuous evolution

Conveyance has become more efficient within the last decades, making continuous conveyors ideal for urban tunnels and variable ground. Both Martz and Redmond see a growing acceptance of conveyors in a wide spectrum of geology. "I think conveyors are being used more today than ever—when we used the belt in Sacramento just a few years ago to remove soft ground, a lot of people thought we were crazy. But, that belt made the job a success," Martz says.

Redmond sees several improvements that could be made to conveyors in general, with regards to better control of muck spillage and handling of large pieces of material in blocky ground. Martz also hopes improvements will be made with conveyor operation: "It is important to remember that this is not a magic piece of equipment that moves huge amounts of material at the flip of a switch. I think the biggest challenge is in finding experienced people to set up, operate and maintain the system, so that it can achieve what it is designed to do."

CLEVER CONVEYING. FINNE TUNNEL. GERMANY.

One for two.

Herrengrosserstedt/Germany. As specialist in conveyor belt systems, H+E Logistik GmbH supplied the equipment required for the new construction of 2 tunnel tubes with a length of 7,000m each, which will accommodate a high speed train on the German railway route from Erfurt to Leipzig/Halle. This equipment guaranteed rapid tunnelling progress. The system includes two continuously extendable tunnel belts which are connected to a heap belt and operate a pivoting stacking system. This saves costs and maintenance work. Typical H+E.

The bare facts:

Tunnel diameter:	10.90m
Conveyor length:	2x 7,000m
Belt width:	1,000mm
Capacity:	2x 1,400 t/h
Installed power:	3x 250kW per tunnel
Belt storage capacity:	2x 500m/horizontal
TBM:	2x Hard Rock Shield
Installation:	2008
Contractor:	JV Finnetunnel

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Of the rising sun

An economy in recession, a landscape reeling from an unprecedented natural disaster and, as yet, unknown damage to subterranean structures. Yet no country could be as well-prepared as Japan to take hits on both these fronts. With the help of the Japanese Tunnelling Association (JTA), Alex Conacher explores the situation in North East Asia, with focus on a Japan determined to hit the ground running

It is difficult to mention Japan at the moment without including the 2011 Tohoku earthquake and its effects. The obvious destruction and effect it has had across all industries and interests, not least the environment. Even the special committee for studying seismic damage to tunnels has had its efforts hindered.

Following the crisis, the Japanese Ministry of Economy, Trade and Industry indicated that the production output index of factories and mines in the country stands at 82.7 (with the base of 100 set at 2005 levels). The record drop of production in March, 15.5 per cent, is not a surprise given the circumstances but shows the level of impact that might be expected across the board. The Japanese economy is in its third recession in 10 years.

The JTA's pick of the projects

Although the damage to tunnels in Japan has yet to be gathered in full, and projects under construction are particularly at risk (see article on page 32), the health of the industry and amount of work available is undeniable. A lot of this work is on the Metropolitan Expressways in the Greater Tokyo Area. Contractors Kajima, Taisei, Obayashi and Hazama are handling Shinagawa Tunnel on the Central Circular Route, while Obayashi and Shimizu are working on the Northern Tunnel on the Yokohama Circular Route. Aside from these, there is also work on the Hokkaido and West Kyushu Shinkansen (Bullet Train) lines, the new Tokyo-Nagoya Expressway and also the Horobetsu Radioactive Waste Research Facility, according to Toshinori Mizutani, executive director of the JTA.

The JTA is publishing a book to include the rest of the world in its activities. 'Tunnelling Activities in Japan, 2010' is available for JPY 3,600 (USD 44.16) from the JTA website. The book has a juicy range of topics, including a look at tunnelling in geological formations characterised by extreme swelling tendencies with a high-pressure aquifer, recent technological innovations and several interesting projects that have been underway in Japan.

Key project: Trans-Tokyo Bay

At 14.14m, the Hitachi Zosen slurry shield TBM working on the Kawasaki tunnel Ukishima-North phase one section of the project is one of the largest in the world. The completed tunnel will have an internal diameter of 11.9m and a grade of four per cent and a horizontal curve with a radius of 1600m. The project client, the Trans-Tokyo Bay Highway Corporation, awarded the contract to a JV of Kumagai Gumi, Hazama and JDC. The overall project involves the construction of artificial islands.

Special report

In this special report on North East Asia you will find an article discussing what is known and can be expected from seismic damage assessments in Japan. *T&TI* speaks to the chair of the damage study committee, Toshihiro Asakura, to bring you the latest approaches, and past studies into the mechanics of seismic tunnel damage.

On page 37 Hee Soon Shin of the Korea Institute of Geoscience & Mineral Resources gives a paper on the Use of Underground Space in Korea. The article reviews underground projects in Korea, including refrigerated food storage, oil and gas storage, pumped storage, road, metro and rail tunnelling projects.

Underground Construction

Conference and Exhibition
Incorporating the International Tunnelling Exhibition

Earls Court, London, UK
29th and 30th June 2011

The eyes of the global tunnelling industry are swivelling towards the UK in anticipation of some of the world's largest underground construction projects getting underway. Already some £20bn of tunnelling work can be foreseen with Crossrail, the massive Thames Sewer Tunnel, underground rail line extensions, Dublin's DART project, and tunnels at the new nuclear power stations being started shortly.

In recognition of the interest that these projects will create, we are pleased to announce the Underground Construction Conference and Exhibition at Earls' Court, London on 29th and 30th June 2011.

The two-day Conference is being co-ordinated by British Tunnelling Society, Institute of Materials, Minerals & Mining, the Pipejacking Association and the International Tunnelling Association with support from many other professional bodies.

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Gauge the strain

Following the 2011 Tohoku earthquake off the east coast of Japan, surface devastation in the country has been extreme. The desolation left by the tsunami, and subsequent losses of power has made it difficult to communicate, let alone begin to pick up the pieces left by one of the greatest natural disasters in Japan's history. Alex Conacher speaks to the chair of a committee that means to do just that, Toshihiro Asakura, professor at Kyoto University and chair of the Special Committee for the Tunnel Disaster by the East Japan Earthquake

Formed by the Tunnel Engineering Committee of Japan (TECJ), the Special Committee has the mission of assessing the damage to underground structures in the wake of the 2011 earthquake. As T&TI goes to press, the committee is working on making a list of all tunnels within the disaster area, though determining the disaster area is not as simple as getting a set of compasses and a map, as committee chair and Kyoto University professor Asakura explains later.

Inspections

The tunnel inspections are also delayed, as Asakura puts it, by the 'disturbed' environment. Carried out by the respective tunnel operating companies, inspections involve a walkthrough observation of the tunnel, then further detailed inspections.

The only reports of notable damages when T&TI spoke with Asakura were those of two Shinkansen (Bullet Train) running tunnels, Fukushima and Shiga, after immediate inspection by the East Japan Railway company. In these tunnels, the track bed concrete and invert concrete was damaged by strong lateral ground pressure, causing serious but not extremely serious cracking. The damage in these tunnels has already been repaired by grouting the cracks and service has resumed, though as a result of this the rail level has been brought up by some tens of millimetres.

"The Special Committee will compile and analyse [all data generated through inspection] as the mechanism behind earthquake damage to tunnels requires further study," Asakura says.

"There are many unknown conditions related to such damage. Although mountain tunnels are assumed to be earthquake-resistant structures, previous studies have shown that they may sometimes suffer damage such as cracking or spalling caused by flexural compression failure."

Although no papers exist yet on the 2011 Tohoku earthquake, prior to this, in August 2010, a paper was published by Asakura and a number of his colleagues: Naritoshi Fukazawa, director of the Design and Technology Department for Japan Railway Construction of the Transport and Technology Agency; Yoshiyuki Kojima, laboratory head of the Tunnel Engineering Laboratory, Structure Technology Division and Kazuhide Yashiro, senior researcher of the same. Titled 'The Mechanism behind Seismic Damage to Railway and Mountain Tunnels and Assessment of their Aseismic Performance', it gives details of a study in which case studies and model experiments are used to investigate this mechanism and its effects.

Definition

Flexural compression failure is a compressive failure due to the bending moment.

Past damages

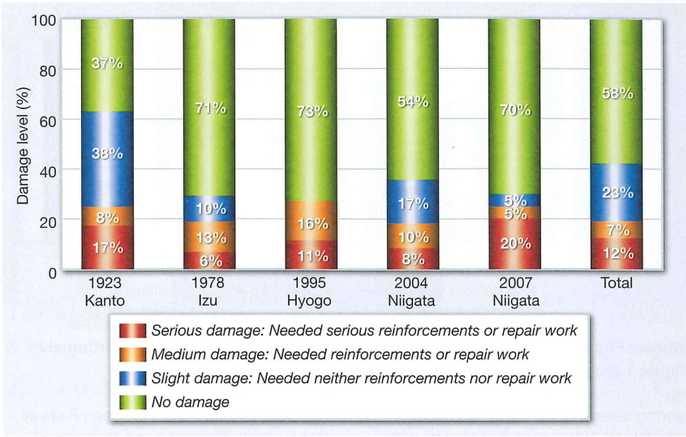
At the time of the paper's publishing, 19 tremors had caused damage to Japanese mountain tunnels since the Kanto earthquake of 1923, with five causing serious damage (see figure 1). Some 25 tunnels collapsed during Kanto, needing reconstruction and earthquake countermeasure work to reinforce against future tremors.

The Izu-Oshima-Kinkai (Izu) earthquake of 1978 caused serious damage to tunnels on the Izukyu line, particularly the Inatori tunnel, the lining on which was seriously damaged by fault displacement, closing the tunnel for half a year during repair works.

The 1995 Hyogoken-Nanbu (Hyogo) earthquake was a near-field tremor in an urban area resulting in the serious damage of 12 tunnels at the foot of or within the Rokko mountain range near Kobe City in southwest Japan. The damage was particularly bad in the Higashiyama tunnel, part of the Kobe electric railway and also in the Rokko tunnel, which forms part of the 553.7km Sanyo Shinkansen Line between Osaka and Fukuoka.

In 2004 the Niigataken Chuetsu (2004 Niigata) earthquake seriously damaged 11 tunnels including the lining of the Myoken tunnel, the Uonuma tunnel and the Wanatsu tunnel. All are on the Joetsu Shinkansen Line running between Tokyo, on the Pacific side, and Niigata, on the Sea of Japan side of Honshu Island. The Wanatsu tunnel took two months to repair.

The 2007 Niigataken Chuetsu-Oki (2007 Niigata) earthquake seriously damaged four tunnels, three of which were on the Shinetsu Main Line. In particular, the First Yoneyama tunnel experienced serious flexural compression failure and shear failure of the lining.



Above: **Figure 1, five of the earthquakes in Japan that caused serious tunnel damage since 1923**

Damage categorisation

Tunnel damage analysis in Japan is categorised in four main ways. The level of damage; modes of damage, which are divided into three types discussed below; distance and magnitude relationships and also whether the tunnel is subject to any of the 'special conditions' discussed by Yoshikawa in his treatise 'Earthquake Disaster Survey on Railway Tunnels' published in the Research Report of the Railway Technical Research Institute in September 1979 (see below).

Damage levels

Damage level assessments range from no damage to serious damage, meaning a tunnel in need of serious repair or reinforcement work. Of the five earthquakes shown in Figure 1, the percentage of tunnels displaying serious damage averaged around 12 per cent, with medium damage at 7 per cent, slight damage at 23 per cent and an average 58 per cent of all affected tunnels exhibiting no damage.

Modes of earthquake damage

- Type I
  Cracks in the arch shoulder, characteristic to shallow tunnels in soft ground, is believed to be caused by shear deformation in the ground inducing shear deformation in the tunnel, causing an increased bending moment at the lining arch shoulder that results in failure.
- Type II
  Flexural compression failure and spalling at the crown are typical in tunnels through poor geological conditions. A probable result of the poor, usually soft geology is the exacerbation of deformation caused by the ground motion during an earthquake, as well as the loads caused by loosening ground pressure and squeezing ground pressure that could be present before the tremor strikes.
- Type III
  Damage caused by fault displacement, including lining fracture resulting from local forced displacement accompanied by fault displacement.

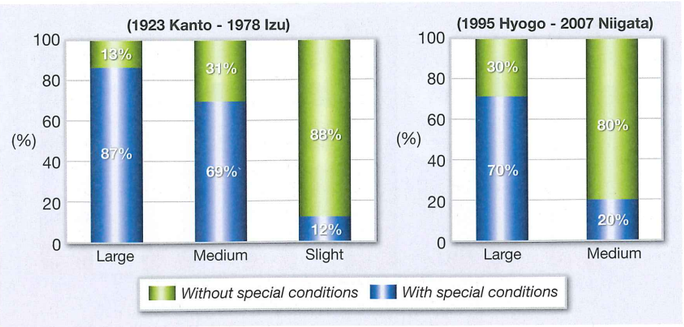
Asakura also notes in his paper that type two damage in ground with poor geology, and type one in shallow tunnel situations, accounts for the majority of damage reported, if slope disasters are excluded as a matter of secondary damage. Tunnels in these conditions are highly likely to suffer earthquake damage.

Distance and magnitude

An increasing magnitude and a decreasing distance both escalate the probability and severity of tunnel damage. Although a general guideline is given stating that for a magnitude eight earthquake, the possibility of medium or serious damage greatly increases when the distance from the quake epicentre is less than 30km, and 10km for a magnitude eight, Asakura points out that this is flawed, and at least one tunnel further than 100km from a tremor epicentre has been damaged. As there are so many other factors, and because the 2011 Tohuku earthquake was the largest yet detected in Japan, this guide is unreliable.

Yoshikawa's special conditions

Yoshikawa listed seven special conditions in his survey: landslide, deformed tunnel, poor geological conditions, shallow tunnel, under construction, fault slide and lining defects. Figure 2 shows the percentage of tunnels damaged by the five major



Above: Figure 2, the percentage of tunnels damaged by the five major earthquakes in figure 1 (page 33) that fall under special conditions

earthquakes that fall under the special conditions. This shows that tunnels with special conditions make up the overwhelming majority of cases of serious damage and are at most risk.

