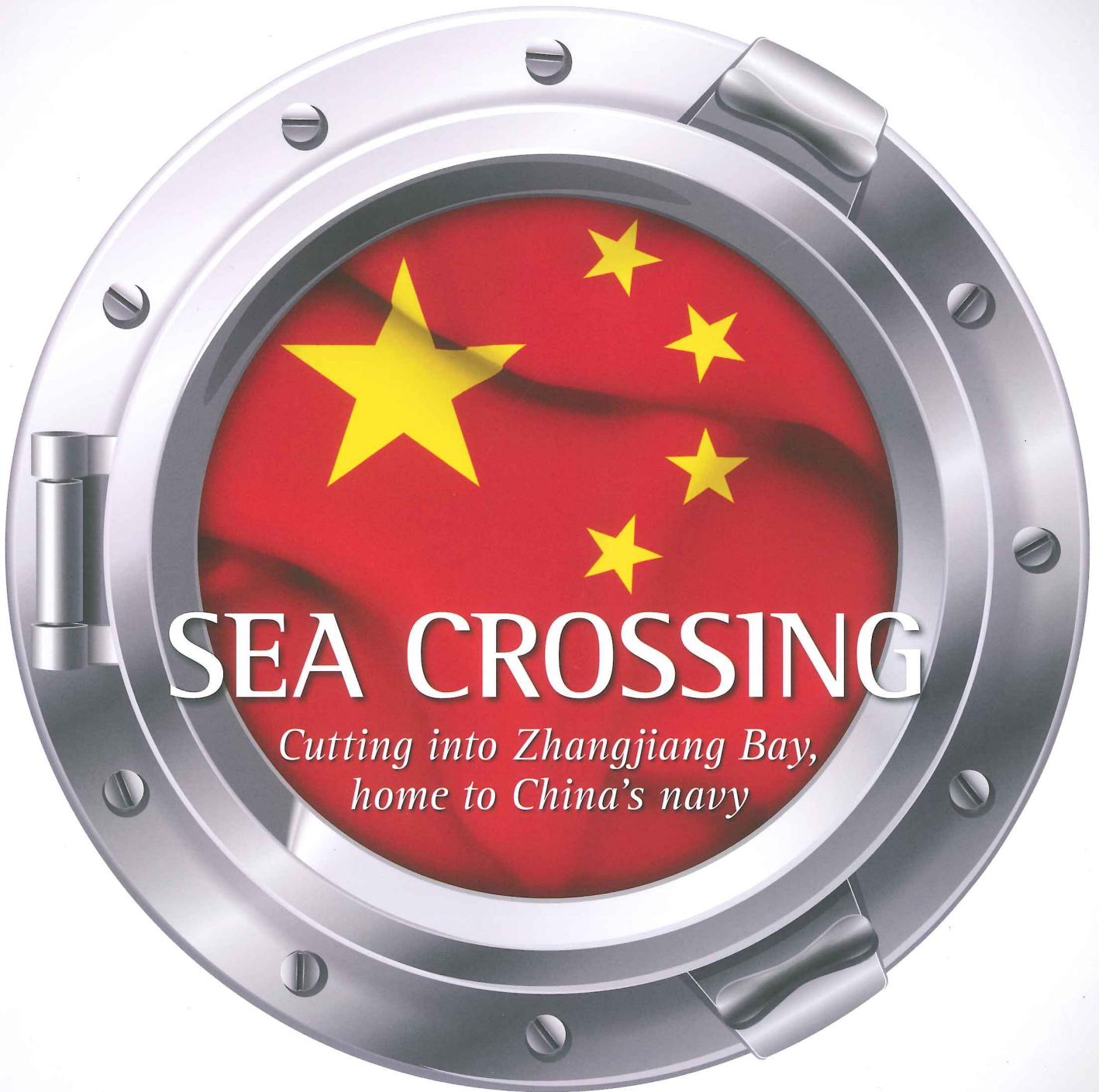


INTERNATIONAL EDITION

October 2012

Tunnels

AND TUNNELLING



SEA CROSSING

*Cutting into Zhangjiang Bay,
home to China's navy*

Uncertainty and risk • Traditional tunnelling • Focus on central Asia



CHINA: TWO EPB SHIELDS FOR CABLE TUNNELS IN GUANGZHOU.