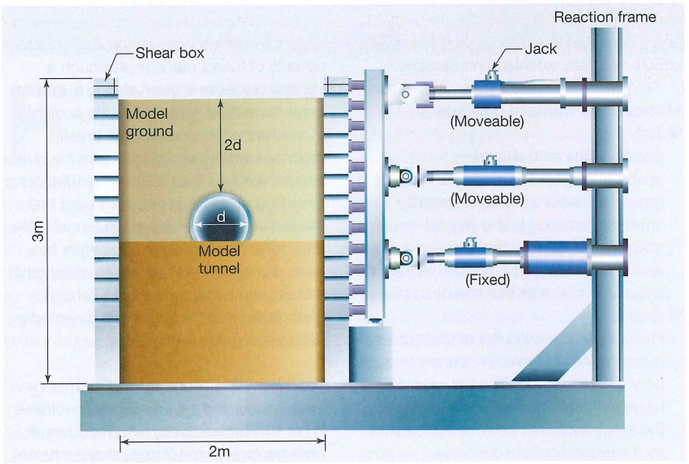
"Before 2011 Tohoku Japan Earthquake, railway companies in Japan checked the tunnels that had special conditions, and reinforced where required," says Asakura. "We now intend to check all the tunnels because we have to know what is the dominant condition. We need to know what the mechanism of damage is more exactly.

"Although the special conditions are not unique to Japan, the geology in this country is relatively more complicated and of lower quality than that found in others."

Past experiments and studies

Experiments were undertaken jointly by Kyoto University, the Railway Technical Research Institute and the Japan Railway Construction Transport and Technology Agency, under the 'Program for Promoting Fundamental Transport Technology Research' of the Japan Railway Construction, Transport and Technology Agency (JRTT). The model experiments focus on earthquake damage to mountain tunnels and place an emphasis on tunnels with shallow cover and in ground with poor geology.

One of the experimental investigations into type one damage was conducted through the use of a two-dimensional shear box (see figure 3). A model tunnel was placed in the box and then shear displacement was applied to the tunnel through the boxed ground by three movable jacks. The ground was represented using dry silica sand. Compaction brought the sand to a relative ground density of 80 per cent. The model was made with mortar possessing a uniaxial strength of around 26MPa.



Above: Figure 3, an investigation into type one damage that models a tunnel with shear displacement

The model tunnel was equipped with a webcam and displacement transducers. During the experiment, the lowest jack was fixed with the upper two actuated to provide displacement with a triangular distribution pattern. Loading was applied under displacement control to statically provide alternate loading up to six per cent of the shear strain of the ground. The shear strain of the ground was increased at every loading cycle.

Displacement of the tunnels inner surface was measured and any cracking was observed through the webcam. This was done for models with sound and defective linings (with a void and lack of thickness).

Conclusions

"The experiments and studies further clarified the damage mechanism and seismic performance of the [case] tunnels in question," says Asakura. "Sound tunnels and those with inverts are less susceptible to seismic damage. It was also confirmed that such damage tends to be greater when tunnels have voids above the lining and a lack of thickness, no invert or when local displacement acts on them.

"In the future work we intend to execute investigation of numerical analysis and design methods, and plan to reflect the results of these investigations—in addition to those of our present study—in guidelines and manuals for use in the aseismic design of lining in mountain tunnels.

"We are in the process of gathering more information and will be able to contribute more detailed and accurate information in the future," he explains.

Despite all the experimentation and study, more is needed. As Osamu Kiyomiya—a colleague of Asakura—told T&TI (April 2011, p.13), "Even though various countermeasures were arranged for tsunamis, the damage was past imagination, and beyond engineering judgment. Seismologists never imagined such a strong earthquake. The worst possible scenario had happened. We now have to consider the possible reoccurrence of such a strong tsunami, and countermeasure to protect underground structures in the cities."

"It is important to maintain tunnels carefully at all times, not just in the event of a tremor," adds Asakura.

"The conditions in which tunnels are damaged easily by earthquakes will cause them to be deformed easily even without regard to earthquakes."

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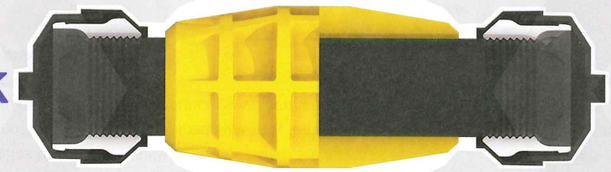

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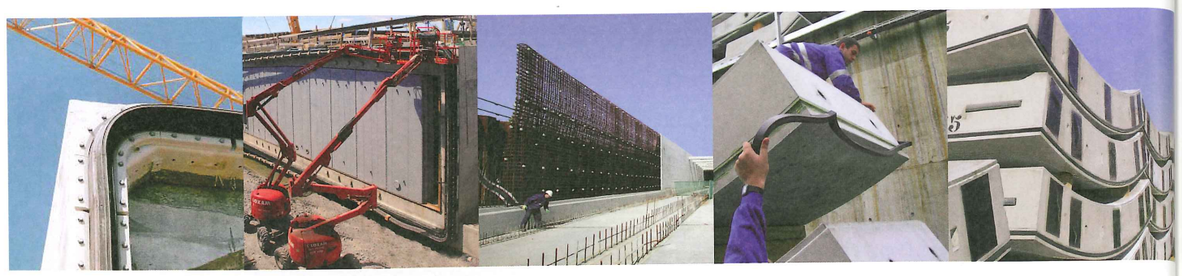

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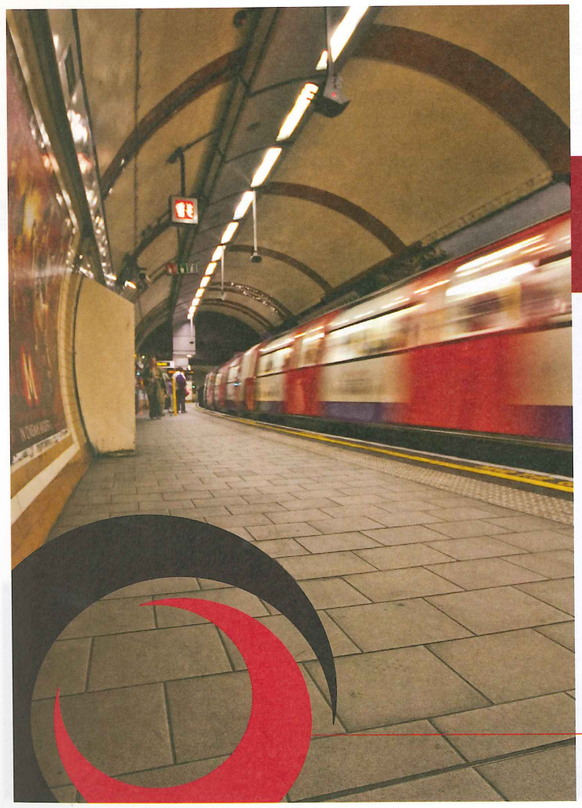

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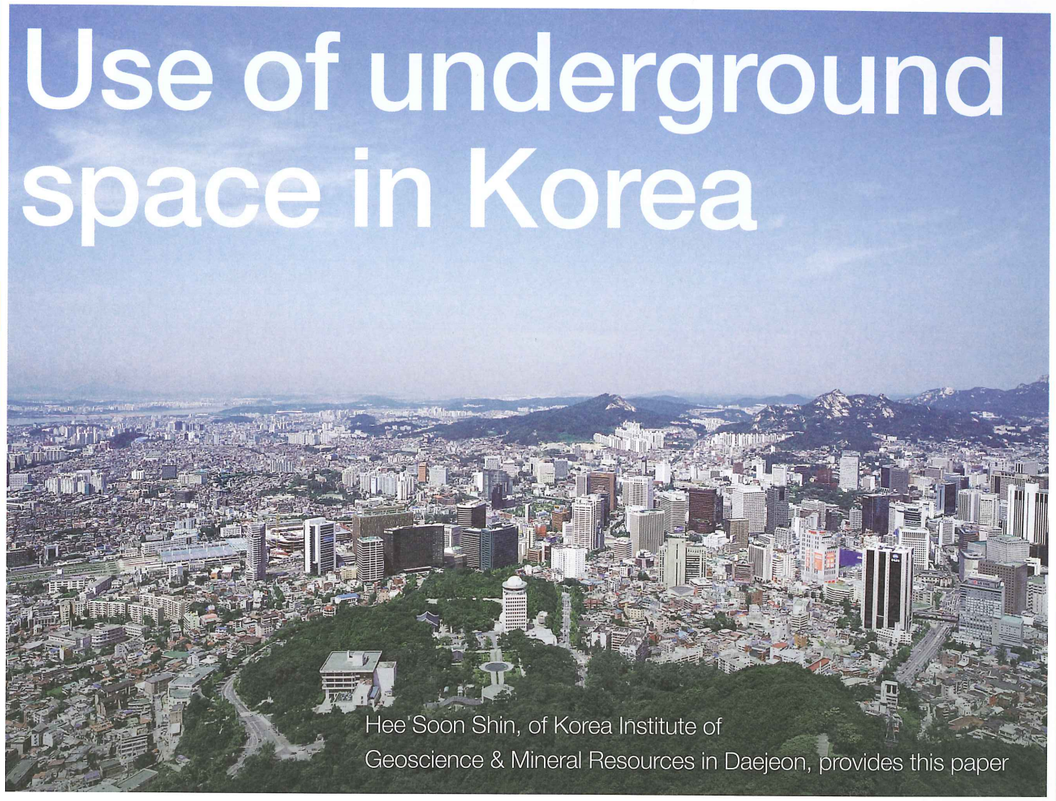
Use of underground space in Korea



Hee Soon Shin, of Korea Institute of Geoscience & Mineral Resources in Daejeon, provides this paper

Located in northeast Asia, 70 per cent of Korea is mountainous. Typical rock types are granite and granitic gneiss, though limestone and other complex sedimentary rocks are found in southern part of the country. The granite and granitic gneiss are hard with the major horizontal stress in the rock mass in the east-west direction.

Korea's first railway tunnel was constructed in 1905, and today the total length of conventional railway tunnels is 356km—about 7.8 per cent of the country's railways. The start of high speed-rail has brought about a renaissance of the railway industry in Korea. Along the high-speed rail route, tunnels total 191km, which is about 46 per cent of the line. Underground structures are also widely used for oil and gas storage (28km), food storage caverns, pumped storage power plants (15km), road tunnels (339km), water supply tunnels (145km), electrical power cable tunnels (339km), telecommunication tunnels (267km) and multi-purpose utility tunnels (87km).

Underground food storage

In Korea, the total capacity of on-going refrigerating facilities was reported to be 600,000t for food storage, which has been increasing 11 per cent annually. The total annual consumption of electricity for keeping food storage tanks cool is reported to be as high as 475,000MWh. Because of the high electrical load during the summer, more and larger capacity power plants will be required. The use of underground storage caverns has been suggested as an alternative.

The test site of a pilot plant was located within the premises of Korea Institute of Geoscience & Mineral Resources, which has a granite base rock type. The total area of the pilot plant is 350sqm with two rooms for food storage (operating temperatures of -25 to 0 degrees C), one room housing the cooling system and another room serving as a monitoring laboratory. Each test room was located 10m below the surface with dimensions of 4.5m to 7m wide, 3m high and 8m to 12m long.

Two kinds of fruit—pears and apples—were selected because their prices vary depending on the availablity of supply in certain seasons. For the quantitative comparison, some indices representing the quality of fruit, such as moisture content and total acid, were selected. This study showed that using underground storage with a cooling system is best for keeping the fruit in good condition. This test run was successful for obtaining real behaviour of an underground food storage cavern.

Based on the above test results, the first commercial underground food storage facility was constructed 30m to 70m deep in Gonjiam area gneiss in December 1997. The facility consisted of four cold caverns, two refrigerating rooms 12m wide by 8m

Acknowledgements

The research presented in this paper is funded by a grant (05 Construction D10-01) from Ministry of Land, Transport and Maritime Affairs of Korean government and KICTEP. This support is gratefully acknowledged.

Table 1: Crude oil and LPG storage caverns

Project	Material	Section	Length	Capacity	Rock type	Construction
U-2	crude oil	18.0×30.0	8,814	4,293,000	granodiorite	1981-1985
L-1	LPG	18.0×22.5	879	300,000	andesite	1986-1989
K-1	gasoline kerosene	15.0×20.5	1,262	231,000	granite	1975-1982
Yeosu	LPG	1.5×19.5 16.0×21.0	968	290,000	andesitic tuff	1981-1983
Ulsan	LPG	19.0×21.0	1,482	500,000	Siltstone sandstone	1985-1988
K-1*	gasoline	18.0× 22.5	440	159,000	granite	1990-1994
Yeosu*	crude oil	18.0×30.0	8,685	4,452,000	andesitic tuff	1990-1998
U-2*	crude oil	18.0×22.5	3,794	1,908,000	granodiorite	2002-2006
L-1*	LPG	16.4×20.0	1,180	325,000	gneiss	1991-1997
Y-2	LPG	16.0×26.0	800	928,000	gneiss	1997-2000
Yeosu*	crude oil	18.0×30.0	14,800	2,021,000	andesitic tuff	1997-2008

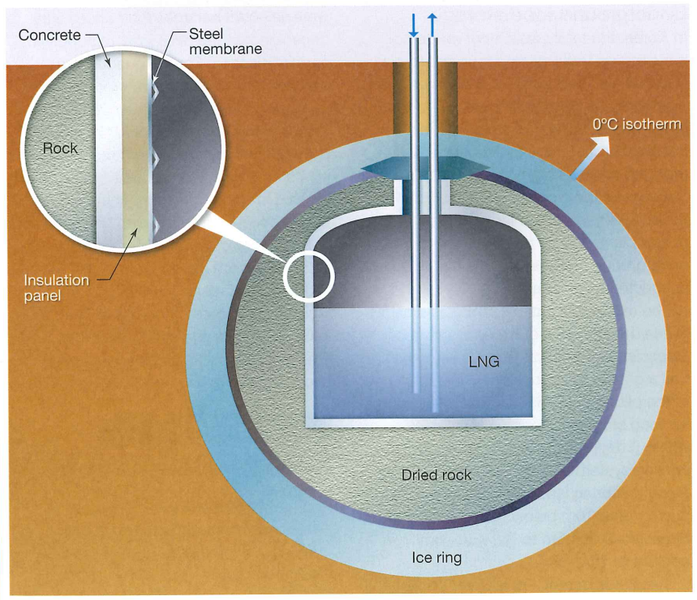
*Extension

high by 50m long and two chilling rooms 12m wide by 10m high by 60m long. Total area of the storage facility is 3,423sqm with a storage capacity of 4,700Mt. The cost of civil construction and cavern excavation was USD 3.28M. The facility operates at a temperature of -22 degrees C. The results show that the minimum storage capacity should be more than 20,000Mt to be more economical than surface facilities.

Underground oil and gas storage

Korea is the fourth largest oil and gas importer in the world. Since the first large underground caverns for storing crude oil were built in 1985—the first with a capacity of 1.5M barrels—10 more caverns for oil and gas storage have been constructed. In 1994 another extended cavern with similar capacity was built near the first one. In 1984 an (liquefied petroleum gas) LPG storage cavern containing pressurized butane and propane was brought into service in Yeosu. Since then five more LPG storage caverns were built in Ulsan, Pyongtaek and Incheon. There are four commercial storage sites and five strategic storage sites. Table 1 (above) shows crude oil and LPG storage caverns.

The Yeosu crude oil storage facility has the largest storage capacity in the world. Liquefied Natural Gas (LNG) storage in rock caverns has not yet been commercialised in the world because of the technical challenges in sealing LNG at extremely low temperatures (-162 degrees C). A Korean company is developing technology for storing LNG in hard rock caverns equipped with containment systems and concrete lining in a joint venture with French companies. When LNG is stored in lined, rock caverns, the formation of an ice-ring from the extremely low temperature of LNG can be a natural barrier in the containment system. In order to implement this concept (figure 1), a drainage system should be dedicated to the conceptual design and testing program. The validity of the design is being tested at an LNG pilot cavern at the Korean Institute of Geoscience & Mineral Resources. The LNG pilot is located in an existing rock cavern where, within a 4m wide by 4m high by 10m long space, reinforced concrete was cast in place between rock and a containment system. The pilot plant was commissioned at the end of 2003 after one year of civil



Left: Figure 1, concept of LNG storage lined rock cavern

Table 2: Pumped storage power plants

Classification	Underground powerhouse				Capacity (MW)	Construction
	Rock type	Depth (m)	Cross section shape	Dimension (m) (WxHxL)		
Chongpyong	gneiss	350	mushroom	22.5×46.6×86.0	400 (200×2)	'75-'80
Samranjin	tuff rhyolite	150	mushroom	20.0×42.0×90.5	600 (300×2)	'79-'86
Muju	granite, gneiss	260	mushroom	21.0×49.0×98.0	600 (300×2)	'88-'95
Sanchung	gneiss	250	egg	25.0×54.3×116.0	700 (350×2)	'92-'02
Yangyang	gneiss	650	egg	20.0×42.3×120.0	1,000 (250×4)	96-'06
Chungsong	sandstone, granite	186	egg	25.5×55.7×114.6	600 (300×2)	'00-'06
Yechon	gneiss	300	egg	25.8×53.5×129.1	800 (400×2)	03-'11

works, piping and instrumentation. Since January 2004 the plant has been operating using liquefied nitrogen.

Pumped storage power plant

In Korea, pumped storage power plants usually consist of intake tunnels, headrace tunnels, surge chambers, underground powerhouse, penstock tunnels, tailrace tunnels and cable tunnels. The underground powerhouses have the largest cross sectional area. Penstock tunnels that are under high water pressure require the most sophisticated technology to ensure stability. Chongpyong pumped storage power plant, the first one constructed in Korea, started service in 1980. Table 2 (above) shows the current situation of the pumped storage power plants in Korea.

Subway construction projects

In Seoul, a network of 337km of subway lines has been open to public since the first subway in 1974. Until the introduction of NATM in 1980 the conventional method using steel support had been used. As shown in Table 3 (below) currently six major cities have subway systems.

Seoul, the capital city, has more than 2.9M automotive vehicles, which increases annually by about 200,000. Seoul has a subway network of eight lines in operation and one line under construction. The system is well connected with the Korean National Railways.

In 1990 TBMs were introduced, and recently shield TBMs were used for subway tunnels. To cross rivers and streams construction methods using TBMs or cut-and-cover with cofferdams have been used. In the cases of the sufficient overburden under the riverbed the bored tunnelling method was used, while in cases of the shallow overburden the cut-and-cover method was used. Unlike the previous method of crossing the Han River by the viaduct, a section of Line Five connects the Yoido and Mapo by a 1,280m tunnel beneath the riverbed.

In 1996 the excavation of two parallel tunnels 20-30m beneath the riverbed was completed. A manmade island was built in the middle of the route. The main rock type of the tunnel was banded gneiss. The rock mass was in poor condition revealing weathered and fractured zones along the discontinuities. To strengthen the rock mass and to decrease the water inflow prior to face advancing, the ground within 7m around the tunnel was grouted.

The Bundang subway tunnel that passes beneath the Han riverbed was constructed. The average rock cover is 23m and the total length of the tunnel is 1,270m. It took 18 months for the completion of the tunnel. The length of ground section constructed by drill and blast is 380.5m and the length of the river-bed passing section constructed by an EPB TBM is 845.5m. The structures of tunnel include two ventilating openings and two shelter connection pits. The use of EPB type shield TBM increases stability and workability during digging of the fractured zone and hard rock mass. The disaster prevention system consists of water leakage sensing systems, water protection gates, pumping systems and fire protection.

Table 3: Metro systems

City	Lines	Stations	Length of tunnel (m)	Year of opening
Seoul	8	409	337	1974
Busan	3	90	112	1985
Incheon	1	22	101	1999
Daegu	2	56	154	1997
Gwangju	1	19	103	2004
Daejeon	1	22	101	2006
Total	17	618	908	

Railway tunnels

In 1905 the first railway tunnel was built. Today the total length of railway tunnels is 356km, with the longest running for 6.1km. The most interesting project is the Solan tunnel, which has a length of 16.3km and will be the longest tunnel in Korea. A special loop shape has been employed to overcome abrupt gradient changes. The tunnel must run through fractured zones of limestone, large faults and abandoned coal mines. High-speed rail tunnels are both in service and partly under construction, comprising 191km, or 46 percent of the alignment's total length. There are a total of 80 tunnels along the route with nine tunnels more than 5km long. The longest tunnel is 18.5km. As of April 2004, Korea has been on par with France, Japan, Germany and Spain, and entered into the super high-speed train era operating at speeds of 300km per hour. The double-track tunnel internal cross-sectional area of 107sqm is based on a design speed of 350km/h.

Above: Figure 2, Korea-Japan subsea tunnel routes

NATM has been used for mountain tunnels and TBMs for the tunnels crossing beneath rivers. The cut-and-cover method is only used for tunnels relatively close to the ground surface or in various situations where the NATM or TBM cannot be applied effectively and economically.

Road tunnels

Korean roads are classified into several types: national expressways, national highways, provincial roads, city roads and country roads. Tables 4 and 5 show road tunnels in Korea that are in use or under construction. The longest road tunnel is the Juk-Ryeoung Tunnel, which is 11.6m wide, 7.2m high and 4.6km long.

Since the 1980s NATM has been used as a tunnelling method. There are also several cases in which TBMs were adopted for road tunnel excavation. Between 1927 and 1932 the Chungmu subsea road tunnel was constructed by cut-and-cover. The subsea tunnel is 5m wide, 3.5m high and 483m long. The 3.2km long Busan-Geoje immersed tunnel, now under construction in Korea, will be the deepest tunnel built using the concrete segmental immersed tube system. The immersed tunnel is constructed as a concrete tunnel and is connecting two artificial islands containing service buildings: one at the Jungjuk/Daejuk Island and one at the Gaduk Island.

Another 6.9km long subsea tunnelling work will be started on the coast of Boryong city later this year. The tunnel has its deepest point 34m below sea level and a rock overburden of over 40m. The ground is made up of granite and schist. The main tunnel is 11.9m wide and 8.3m high. The escape tunnel is 6.4m wide and 5.5m high for cars, while 3.6m wide and 4.1m high for passengers. The tunnel will be excavated by drill and blast.

Other underground facilities

Underground space is widely used in Korea for water supply tunnels (145km), multi-purpose utility tunnels (87km), military bunkers, five research laboratories, car parks, 70 shopping malls, five mine museums, five wine shops and 10 mushroom farms. Ultra-long subsea tunnels are being considered, such as a link from Korea to Japan and Korea to China. There are three routes for Korea-Japan subsea tunnel (table 6, below, and figure 2, left). Four routes have been considered for a Korea-China subsea tunnel that would be constructed beneath the Yellow Sea, which has and average depth of 40m and a maximum of 76m.

Table 4: Total length of road tunnels

Type	Number	Length (km)
National expressway	402	315
National highway	272	173
Provincial road, city road and country road	258	161
Total	932	649

Table 5: Number of road tunnels

Type	<500m	500 to 1,000m	1,000m<
National expressway	157	162	82
National highway	138	99	35
Provincial road, city road and country road	148	65	45
Total	444	326	162

Table 6: Korea-Japan subsea tunnel option

Routes	Maximum water depth (m)	Total length (km)	Subsea tunnel section (km)	Inland tunnel section (km)
A	155	209	145	64
B	60	217	141	76
C	220	231	128	103

Conclusion

Korea has many world-scale underground structures and many large projects are in progress. Despite the steady expansion of its infrastructure, rapid industrial development and population growth in urban areas still create many problems such as traffic congestion and environmental concerns. Continuous development of the underground space in the future is expected to resolve some of these problems.

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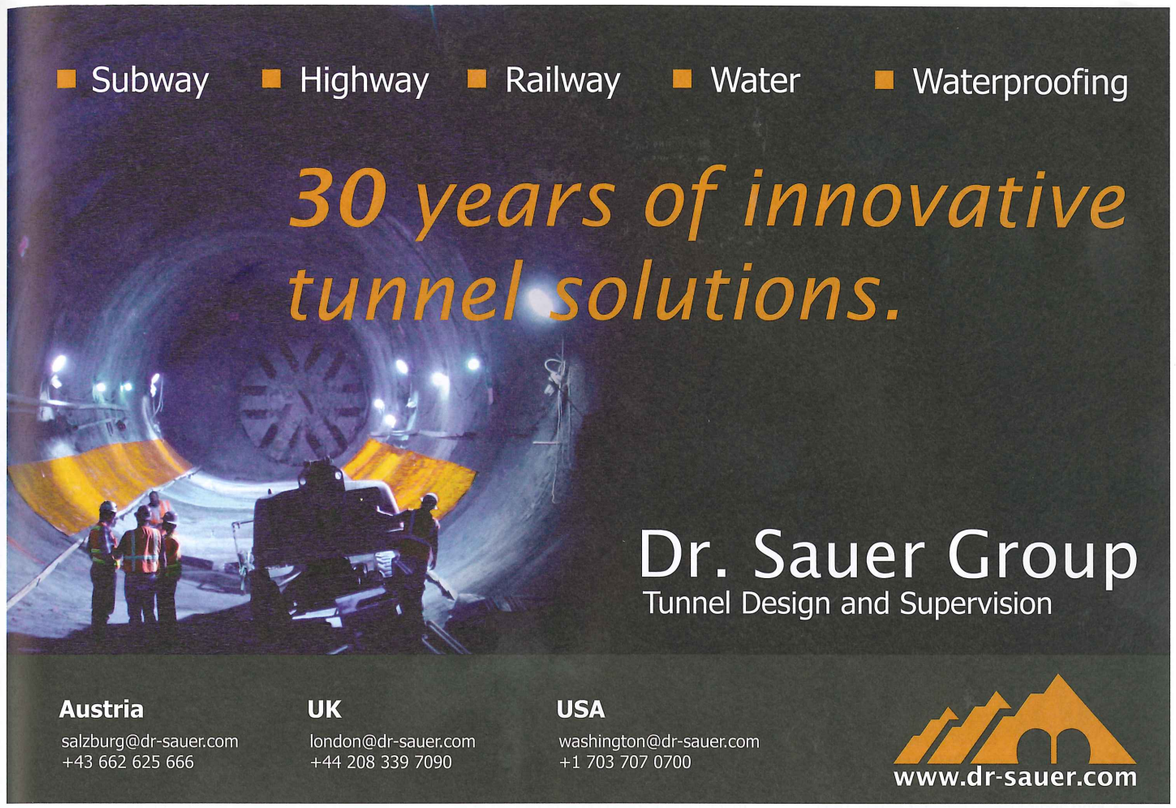
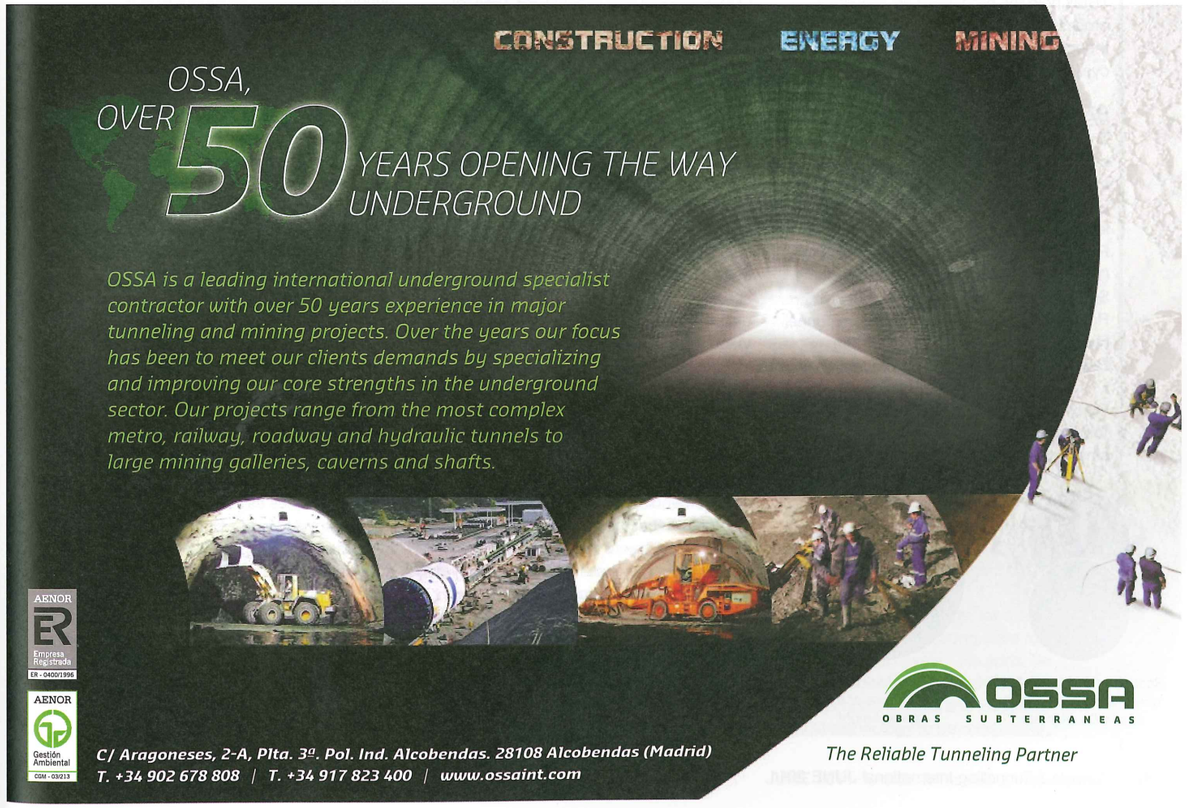




Choices for excavation – part 2

In this second and final part of our review of the extended capabilities of modern tunnel excavation methods, we examine the leading role of tunnel boring machines. Maurice Jones contacted some leading TBM manufacturers for their views and developments to expand the envelope of capabilities

While there have been major developments in the capabiltiies of all major tunnel excavation methods in recent years, it is TBMs that have led the drive for more efficient tunnelling, at least of long and/or large diameter bores. They have also improved the security of tunnelling in urban environments where ground control is a particular concern. TBMs hold the promise of an 'industrial' process for constructing a tunnel even though, in most cases, the process is still cyclical rather than continuous.