The first of the two Herrenknecht machines for the extension of the power network of the metropolitan region of Guangzhou has started. With 650 meters already excavated, the M-1586, which was especially designed for mixed soils of broken rock, sand and clay, is currently making its way through the pipe system. On the 3,975 meter long route between Xiniu and Qilin, a curved radius of 160 meters had to be driven at the very beginning, another narrow radius of 114 meters will follow. The second machine, the S-675, is expected to start tunneling soon. The machine will drive a 2,490 meter long cable tunnel to connect the underground substations Modiesha, Liuyuan and Houde. The tunnel construction is scheduled to be completed at the end of 2012. Further extensions of the infrastructure will follow, in order to prepare this increasingly built-up and frequented area for the future. In the coming five years, the population of this still growing, largest mega city of China is expected to increase to 42 million inhabitants.

GUANGZHOU | CHINA

PROJECT DATA	CONTRACTOR
<p>S-675, EPB Shield Drilling diameter: 6,280mm Cutterhead power: 945kW Tunnel length: 2,490m Geology: soft ground with silty sand, medium-coarse sand, clay stone and silt stone</p>	<p>China Coal No. 3 Construction Co. Ltd.</p>
<p>M-1586, EPB Shield Drilling diameter: 4,396mm Cutterhead power: 400kW Tunnel length: 3,975m Geology: mixed soil of broken rock, sand and clay</p>	



BREAKTHROUGH SOLUTIONS FOR TOUGH JOBS AROUND THE WORLD

BRIGHTWATER TUNNELS BT4 + BT3-C
 SEATTLE, WASHINGTON USA
 RME 184 SE - Mixed Face 4.67 meter EPB TBM

- ✓ Initial drive of 21,000 ft. successfully completed (BT4).
- ✓ Difficult geological conditions and up to 5.1 bar pressure.
- ✓ Upgraded TBM for an additional drive of 10,000 ft. (BT3-C).
- ✓ Extremely abrasive ground and up to 7.3 bar pressure.
- ✓ Both drives completed ahead of schedule.
- ✓ Spectacular finish to a tough job and satisfied clients.



International Tunnelling Awards 2011
 Tunnelling Contractor of the Year – WINNER: Jay Dee Coluccio Taisei & Jay Dee Coluccio JVs

GETTING THE GIRLS

Jon Young
Based in London, Jon has been editor of *Tunnels* since 2009



AUTUMN IS upon us, the morning rush hour is once again full of SUVs on the school run and summer researchers are beginning to report back their findings. The most outstanding of which is the revelation that nearly half of England's state schools do not send any girls on to study physics at a higher level.

The Institute of Physics analysed data from the national pupil database and found that 49 per cent of state co-educational schools in England did not send any girls to study physics at A-level in 2011.

The problem of attracting girls into sciences was recognised by the European Union this summer and the response was 'Science: It's a girl thing' – a flirty promotional campaign where lab equipment is mixed with makeup and fronted by catwalk style models to promote the sciences to young women. It was quickly criticised as being offensive and is more likely to lure boys into the sciences than girls.

The shortage of girls studying physics is apparent when you look around the tunnelling industry; this 'fraternity' is heavily male dominated. But there are changes afoot.

The chair and immediate past chair of the British Tunnelling Society Young Members (BTSYM) groups

are both women. The BTSYM was recognised last year in the *Tunnels* awards for its work promoting the industry to young engineers and in schools. The group, with far more dignity than the EU's efforts, aims to help raise the profile of tunnel engineering as a rewarding career option for students by visiting schools and universities (six a year) to introduce the underground world.

Out of the US has come the Women in Tunnelling group, which is a social networking group set up by employees of TBM manufacturer Robbins and has a growing online presence. It held its inaugural event (wine tasting) in Indianapolis during the summer.

The UK government has given the Institute of Physics some GBP 6M (USD 9.5M) to tackle the issue. The industry could further efforts by getting involved with local schools, offering work experience placements, competitions, apprenticeships and scholarships.

On a final note, the sharp eyed among you will have already noticed the new look to *Tunnels and Tunnelling*. We hope the new presentation makes the material more accessible and easier to digest. Send us your thoughts ☺

THIS MONTH...