Size matters

The maximum diameter records for TBMs, both planned and actually constructed, have been broken regularly in recent years, albeit by small increments. Herrenknecht leads the way in most cases with the Fourth Elbe Tunnel (14.65m), Madrid M-30 (15.20m), Shanghai (15.43m), and now the Sparvo Tunnel in Italy (15.62m), but also Robbins for hard-rock in the Niagara Tunnel hydropower drives with the TBM 'Big Becky' (14.4m diameter), that recently broke through on its final drive, and NFM (14.87m o.d.) for the Groene Hart high-speed rail tunnel in The Netherlands a few years ago.

Hitachi Zosen's largest diameter TBM to date, at 14.14m, is the slurry-shield machine employed by a JV of Kumagai Gumi, Hazama and JDC for the Trans-Tokyo Bay Highway project on the Kawasaki Tunnel Ukishima North Phase One. Previously the largest EPB TBM to have worked in Japan was of 13.6m diameter, having recently completed excavation of the Central Circular Shinagawa Ohi highway tunnel.

Despite suspicions amongst many that the increasing size of TBMs was just a matter of 'one-up-manship', the larger diameters can be easily justified if the capacity is required, as it often is for busy road tunnels. The usual philosophy is that construction of one large tunnel bore is more economical than two smaller ones although, as ever, site conditions might dictate otherwise. Now the Alaskan Way Viaduct Replacement Project is due to use the largest diameter TBM to be built yet, at 16.5-17.0m, following studies of the twin-bore alternative as well. Selection criteria over side-by-side twin bores included lower purchase cost, a smaller operating team, a narrower settlement corridor and escape arrangements.

It follows that the manufacturer has to have the facilities to manufacture and transport such monster TBMs, usually involving cavernous workshops, which have often been in short supply, and carefully planned logistics to reach the tunnel launch site.

Robbins president Lok Home confirms that logistics for site delivery can be a factor limiting TBM size, as can the availability of large machine tools to machine the large components of a TBM. 'Despite these challenges diameters of up to 20m are feasible today, with larger diameters possible in the next 10-20 years."

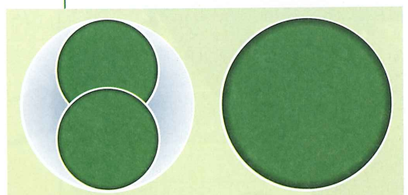
Italian contractor and manufacturer Seli entered in a five-year co-operation agreement with Japanese manufacturer Kawasaki in April to develop earth-pressure-balance TBMs further, and their overall market. Seli president Remo Grandori also believes that TBMs of up to 20m diameter are mechanically feasible today. Although some proponents of drill-and-blast have questioned the desirability of such large machines, particularly in mixed ground, Grandori says, "TBMs for large diameters are always better than conventional methods for tunnels in soil and/or weak rock. In hard, but not abrasive rocks like limestones, the convenience of large diameter TBMs depends on the length of the tunnel, lining, and design requirements. For hard and abrasive rock formations like granitic rock, normally conventional excavation is preferable for large diameter tunnels."

And shape

It most cases the use of TBMs is synonymous with achieving circular bores, but non-circular bores are possible with similar machines as has been the case in Japan for many years. Such special designs are still in active use there to meet special requirements. Risa Hirano of Hitachi Zosen points out that the spoil excavated by a special-shape 'TBM' can be less than that of a single, circular TBM (as shown in figure 1). Such special TBMs can also be used to avoid the numerous underground obstacles (see below), where a circular TBM would not fit. It is usual in Japan to only use TBMs under public space and not private space, particularly under structures, further restricting easement.

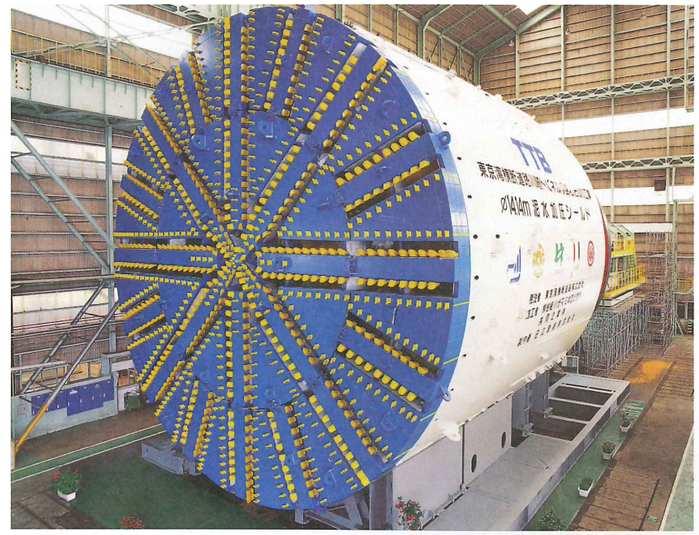
It is also worth noting that circular TBMs have been used to carry out the bulk of excavation in larger, non-circular sections such as the hard-rock cavern in New York's East Side Access Project under Manhattan.

Below: **Figure 1, comparison of twin 'binocular' mechanical excavation with a single, circular TBM bore [Hitachi Zosen]**



Section of TBM with twin overlapping cutterheads of smaller diameter

Section of full diameter TBM bore of the same height



Above: **Hitachi Zosen's largest TBM is a slurry-shield machine for the Trans-Tokyo Bay (TTB) Highway project, Kawasaki Tunnel Ukishima North Phase One.**

Long drives

It is generally accepted, even by proponents of drill and blast (D&B), that TBMs have a great advantage over D&B when the project has long tunnel drives – variously described as over 2500-3000m depending on other conditions. If the project consists of one heading the bias is also towards a TBM as the D&B process is more cyclical. In general the faster speed of TBM progress outweighs the longer set-up time for the TBM once the drive, including any pull-throughs, is over the stated length.

According to Lok Home there are also other major criteria to be considered. "The project schedule must be able to accept the longer TBM delivery period, compared to drill and blast equipment."

Substantial savings can be made by reducing or eliminating set-up times so as this part of the process can be more competitive with D&B, increasing the theoretical advantage of TBMs. If the topography allows, it is preferable to launch the TBM from a fairly level surface straight through a portal into the drive, such as through a mountain. If launch and/or reception shafts are necessary, this will increase the time required for set up due to the restricted space available. Robbins, for example, has made efforts to reduce set-up times with its Onsite First Time Assembly (OFTA) procedure as used in Mexico City and Andhra Pradesh.

Another approach, facilitated by the accuracy of modern directional monitoring and guidance systems, is to eliminate shafts with planned vertical curves. Such approaches were pioneered for microtunnelling and other small-bore systems, following the example of directional drilling/guided boring, but now the principle has begun to be applied to larger and larger diameters, employing special steel structures to achieve the initial thrust reaction necessary such as with the Herrenknecht TBMs in St Petersburg driving metro connections at steep grades.

Hitachi Zosen cites the example of the so-called URUP method employed by a JV of contractor Obayashi and Jinno for an undersea gas pipeline conduit for Chubu Gas. It employed a Hitachi Zosen EPBM with a 2.13m cutterhead for a 1.1km-long drive. No shafts are necessary in this procedure, the first drive of which was completed a few months ago.

Once the set-up has been made, the maximum length of a single drive is generally well over most current needs. Remo Grandori, president of Italian engineers Seli, reports, "The maximum length of tunnel we have excavated from one portal is 25km, and we could have continued for a few kilometres more. Normally the limiting or critical factors, in maximum length, are ventilation and transport systems for spoil and personnel. The tunnel diameter therefore has an influence since, in smaller tunnels, it is difficult to fit in a suitable ventilation system and transport system. In general the ideal diameters to bore long distance are between five and six metres."

"For greater lengths than 25km, or with smaller tunnels, intermediate shafts can help with ventilation and/or mucking out."

Similarly Home reports, "We have tunnels currently under construction that are over 25km in length, double this distance could certainly be feasibile."

These statements concentrate on technical capabilities whereas the limiting factor is usually running cost. Home says, "After 10,000m, the costs per metre goes up as amortisation of the basic machine is no longer the driving cost factor. Other factors come into play at this point, such as labour-related costs to get to the machine (mainly muck haulage over a long distance and adequate ventilation). Long distance tunnels also mean more risk because less geological knowledge is typically available over the entire length."

Hard and soft

Several experts have remarked that excavation choice 'all starts with the ground conditions'. While TBMs, in general, have become better at tackling a wide range of ground conditions, mixed ground still presents the most difficult challenges. Mixed ground, particularly with hard inclusions, could cause havoc with excess wear and other damage to cutters if they are not designed for it, thus causing delays and extra running costs even with backload changing possible.

Expert Lok Home of Robbins claims, 'A mixed face isn't really problematic for disc cutters. Today's high quality designs are capable of excavation in a wide range of conditions, so the percentage of rock in the tunnel face is not problematic.

Grandori commented, "Large-diameter cutters with stronger bearings and discs can handle mixed faces and hard-rock intrusions without problems. Of course the TBM in these conditions must be operated properly."

At the extremes, Home, for example, claims, "There is no strong, hard rock that a TBM cannot excavate." He adds, "In unstable squeezing ground TBMs need design improvements and integration of NATM technology to be competitive."

Above: **Breakthrough on the Brenner base tunnel pilot bore (10.5km long) by the ATB Consortium using a 6.3m-diameter Aker Wirth double-shield TBM**

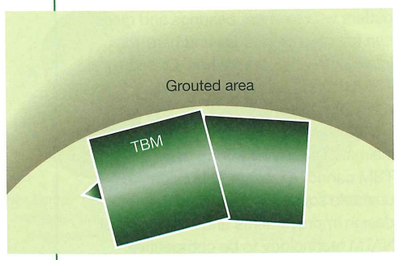
Performance

The main advantage of TBMs is speed, once set up, so what can be expected? Remo Grandori of Seli says, "In (ideal) rock the record advance rates we have performed for excavation and precast lining are 2500m in one month (30 days) and 110m in one day. In soft/EPB TBM operation the records we achieved are in the range of 22 rings (33m) per day. A rock TBM should normally perform better than 20m/day to 'overkill' drill and blast."

Precision

Highly sophisticated, laser-based, directional monitoring and guidance systems are now widely available for all types of TBM. Not only are these used to ensure precise direction in all planes, including around curves, but also to optimise installation of pre-cast segmental support rings. Their integration into the overall TBM control system aids ground control.

Even with all this sophisticated instrumentation and guidance systems, the ground properties can still make guidance difficult, especially if very mixed or soft. Risa Hirano of Hitachi Zosen says, "It is popular in Japan to excavate tight curves with small/middle-size TBMs. Contractors have to do grouting [to make soil solid] on the external side of the curve when going round it in very soft ground [see figure 2]. If they do not grout the external side of the curve the TBM will go straight, not making the turn."



Left: **Figure 2, it may be necessary to grout the outside of a curve to provide enough resistance to enable the TBM to follow a curve [Hitachi Zosen]**

Good neighbours

There are many factors affecting whether a tunnel excavation method is suitable for urban environments including, primarily, settlement control, as well as noise/vibration, spoil transport, supplies delivery, services and road diversions, and rights of way.

TBMs offer many advantages under cities, at least in theory, helping to increase the amount of tunnelling under densly populated areas, particularly in difficult ground, but ground control is always of particular concern, especially to avoid differential settlement that may damage adjacent and overlying structures. TBMs offer the prospect of more accurate control of excavation rates, which is now beginning to be linked with the geotechnical instrumented monitoring of structures. Such control can also be of benefit in non-urban situations, particularly where the ground structure is understood to be potentially unstable. Developments in the use of EPBMs, especially the use of additives for soil conditioning, have greatly improved ground control measures and the range of ground that can be tackled more simply. That is not to say that EPBMs do not still need skilled operation and application expertise.

Other ground support and monitoring systems can be used in conjunction with TBMs, even though a TBM can be an integrated system itself. "Face support, ground conditioning, backfill grouting and monitoring...all these technologies are improved year by year by the industry and today technology is well advanced," say's Seli's Remo Grandori.

Of course accurate monitoring of settlement is not just a matter of checking on its effects but also the usual cause – over excavation – including the measurement of material removed by hard rock and EPBMs. "The most commonly used systems are measuring devices that calculate the volume of muck removed," says Home. "These include radar monitoring of the the muck profile, and belt scales. Radar devices 'fire' down on the belt over a certain area, measuring the height of the muck. They then calculate the volume of muck being moved out versus the TBM advance rate in order to prevent voids. The radar method is not as useful for slurry machines because useful data cannot be generated when the radar passes through the slurry material."

But, predicting future performance in the ground is not so easy. Home adds, "As an industry we haven't advanced very far in terms of good monitoring or predicting ground conditions in advance of the face. The primary and best method is still probe drilling. This and pre-grouting are absolutely recommended and, in most case, necessary. Probing and grouting are becoming integrated into TBM design, which allows for ground consolidation ahead of the machine. New systems such as the McNally Ground Support System utilise steel or wood slats to hold disturbed rock in place, with the result of vastly increased safety."

In hard ground under built-up areas, where ground control is unlikely to be so much of a problem, TBMs can still have some advantages over the main competition of roadheaders and drill and blast. "Roadheaders have their limits in hard rock," says Home, "Particularly above 100 MPa UCS, when advance rates tend to drop off dramatically. D&B is restricted in many urban areas because of regulations on the use of explosives. In general TBMs are more cost effective in urban environments," he claims, "Although it depends somewhat on the individual project conditions."

Urban environments are often crowded underground as well as on the surface. This can be a particular problem in Japan affecting passage rights.

Hirano points out that there are a lot of obstacles including pipes, other tunnels and piles of various types. "If the government cannot acquire enough cross section for a single, circular TBM avoiding such obstacles, they could use an odd-shaped such as horseshoe section, rectangular or twin-circular."

Ground control extras

Where sufficient ground support cannot be assured by normal TBM control methods, such as face pressure counterbalance, excavation volume control and designed lining, design engineers may insist on other measures that could necessitate modifications to the TBM to create necessary space for, typically, probe drills, rock-bolting rigs, grouting and sprayed concrete systems.

Opinion seems divided on the need for such measures but obviously a lot depends on the ground conditions anticipated and/or encountered, especially such features as cavities, flowing ground and high groundwater pressures. Even so, such additional equipment may not be enough.

Grandori states, "A TBM should be equipped with probe drilling and grouting facilities but this is not sufficient to overcome all adverse geological conditions. New TBM designs and extended pre-treatment facilities have been developed, and are being continuously developed by TBM manufacturers including Seli."

Hirano reports that probe drilling is not so popular in Japan, partly because the government and contractors already know well what obstacles are in the ground before starting construction. Also the commonly used small-diameter TBMs do not have enough room for probe drills to be built in the TBM assembly. If unforeseen obstacles are encountered, it may be necessary to disassemble the interior of the smaller diameter TBMs to make room for probe drilling.

As for grouting, contractors in Japan sometimes do separate operations from the surface, including the improvement of ground properties for better TBM control, as mentioned previously.

Above: **Probe drilling within a Robbins double-shield on the Pula Subbaiah Veligonds water transfer project in Andhra Pradesh, India**

The cost

However efficient a TBM might be in mechanical terms, the project budget must be able to handle the cost of the TBM selected, but, as stated earlier, the faster progress of TBMs can compensate for this over longer drives in project amortisation and cost per metre.

Home says, "The cost of TBM boring per metre must be considered in terms of the faster speed, less ground support necessary, and better physical structure compared to drill and blast; all of which ultimately makes the TBM method more cost effective in longer tunnels."

Post-project second-hand value or manufacturer buy-back options might also help, but often the machine is written off against the project. This may include the TBM shield, at least, being 'sacrificed' in the ground, either sealed off or used as part of support design.

Overall the cost of the TBM(s) is a vital matter for negotiation in the financial as well as the physical success of a project.

Many suppliers are also experts in refurbishing previously used TBMs to reduce costs.

Seli has been a leader in refurbishment. President Remo Grandori reckons that TBMs tend to depreciate 70-80 per cent on the first project. If refurbished for a second project costs for this, he says, vary between 15 and 20 per cent of the cost new, if no modifications are required.

Whilst price can be forecast, it is virtually impossible to predict running costs without reference to particular project conditions. In addition to amortisation, running costs that must be considered include power, lubricants, cutters, service parts, other consumables and manpower costs. However, more generally, cost per metre rise with drive length and can be a limiting factor as stated previously.

Right: **This Seli double-shield is designed for tough duties in squeezing ground for HCC on the 14km-long Kishanganga hydro project in northern Kashmir**

Changing envelopes

The review of tunnel excavation methods in this and our May issue holds no claim to be comprehensive. However, we hope to have covered major issues and have highlighted recent trends in the possibilities in using TBMs, drill and blast and roadheaders, and in what circumstances they compete.

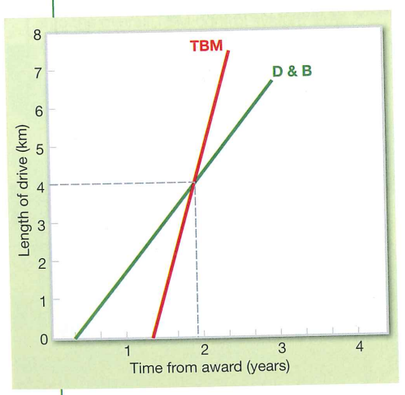
Large-section, or sequential excavation open-face methods have not been covered in this review since they can use a wide variety of excavation means such as conventional hydraulic excavators and hydraulic hammers as well as the drill and blast and roadheaders already mentioned. Such operations require integrated and careful attention to temporary as well as permanent support measures and philosophies such as NATM and Analysis of Controlled Deformation in Rocks and Soils (ADECO-RS).

The advances in the development and capabilties of TBMs has made this method the 'yardstick' by which other methods are now measured. The promise of a factory-like means by which tunnels can be constructed has been very attractive, especially with the increase in instrumented functions.

Hard rock

Since Dick Robbin's development of disc cutters for TBMs broke the drill and blast monopoly for hard-rock tunnelling, a major focus has been on the achievements made by hard-rock TBMs, but that is far from the whole story. Whether through familiarity, the length of drives required, rapid set-ups or lower investment, drill and blast still retains a high proportion of the market in all areas.

It is widely accepted, at least in Scandinavia, that Atlas Copco and Sandvik between them still supply around 80 per cent of the world market in hard-rock tunnelling, although on long drives the general preference must be for TBMs (see figure 1) for overall economy.



Left: Figure 1, graph showing generalised break even point between use of TBMs compared to drill and blast (by The Robbins Company)

Urban challenges

With the booming market in metro systems and other urban underground excavations, the interaction between existing structures and the population on the one hand, and tunnelling operations on the other, have been increasingly important. The introduction of EPBMs, and then soil conditioning systems, has simplified tunnelling in softer ground and expanded tunnelling possibilities in urban areas and previously unsuitable ground.

Asymmetrical excavations for stations and other underground space are generally unsuitable for TBMs, although the hard-rock cavern in New Work's East Side Access project, with other methods, is a notable exception. In most circumstances, open box construction if surface features allow or sequential excavation is more typical.

A concern in many urban locations is that of vibration. Roadheaders can benefit from such concerns over drill and blast, although locations familiar with drill and blast, such as the WTC host, Helsinki, see no problems with drill and blast for this reason. Tunnellers in other areas familiar with roadheaders, such as Australia, swear by them. Some cities have banned drill and blast due to vibration concerns. This situation has been combated by manufacturers' development of multiple detonators and more adjustable explosive charges to reduce blasting shock.

The big ones

Other major trends in the use of TBMs has been steadily increasing maximum diameters achieved and the maximum possible length of drives.

TBM manufacturers are confident of manufacturing TBMs of 20-m diameter, or perhaps more, and drives of over 25km long have already been completed. Such maxima are generally beyond the economic capabilities of other methods, even if technically feasible, although some doubt has been expressed about the desirability, in ground control terms, of very large diameter TBMs working. It remains whether the client and their consultants want excavations of these maxima. Studies have shown that large single bores are preferable in construction terms to two smaller bores.

Drill and blast, roadheaders and hydraulic excavators can be used with multiple units for large section excavations in suitable ground types, but in softer or saturated ground, substantial ground pre-treatment would be required, raising cost.

Accuracy

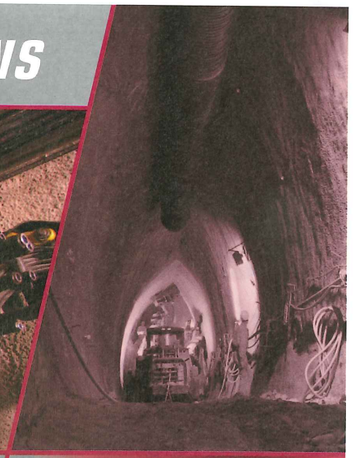
Manufacturers of TBMs claim that the improved accuracy now possible with drill and blast and roadheaders has not affected their market, but it must have made the existing markets those techniques more secure. There is a greater demand for smooth profiles, not only to avoid overbreak and damage to the support qualities of the ground itself, but also to reduce lining costs and provide better surfaces for membrane linings.

Computerised drilling guidance, with drill pattern design input, has allowed peripheral holes to be drilled more accurately. More rigid drill booms have also reduced hole deviation. This, together with improvements in blasting agents, as mentioned above, produce a cleaner break at the designed profile.

Modern guidance systems can now be applied to roadheaders, whereas until recently the movement and vibration of the machines made accurate guidance very difficult. The high-power, heavy roadheaders made for tunnelling can generate large vibrations from slow cutter speeds, and the weight might cause them to sink in softer ground. Now the new generation of lighter yet powerful roadheaders like the Sandvik MT520 can cut harder rock to an accurate profile although not with practicality in the hardest rock.

Maurice Jones

GROUND CONTROL SOLUTIONS



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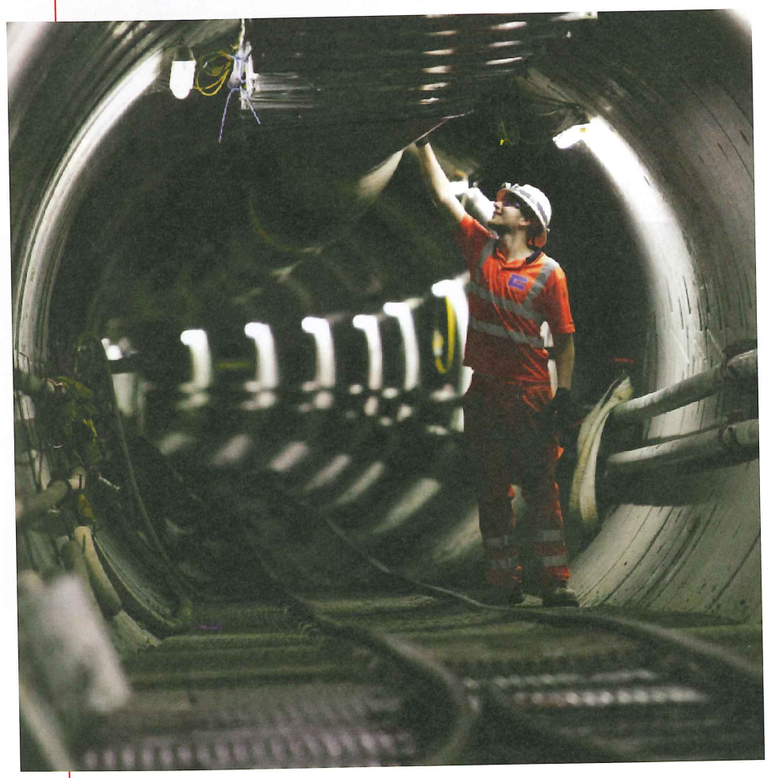
Settlement on the West Ham Flood Alleviation Scheme

Robert Milner of Halcrow won the British Tunnelling Society 2011 Harding Prize this year for this paper comparing predicted settlement with actual settlement



This paper presents the recorded ground surface settlements due to the main tunnel drive on the West Ham Flood Alleviation Scheme. These results are compared to 'green field' settlement predictions made during the design stage to correlate the accuracy of methods used to predict settlement; in particular the assumptions made for ground loss due to tunnelling.

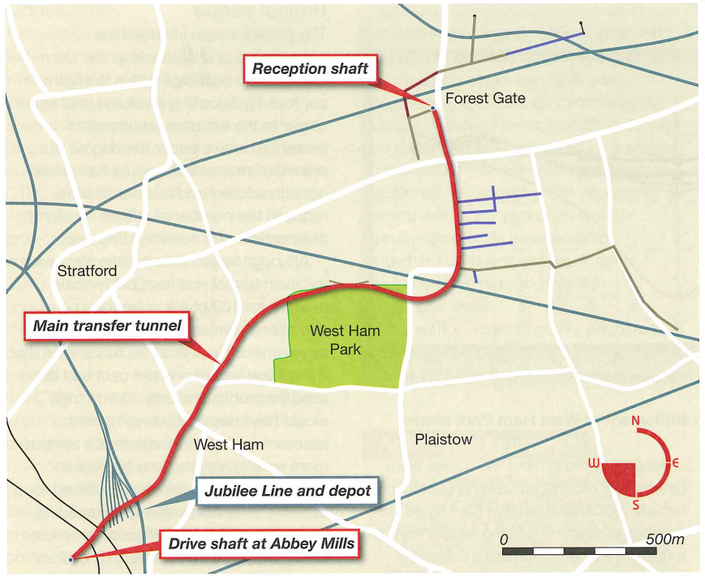
Project overview

The purpose of the West Ham Flood Alleviation Scheme is to reduce the risk of flooding to over 400 properties due to the sewer system overflowing during periods of heavy rainfall. The project was constructed for Thames Water by Costain with Halcrow acting as the detailed designer. The scheme comprised the construction of sewer upgrade works, microtunnels and a 3.3km long 2.87m internal diameter (ID) main transfer tunnel. The main tunnel passes beneath a busy urban environment including residential areas, West Ham Park and several third party assets including the Jubilee Line and Stratford Market Depot.

The Geology across the site comprises of Made Ground underlain by River Terrace Gravels, London Clay, Harwich Formation, Lambeth Group, Thanet Sand and then Chalk. The tunnel was constructed at depths ranging between 10 and 25m, predominantly through the Lambeth Group. The Lambeth Group in this area consists of layers of clay, gravel and sand and contains bands or pockets of shells, silt and fine sands. This stratum also includes bands of calcrete and ferricrete and pressurised perched water within layers of pebble gravels and sand, all potentially hazardous for tunnelling.

Three separate aquifers were also present at the site. The upper aquifer is situated within the superficial deposits overlying the London Clay, the middle aquifer within the Lambeth Group and the lower aquifer in the Thanet Sand and Chalk strata. The tunnel was driven within the middle aquifer and the intermediate zone between the middle and upper aquifers. The varied geology and groundwater conditions (above) acted to destabilise the tunnelling, causing the tunnel face to become unstable, increasing the difficulty in minimising face losses and settlement.

To cope with this complex geology, and address the risk of ground loss the tunnel was driven using a Lovat EPB TBM. The 2.87m ID lining was constructed using 175mm thick steel fibre reinforced concrete segments. The outside tunnel diameter is 3.22m and the excavated diameter during tunnelling was approximately 3.28m.



Above: **Figure 1, plan of the West Ham Flood Alleviation Scheme alignment showing the main tunnel drive**

Settlement predictions

As monitoring was conducted during and for a relatively short time after the passage of the TBM, results and analysis presented in this paper only relate to short term settlement due to construction.

The surface settlement due to tunnel construction was predicted according to the O'Reilly and New method which assumes post tunnelling settlement occurs at right angles to the tunnel axis and approximates to an inverted Gaussian (or normal) distribution curve. The magnitude of settlement is closely related to the trough width coefficient (k) and volume loss. The former is considered to be dependent on the geology present at and above the tunnel which for this project was a mix of cohesive clay and granular material. Following guidance provided in CIRIA Project Report 30, and also past experience, a k value of 0.45 was used for the main tunnel drive.

A volume loss of two per cent was specified within the Thames Water standards. This value is consistent with past experience of tunnel construction using open face tunnelling machines, such as on the Jubilee Line extension where a two per cent value was used for predictions and measured volume losses ranged from 1.1 to 3.3 per cent. The larger loses were concluded to be due to 'a lack of adequate support' where excavation was carried out up to 1.9m in front of the shield. But these values are not thought to be consistent with modern EPB or slurry TBM construction.

Settlement due to tunnel construction at West Ham was predicted as between eight and 13mm. In order to record settlement, surface monitoring pins were installed in arrays perpendicular to the tunnel with points above the centre line of the tunnel, at the predicted 5mm and 1mm contour points and outside of the 1mm contours. The arrays were spaced approximately every 50m along the tunnel drive and monitoring was carried out to an accuracy of plus or minus 0.5mm.

Settlement Results

Two particular areas of interest on the tunnel drive were:

- West Ham Park.
- The Jubilee Line depot and adjacent eastbound and westbound running lines.

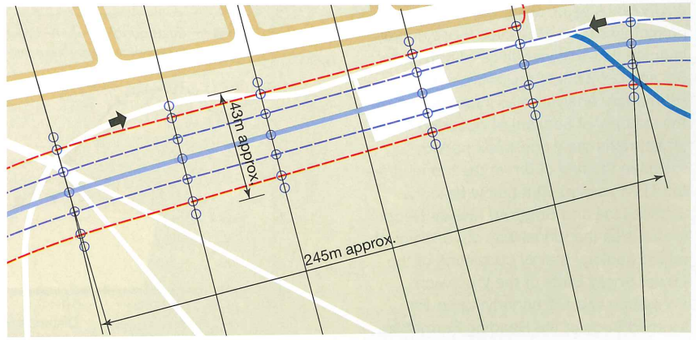
A total of 40 monitoring points were installed within West Ham Park in a series of six arrays (see Figure 2).

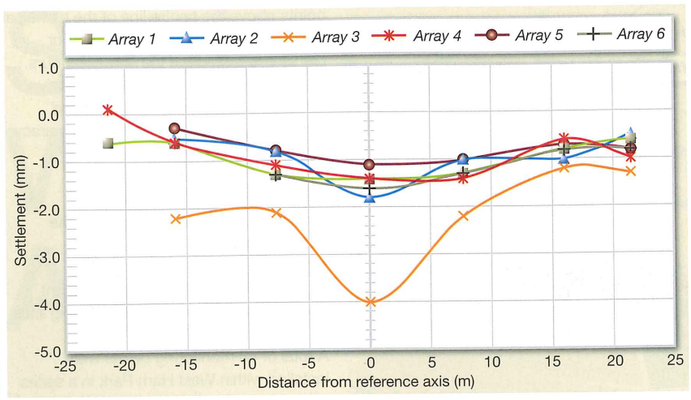
In this paper particular attention was paid to the results obtained from monitoring these six arrays because they can be considered to provide results of 'green field' settlement, as there is no road surface, hard standing or foundations present. Areas of hard standing tend to modify the settlement trough at surface producing a shallower and flatter curve. In this area the tunnel was constructed within the Upnor Formation and the overlying Lower Mottled Beds of the Reading Formation.

The final set of settlement measurements recorded in the six arrays is plotted in figure 3.

Some scatter and small anomalies are present within the data, as would be expected, but the readings at these arrays appear to show the typical Gaussian curve used for predicting settlement. Back analysis of these results using curve fitting techniques indicates that volume loss was generally in the range of 0.3 to 0.6 per cent, although array three indicated a volume loss of approximately one per cent. The reason for this variation is unclear.

Below: **Figure 2, plan of monitoring arrays at West Ham Park**





Above: Figure 3, final recorded construction settlement at West Ham Park arrays

These results are in line with measurements taken from the CTRL London Tunnels, also constructed using an EPB TBM in mixed ground including the Lambeth Group, where volume losses were generally between 0.2 and 0.8 per cent . The obvious difference between these

Above: Figure 5, extent of monitoring shown on aerial photo of the Jubilee Line depot

tunnels is that the West Ham tunnel is less than half the diameter of the 7.15m ID CTRL tunnel, and has a face with approximately one sixth of the area.

As previously stated the trough width coefficient k value assumed for the project was 0.45. However, these curves indicate that a higher value of between 0.5 and 0.7 would provide a better estimation. Analysis also indicated that the majority of settlement occurred over an approximately one week period.

Within the first 500m of the tunnel drive the TBM passed 20m below both the Jubilee Line and Stratford Market Depot. In this area the tunnel was driven through mixed geology mainly consisting of the Lower Shelly Beds of the Woolwich Formation and the underlying Lower Mottled Beds of the Reading Formation.

As part of the project the tracks were extensively monitored using an automated remote monitoring system (see figure 5).

When plotted, monitoring results from the running lines demonstrated a Gaussian settlement curve with a maximum settlement of approximately 3mm (see figure 6).

This maximum track settlement value is significantly less than the 8.5mm predicted. For clarity, measurements from the 20 sidings in the depot are not shown here but were generally found to be consistent with the Jubilee Line tracks showing a maximum settlement of between two and 4mm and also exhibited similar shaped curves.

From the data a volume loss of between 0.5 and one per cent would seem reasonable, and this broadly concurs with the analysis at West Ham Park. Also a higher than predicted trough width coefficient k value of between 0.6 and 0.9 was exhibited which would be expected due to the presence of the railway tracks modifying the settlement trough.

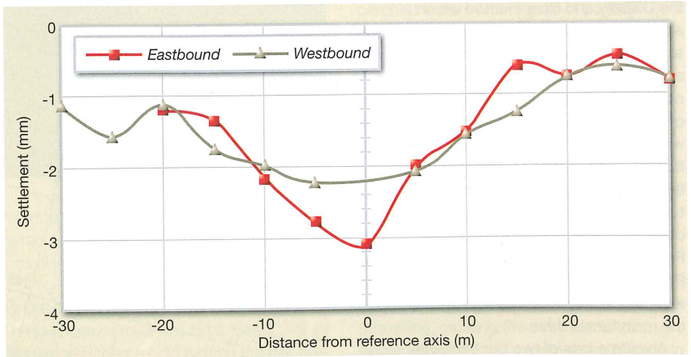
Project scope

The project scope included the assessment of utilities within the 1mm contour and buildings within the 5mm contour. By adopting a volume loss figure closer to the actual measurements presented in this paper the degree of predicted movements would have been greatly reduced and this would have reduced the number of utilities requiring assessment and possibly diversion.

Although where possible the alignment of the main tunnel was kept below main roads, over 100 buildings required condition surveys and stage two assessment. Back analysis has shown that if a volume loss of one per cent had been used for predictions only 30 buildings would have required surveying and assessment. In combination with using a more realistic volume loss figure it is suggested that monitoring be utilised to assess the risk of settlement exceeding predictions, allowing mitigation measures to be employed, if necessary. Therefore adopting this approach could help to avoid unnecessary, expensive and disruptive building protection works and thereby minimise public concern regarding possible damage to their homes as well as providing significant savings to the project.

On the project approval was required to tunnel beneath several third party assets including Network Rail structures, London Underground lines and Utility tunnels. It is likely that the use of a more realistic volume loss figure for assessments of third party infrastructure would give asset owners greater confidence that their assets will not be adversely affected by construction. The author believes this would make gaining approvals for future projects a simpler and more cost efficient process.

Below: Figure 6, jubilee Line maximum settlement readings



Conclusion

Tunnelling was predominantly carried out within the difficult Lambeth Group stratum where there is a significant risk of inundation of water and ground. The analysis showed that volume losses in the range of 0.3 to one per cent were achieved during tunnelling. This is comparable to the CTRL project constructed in similar strata with a much larger diameter tunnel. Both projects demonstrate that volume losses can be controlled in difficult geology by using modern EPBs, which provide continued support to the face. This leads the author to conclude that two per cent is overly conservative for this type of tunnelling and to agree with findings from the CTRL project that the two per cent loss assumed 'could probably reasonably be halved for future similar works'.

Adopting a two per cent volume loss figure for future projects using modern TBMs is likely to produce misleading predictions and increase project scope and costs. As shown in this paper by using a more realistic one per cent volume loss figure the number of buildings requiring assessment and condition surveys on the West Ham project could have been reduced by 70 per cent. It is expected that the number of utilities requiring assessment and diversion could also have been considerably reduced. By minimising the number of assessments, condition surveys and mitigation works required for a project a client could make considerable savings. Additionally by adopting this approach, gaining third party approvals would become simpler as more realistic settlement or movement predictions would be more likely to be within acceptable limits.

The author would therefore encourage a move away from adopting a two per cent volume loss figure for predictions on projects where modern tunnelling machines are being used. A figure somewhere between one and 1.5 per cent would seem reasonable, with the figure dependent on ground conditions and confidence in the construction methods employed.

Acknowledgements

The author would like to thank the Halcrow, Costain and Thames Water project team for their support and provision information for use in this paper. I would also like to thank Ian Blight, Philip Quelch, Bob Allen and Eddie Woods for their insightful comments.

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Conquering Gotham *again*

At the January meeting of the British Tunnelling Society, Andrew Thompson of Hatch Mott MacDonald, currently acting as the program manager for construction on the East Side Access (ESA) project gave a presentation on the various tunnel construction techniques in use

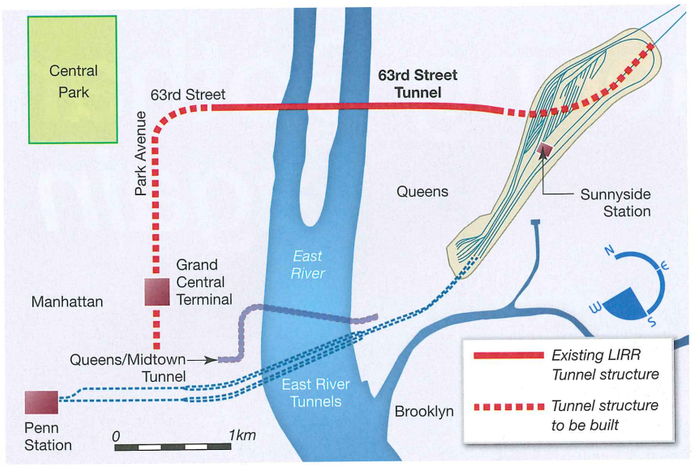
The East Side Access (ESA) project is, at USD 7.3bn, the largest infrastructure project under construction in the US and forms part of the Capital Expansion Program of the New York Metropolitan Transportation Authority (MTA).

ESA, the first expansion of commuter rail into New York for over 100 years, will provide a direct route for LIRR to the East Side of Manhattan. New York has two commuter railroad stations: Pennsylvania (Penn) Station located on the west side of Manhattan serving the Long Island Railroad (LIRR), Amtrak and NJ Transit and, secondly, Grand Central Terminal (GCT) serving the MNR only. Commuters travelling from Long Island and working on the east side of Manhattan currently have to transfer at Penn Station and travel east by subway. With the construction of the 5.6km route and eight platform tracks beneath the existing GCT, it is expected that ESA will cater for 160,000 commuter trips per day, thereby relieving pressure on Penn Station and the subway lines.

Construction in an urban setting inevitably leads to restraints intended to minimise environmental impact. Sensitivity to this has been heightened on ESA with its proximity to structures such as the Waldorf Astoria Hotel, Carnegie Hall and GCT. Most of the construction work is undertaken with no visible presence at street level, resulting in extended supply lines.

Other influencing factors include the use of the 63rd Street tunnels constructed in an earlier incarnation of the project, effectively fixing the project alignment, and the lack of surface space to create a shaft at the southern end of the project. One major factor is that some 95 per cent of the construction work is being undertaken either on, adjacent to or under active railroads whose operations cannot be impacted; a major 'headache' being that the Queens portion of the project is being built within the busiest interlocking (junction) in the US, which handles more than 800 trains daily.

Project construction is phased over a number of years and 35 separate construction contract packages with currently 13 active contracts valued at USD 2.2bn, ranging from the USD 1.2bn Manhattan tunnels package to the USD 2M instrumentation installation contract in



Above: Map of the new tunnels in Manhattan and Queens to connect with the existing Long Island Railroad (LIRR) tunnel

Queens. It is expected that a further six contracts will be awarded during 2011 bringing the total value of construction to USD 3.3bn.

The project's signature is the new 47,000 sqm terminal at GCT. Constructed in 1910, the existing terminal is not only one of the most recognisable stations in the world due to its stunning architecture, it is also one of the top tourist attractions in New York and handles more than 250,000 passengers daily. To find the space to build the new terminal two, large caverns are being excavated directly beneath the existing GCT train shed to house the eight new LIRR platform tracks. With the platforms located beneath the surface, space was found for the concourse to house passenger and other facilities in what was Madison Yard, a midday storage yard located on the west side of GCT. Considerable effort has been expended to ensure that, architecturally, the station caverns are unique and will, over time, acquire iconic status.

TBM work

The bulk of the 11.5km of running tunnel excavation beneath Manhattan is being undertaken using TBMs, ensuring that disturbance to the overlying residential properties is minimised, allowed mining operations to progress around the clock.

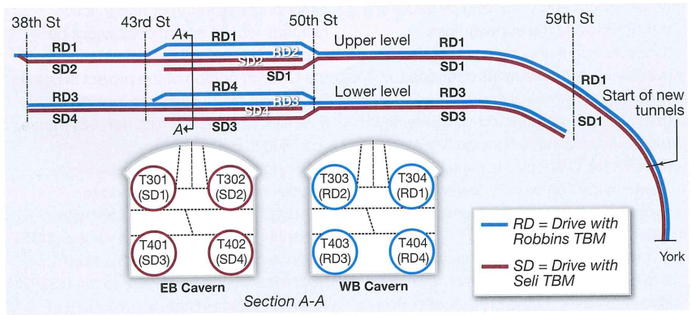
The 1960s tunnels constructed beneath 63rd Street were used in the project alignment and after limited drill and blast enlargement became the TBM starter chambers. From the 63rd Street and 2nd Avenue junction the tunnel alignments were dictated by the future railroad operational needs. Heading in a south-west direction, the two tunnels reach position GCT5, a vertical separation point where the running tunnels split into the upper and lower level drives. From this point four tunnels head south beneath Park Avenue and, shortly before entering the station caverns, crossover caverns are provided at GCT3 on the upper and GCT4 on the lower levels. Once through the crossovers, the running tunnels bifurcate and four tunnels pass through the caverns on each level before the eight tunnels rejoin to create four tail-track tunnels that run to 37th Street.

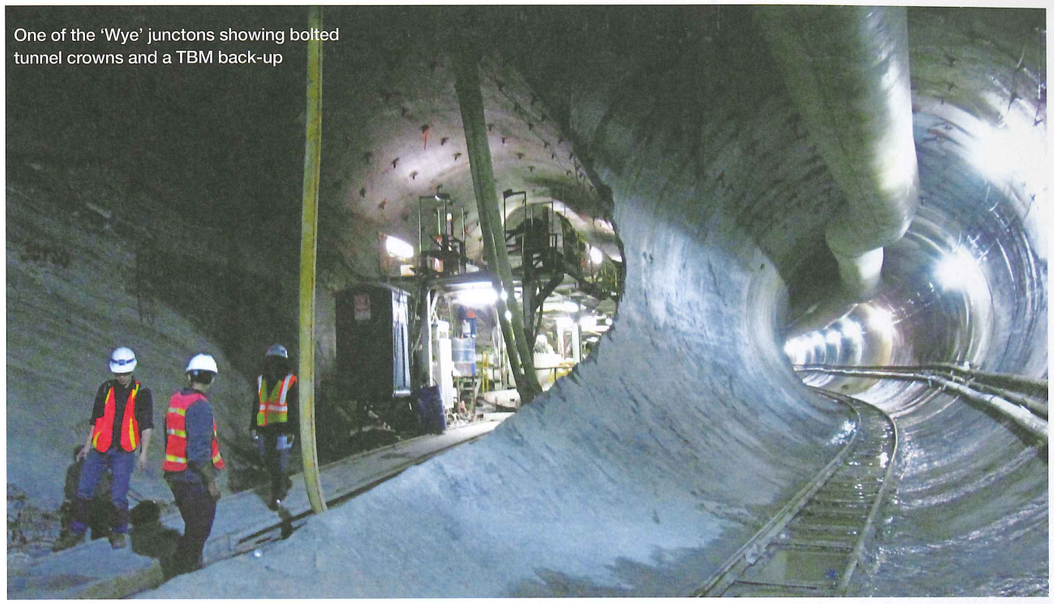
In total there are eight separate TBM tunnel drives ranging in length from 2,400m to 500m, all driven from north to south. As the tunnels are constructed in Manhattan Schist, which varies in strength from 68 to 275MPa, the contractor selected two hard-rock TBMs: a Robbins main-beam TBM that previously worked on the Parramatta Link in Australia, and a double-shield TBM supplied by Seli. Initial support of the rock was planned using a combination of rockbolts, mesh and full-circle steel ribs. In reality, less than five per cent of the tunnel needed the full-circle ribs, although they were used in areas where the pillar between tunnels was less than 2.5m to provide resistance to gripper loads on the pillar. TBM operations were undertaken on a five-day, three by eight hour shift basis and production rates averaged 13m per day.

A major challenge was relaunching the TBMs as there was no shaft at the southern end, meaning that the TBMs had to reverse through the completed tunnels. Segments were removed from the cutterhead creating sufficient clearance to enable the TBM to be reversed. For the shielded Seli TBM, additional effort was required to provide clearance including removal of steel ribs installed during mining. This required a staged resupport to be undertaken using MAI SDA rockbolts drilled into sound rock and the application of mesh and sprayed concrete, prior to dismantling the ribs. This used a custom-built gantry to ensure workers remained under supported ground. The phasing of the TBM back-up and provision of connections between the tunnel drives had to be carefully planned as access ahead of the TBM would be blocked. At times only one tunnel was available for mucking and material delivery to the active TBM and the relaunch operation. As noted previously there are a number of locations where the future running tunnels bifurcate and caverns excavated to create the necessary space for this. These cavern locations or Wyes became the TBM relaunch locations.

Two methods were used to create the space for TBM relaunch in the Wye caverns. The original design of the Wyes provided sufficient space to enable them to be reused for TBM relaunch with only a short starter tunnel being required to create

Below: Tunnel drives layout plan and sections through chambers




One of the 'Wye' junctons showing bolted tunnel crowns and a TBM back-up

gripper pads. The first TBM relaunch was undertaken at GCT3 East Wye Cavern. Once the TBM had mined through the cavern location the cavern was excavated to its finished dimensions using a combination of drill and blast with a Sandvik MT720 roadheader. Subsequently the contractor, designer and MTA developed a revised method, which was used at three TBM relaunch locations and in mining through the lower level crossover. This method involved reversing the TBM to a location upstream of the relaunch location, installing a concrete plug in front of the TBM and then driving the TBM into and through the concrete plug. This gradually engaged the cutterhead into rock along the new alignment with the plug acting as a temporary gripper surface. Besides significantly reducing the amount of excavation required at the Wye Caverns, the use of the plug reduced TBM relaunch duration from four months to six weeks. Once this method was proven, redesign of the permanent structures to take advantage of the reduced excavation profiles was undertaken and some 15,000m³ of excavation was eliminated at each Wye and crossover location. Given that the Wyes and crossovers were located some 13m below the main station throat interlocking of GCT, the elimination of drill and blast at these locations to create the Wye caverns proved beneficial.

One major interface that has required significant attention is that of blasting beneath GCT. Due to the age and proximity of the train shed and concourse to the excavation locations, and MNR operational requirements, blasting and the vibrations resulting from blasting are tightly controlled. In fact, MNR suspends train operations in an influence zone during blast events.

Two station caverns, 370m long, 20m wide and 20m high, to house the eight platform tracks are being constructed, with, in some locations, only 13m of rock between the cavern arch and the operational tracks of MNR in GCT above. Excavation is undertaken using a combination of drill and blast and roadheader to enlarge the excavation around the previously driven tunnels, which were supported using either GRP dowels or Swellex rockbolts. Initially the roadheader is used to mine two side drifts expanding the TBM driven tunnels upwards to create the side portions of the cavern arch and haunch on which the permanent crown lining will sit. Thereafter drill and blast is used to remove the remaining pillar and bench in 3-5m rounds depending on rock quality and allowable vibration criteria, which varies from 12mm/s in the proximity of historical structures, 25mm/s in the vicinity of high-pressure steam-lines and up to 75 mm/s elsewhere. Rock support consists of tensioned 5m-long rock bolts in conjunction with welded mesh and sprayed concrete as necessary. Following behind the excavation, wet-mix sprayed concrete is applied and then PVC waterproofing installed over the shotcrete in preparation for the cavern arch pour. The arch has been designed independently from the cavern walls and is installed once the top heading excavation is completed to minimise the height of the formwork. It also provides the permanent lining as early as possible to minimise the possibility of any deflection of the arch leading to movement of GCT above. Once the arch is poured, the bench between the upper and lower running tunnels will be excavated to enlarge the final caverns. It is hoped the contract for this work will be awarded during 2011.

Ventilation plant

Other work undertaken in Manhattan includes the construction of four ventilation plants located at 37th, 44th, 50th and 55th Street, the only locations in Manhattan where there is ESA construction visible to the public.

At 37th Street the fan plants are located within the tunnels and the only surface presence will be a grating in the sidewalk covering a chamber. This is connected to the fan plants through 12ft (3.66m) shafts constructed by raiseboring. At 44th Street the vent shaft and a four-storey ventilation plant is being constructed on a 30m by 10m footprint sandwiched between the MTA Headquarters building, the Yale Club and the perimeter wall of GCT. No blasting is permitted at this location so the contractor elected to drill more than 40,000 holes, 100mm in diameter before

Left: A mud-slab cast in one of the Manhattan caverns

commencing rock breaking using hammers in an attempt to minimise vibration and noise in the adjacent structures.

To connect the existing 63rd Street tunnels to the mainline tracks in the Harold Interlocking, two separate contracts were awarded. The geology in the project area in Queens is completely different than in Manhattan, primarily comprising boulder-riddled glacial till and manmade fill overlying the Manhattan Schist. Construction of the four running tunnels, three for revenue and one to feed trains into the future midday storage yard, is being undertaken using two 7m diameter Herrenknecht Mixshield TBMs with pre-cast segmental linings. This particular combination is being used for only the fifth project in the US and will be the first time that the local mining workforce, the 'Sandhogs', have constructed tunnels under this combination. Slurry TBMs were chosen as they potentially offer greater control of ground movement than an EPBM, which will be of importance when passing 10m beneath the 60mph (96km/h)-rated mainline tracks linking New York to Long Island and Boston.

In an effort to minimise the need to enter the cutterhead under compressed air, the contractor will create 'safe havens' within the future emergency egress shaft locations permitting free-air interventions. Originally a combination of jet-grout and secant piles were planned to create these but as one of the shaft locations was deleted, groundfreezing will be used to create a block of stabilised ground into which the TBM will be driven. In an effort to ensure the TBM does not get frozen in, additional ports are being added to the TBM skin through which grease will be pumped creating a non-frozen but watertight interface between the ground and the TBM.

The TBMs will be launched from a slurry-walled shaft structure that was partially constructed under a previous contract. To prepare the shaft it was necessary to seal the interface between the slurry wall panels and the rock.

This was achieved by installing 5m-high jet-grout columns along the outside edge of the wall that which were drilled 1.5m into rock and then grouted. Based on the construction records it was decided that some portions of the wall received a single row, double row or no jet grout columns. Once this work was completed, some 25 million US gallons (95 million litres) of water were pumped from the structure. The excavation and support was completed with the installation of struts and tiebacks. Another innovation was to cast launch blocks within the slurry wall structure rather than carry out ground treatment beneath the rail-yard immediately outside and above the launch walls.

The intent of the launch blocks is to enable the slurry-shield TBM to be installed, and to pressurise the cutterhead before it mines through the headwall, thereby ensuring there is limited ground settlement behind the wall.

Soft ground

Connecting the Manhattan and Queens portions of the project is a short (37m), but highly technical, section of tunnel. If constructing a 20m-wide, three-track section of tunnels in soft ground using a Sequential Excavation Method together with sprayed concrete lining (a first for the New York area) were not enough, doing this beneath a five-track cut-and-cover subway box, a major highway (Northern Boulevard) and an elevated metro line adds a element of risk and complexity that is difficult to quantify, but is very real.

Excavation of this section of tunnel will commence from the so-called 'early access chamber' at the west end of the existing slurry wall structure. To enable excavation to progress to the invert of the structure, bracing is required and cast-in-place slabs have been placed at approximately 4m intervals. Additionally, 150 jet-grout columns were drilled within the chamber to act as temporary bracing until the cast-in-place slabs can be poured.

Control of the overlying structures is absolutely critical to the success of this work and extensive ground treatment has been undertaken to provide the capability to lift and lower the overlying structures. Grout holes to voids were drilled and grouted with a non-setting grout, and compensation grout holes were drilled with tube-a-manchettes installed.

As excavation of the chamber progressed, 45 freeze-pipe holes were drilled for the full length of the future tunnel excavation to create a frozen ground water cut-off wall around the excavation perimeter. Heat pipes and temperature probes were also installed.

A separate and equally critical activity was the installation of piles and beams to enable the loads from the existing pile groups supporting the elevated structure to be temporarily transferred.

During the mining operations the existing piles will be mined through, cut back and ultimately connected to steel ribs cast into the final lining thereby making the final tunnel lining part of the foundation of the existing structure. An extensive ground treatment and instrumentation program has been installed on the overlying and surrounding structures, to provide real-time measurements of heave or settlement. Mining is expected to begin in spring 2011.

Thompson concluded with, "Over 100 years ago Gotham was conquered by the Pennsylvania Railroad with the Hudson and east River tunnel. Today the ESA project team is walking on the shoulders of those giants of the railroad age as they attempt to conquer Gotham again."

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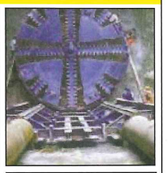

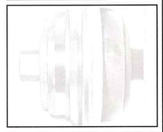

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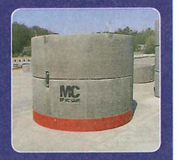
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Keeping grounded

Left: Michael Cash, far right, at the Alameda West Portal of the New Irvington Tunnel

Michael Cash grew up on a sheep ranch in South Australia called Oakfront, 40km away from the nearest town, Streaky Bay, which itself is about 800km west of Adelaide. He describes the landscape where his family has farmed for generations as rugged and beautiful. Currently, home is Danville, California, in his role as regional manager for Texas-based Southland Contracting.

"It is vastly different from the outback ranch I grew up on in South Australia," Michael says. "Here, when driving home at night there is no fear of hitting Kangaroos, a common occurrence back home."

He started working for Southland in 2008, taking on a regional manager position in early 2009. In May of that year he relocated from the head office in Fort Worth, Texas, to the west coast to manage the connector tunnel contract for Lake Mead Intake No. 3. Then in April 2010, Southland Contracting, as the lead in a joint venture with Tutor Perini was the successful low bidder on the USD 227M New Irvington Tunnel project in San Francisco, which he is also currently managing.

"The life of a farmer is very different from the life I lead now," he says. "A farmer's life is difficult, being tied to some factors out of your control—such as rain or lack of it, the price of wool—but there is also a deep pride in one's own land and the sheer satisfaction in physical work."

While he may not have followed the family career path, underground construction had long interested him. He earned a bachelor's degree in engineering from the University of South Australia, Gratrell School of Mines. After graduation he took a job as a nipper in the Darlot Gold Mine, in Central Western Australia, and worked his way up through the ranks.

"I really like to dig and use really cool machines. Even as a child I loved rocks and construction," Michael explains. "Mining is a very respected highly paid field in Australia, and so it was the perfect match."

Mining in Australia does have its drawbacks, as it required living in very remote camps throughout the Australian outback. "I learned a great deal and after working in and developing several mines I decided to seek opportunities outside of the field of mining so that I could live in civilisation again, so to speak."

Tunnelling is a natural progression from mining, he says of his decision to apply the knowledge and skills he gained in the mines to civil engineering. "I helped to create infrastructure for the mining operations," he explains. "This really is essentially crude civil construction."

His first position in the US was as a project manager for Affholder on a tunnel project at DFW International Airport in Dallas, Texas. Michael worked on several other projects with Affholder including the Sacramento River Crossings Tunnels in California. After that he became a partner with civil/geotechnical engineering firm Brierley before joining Southland.

"There are unique challenges associated with tunnelling that I find compelling," he says. "You need to understand geology and be able to adapt to its changing conditions."

But of course, Michael is up for a challenge. "I get to help in the designing of really amazing machines for the tunnelling," he says. "To combine all of these aspects within a framework in which you not only need to complete these amazing projects, but to do so in a timely and profitable manner is an exciting albeit sometimes stressful challenge. Life is never boring."

Speaking more specifically about his current work, he explains: "The most challenging part of my projects is the control of groundwater. Pre-excavation grouting is required on both projects. Lake Mead Interceptor No. 3 is essentially being constructed 450ft (137m) beneath Lake Mead in highly fractured ground. The New Irvington tunnel is being constructed through the coastal mountain range and will be more than 750ft (228.6m) deep and 350ft (106.7m) below the water table. Our tunnel parallels the existing tunnel within 150ft (45.7m) and so we need to be careful not to effect the water currently being conveyed through the existing tunnel."

He enjoys outdoor adventure sports, including a canoeing expedition on the Rio Grande along the border of Texas and Mexico, backpacking in Zion National Park in Utah and back country snowshoeing in the Sierra Nevadas. "I love being able to escape from the rigors of daily life and feel like our family has achieved something out of the everyday norm," he says.

"I am lucky to have a patient and adaptable family as I have relocated them with me six times in the past eight years, over three continents as my career progressed. We live a somewhat nomadic existence, but we find it important for our family to be together, wherever we are."

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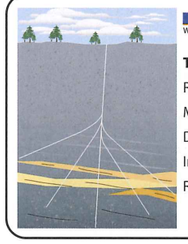

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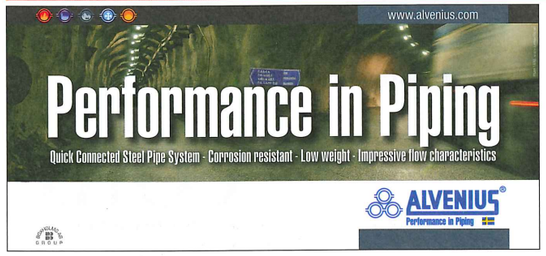

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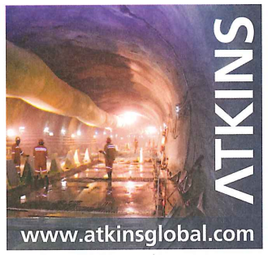

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dates & events

15 - 18 JUNE 2011
6th Annual meeting of chartered civil engineers in Opatija, Croatia
The specific seminar topics, all in the civil engineering sector, include tunnels in urban areas, geotechnics and project management. The opening session and round-table discussion should, say the organisers, show which projects should be started in this immediately before and after entering the European Union. Website: www.hubtig.com. Contact: Ms Dada Papista. Tel: 00385 1 6130 062, email dada.paptista@hubtig.com

19 - 22 JUNE 2011
RETC 2011 - Rapid Excavation and Tunneling Conference and Exhibit, San Francisco, California
RETC is an international forum for the exchange and dissemination of developments and advances in underground construction. For more information contact event organiser: RETC Exhibits, 8307 Shaffer Pkwy, Littleton, CO 80127, 303-948-4213, gury@smenet.org

22 - 23 JUNE 2011
Tunnel Design and Construction Asia, Sentosa, Singapore
Featuring best practices in geotechnical investigation, EPC contracting, project funding and risk management for Asia's tunnel infrastructure. The keynote speaker will be Heinz Ehrbar, chief construction engineer of AlpTransit Gotthard. Tel:+65 6722 9388 Email: enquiry@iqpc.com.sg

29 - 30 JUNE 2011
Underground Construction Conference and Exhibition, London
The eyes of the global tunnelling industry are swivelling towards the UK with some of the world's largest underground construction projects getting underway. Event includes: technical and design developments in underground construction, tunnel operation and maintenance, sustainable development and minimising the impact of underground works, a world wide tunnelling perspective, UK projects - today and the future, ground investigation, treatment and monitoring. Tel: +44 (0) 207 973 6695 Email: g.stringer@hgluk.com Website: 2011.tunnellingshow.com/

12 - 16 SEPTEMBER 2011
6th International Symposium on Sprayed Concrete, Tromso, Norway
Main themes will be design, construction and durability of wet-mix sprayed concrete in underground structures. The Norwegian Concrete Association is currently revising the Publication No. 7, Sprayed Concrete for Rock Support. This will be debated during the symposium. Contact: Siri Engen Email: siri engen@tekna.no Website: www.sprayedconcrete.no

14 - 15 SEPTEMBER 2011
IUT 2011, Sargans, Switzerland
Those involved in tunnelling will get together to exchange views and inform themselves about the latest trends and technologies. The traditional IUT Evening on the first day of the fair, being held in a VSH cavern, will be a highlight: here exhibitors and visitors will be able to exchange views against a relaxed background and experience an unforgettable evening. Contact: Deltacom Projektmanagement +49 (0)40 35 72 32 - 0 Email: info@deltacom-hamburg.de

19 - 23 SEPTEMBER 2011
Hydropower Africa 2011, Johannesburg, South Africa
Hydropower Africa 2011 is a niche meeting forum where comprehensive presentations, panel discussions and focused sessions will address the issues surrounding the financing and the implementation of hydropower projects in Africa. For further information, call: Nicolaas Loretz, Tel. +27 21 700 3555.

17 - 19 OCTOBER 2011
13th AFTES International Congress, Lyon, France
This three-day congress is organised by the French Underground Tunnelling and Underground Space Association (AFTES), with partner associations in Italy, Belgium, Spain, Portugal and Switzerland. Along with technical sessions and an exhibition there are seven site visits planned for the congress focused on underground space. Contact AFTES for more information: 15 rue de la Fontaine au Roi, 75011 Paris, Tel : +33 (0) 1 44 58 27 43

26 - 27 OCTOBER 2011
Underground Infrastructure of Urban Areas, Wroclaw, Poland
Organised by the Wroclaw University of Technology's Institute of Civil Engineering, the Polish Society for Trenchless Technology and the ITA-AITESA Polish group, this will be forum to develop an exchange of experiences and provoke a discussion on the topics related to building tunnels and underground infrastructure in cities. Contact Andrzej Kolonko, Tel. +48 71 320 2914 or email andrzej.kolonko@pwr.wroc.pl

6 - 8 DECEMBER 2011
STUVA Conference, Berlin
The 2011 biannual conference of non-profit research institute STUVA (the German Research Association for Underground Transportation Facilities) will focus on "Underground Construction for Sustainable Environmental and Climate Protection." New this year is a Youth Forum, an opportunity for young tunnel engineers to present. The winner of the STUVA young talent prize will be selected from the speakers, and awarded at the show.There is also an accompanying exhibition. More information available from www.stuva.de Email: info@stuva.de

14 - 16 MARCH 2012
ISTSS 2012, New York
The 5th International Symposium on Tunnel Safety and Security, organised by the SP Technical Research Institute of Sweden, will discuss themes of risk & security, human behaviour, construction, fire fighting, ventilation and fire dynamics. More info at www.istss.se

BRITISH TUNNELLING SOCIETY

29 JUNE 2011: **High Speed Railway Tunnels in Spain**
With the opening of the new Levante line, the Spanish High Speed Railway network has become the longest in the world. HSR lines with their demanding alignments require the design and construction of an unusually high number of tunnels, some of which are amongst the longest and more important in the world.
This presentation provides information of three good examples of the tunnels recently built in Spain: Guadarrama tunnel, Pajares tunnel and finally Atocha-Chamartan tunnel. This is an evening BTS Presentation being held at the "BTS Underground Conference 2011" on 29th to 30th June 2011. It is a 2 day conference being held in the Earls Court Exhibition Centre. Speaker: Jose Luis Arèvalo Segovia of División de Sistemas Ferroviarios

15 SEPTEMBER 2011:
Crossrail
Status update. Latest developments on this major London project. Speaker: Andy Mitchell, Programme Director, Crossrail Ltd (CRL)

20 OCTOBER 2011:
BTS / BGA Joint Event. Towards a Specification for the Ground - The use of Geotechnical Baseline Reports in the UK
Ground References Conditions. Details to follow. Speakers: Mike Black and Darren Page

17 NOVEMBER 2011:
Dulles Airport Rail Tunnel, Washington DC
Dulles Transit Partners is responsible for designing and constructing Phase 1 of the Dulles Corridor Metrorail Project. An 11.6 mile extension of the existing Washington Metro to Dulles International Airport. A central feature of the project is the Tysons Tunnel. The Tysons Tunnel is a twin-bore, two-track tunnel running at 762m in length between portals. The central 534m is being constructed by SCL. Speakers: Dominic Cerulli and Frank Jenkins of (Bechtel) Dulles Transit Partners and Vojtech Gall of Gall Zeidler Consultants

15 DECEMBER 2011:
Cleaner Seas for Sussex
In order to treat the 95 million litres of wastewater generated each day by residents a new wastewater treatment works and 11km of new sewer were required. Now substantially complete find out how more than 11km of 1.8m and 2.4m diameter tunnels and associated shafts and pumping stations were completed. Speaker: Ben Green, Southern Water programme manager and Craig Reade, Costain project manger.

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition that is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site:
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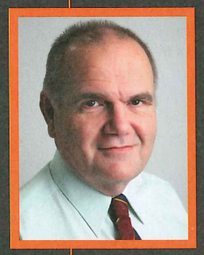

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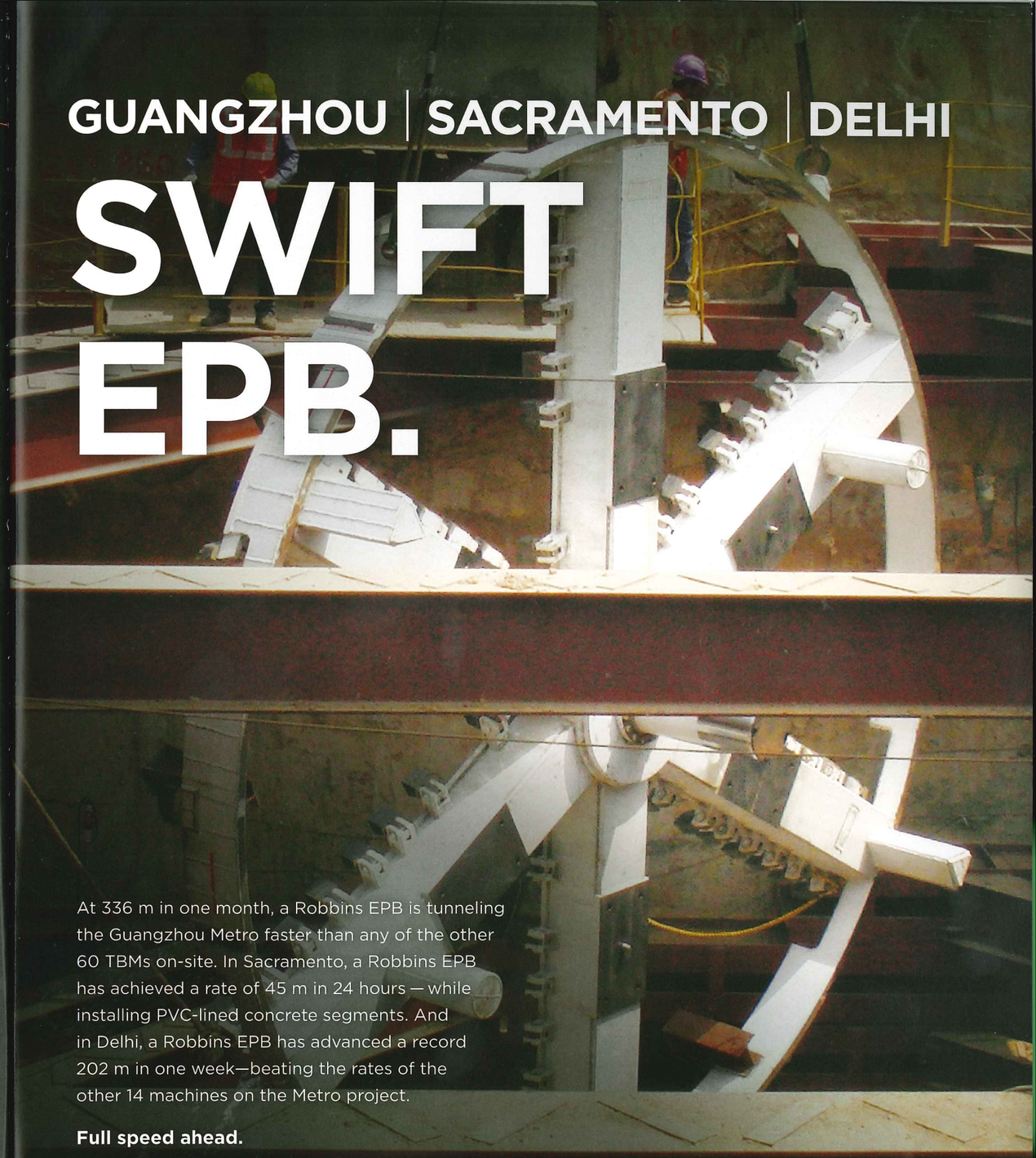

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