10 Years ago

Andrew Crowe, engineering geologist for Halcrow evaluated the UAE's first rock driven tunnel. The Wadi Muddiq tunnel project saw a quantitative investigation, observation and evaluation of rock mass throughout construction. This allowed risks and uncertainties to be identified and managed effectively on the 110m2 elliptical, NATM excavated profile. Geology was basal oceanic crust of Upper Cretaceous age. It comprised a lithological sequence dominated by layered gabbro

20 Years ago

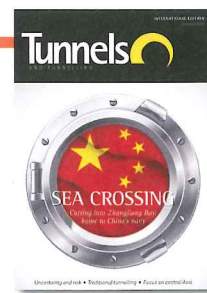
The Swiss people voted by a large majority in a referendum to go ahead with the construction of two rail tunnels through the Alps at a cost of USD 11.4bn. These were the Gotthard and Lotsch tunnels. Work was expected to commence in 1995 with both tunnels commissioned in 2010. Acceptance by voters was a precondition of Switzerland joining the European Economic Area

40 Years ago

An experimental tunnel was being dug by the new bentonite tunnelling shield at New Cross in London. The tunnelling was through bad ground, sand and gravels. Particle sizes varied from 200mm stones to sand finer than 75 microns. The experimental equipment provides for face pressures up to 2.07 bar. The experimental shield was adaptable for use in cohesive strata by removing the central diaphragm and installing a conveyor for spoil handling. The tunnel was of appropriate diameter, 4.1m, to form part of the proposed Fleet Line extension to Lewisham.

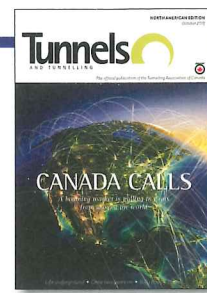
Cover

A water supply tunnel being dug under Zhangjiang, the port harbouring China's South Sea Navy



Cover

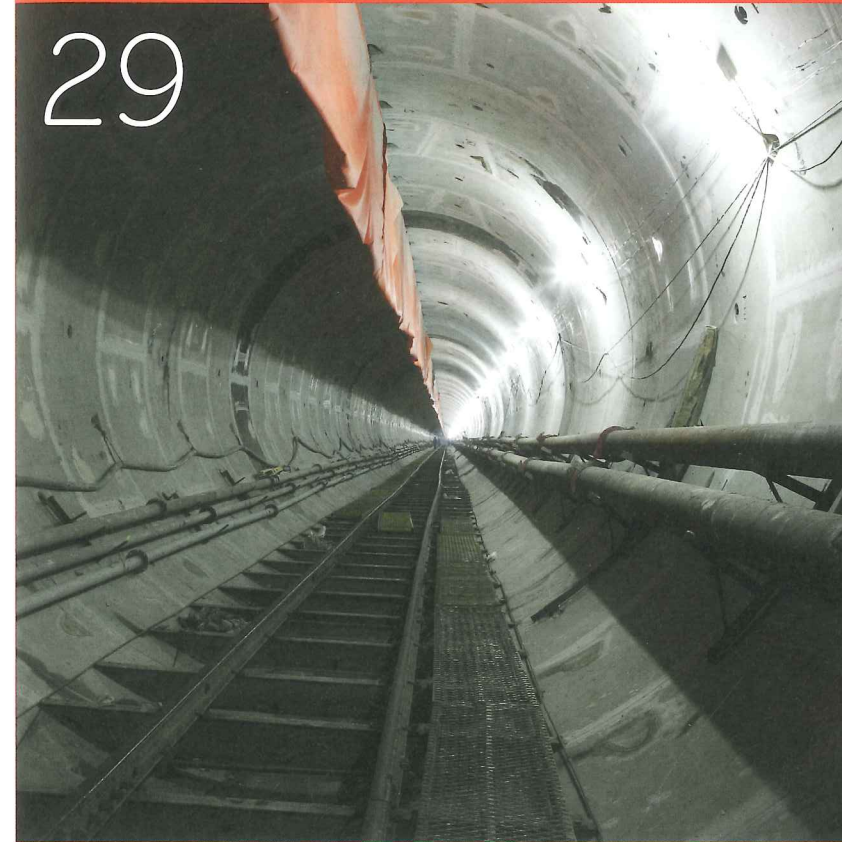
Canada enters a tunnelling boom as the society adopts *Tunnels* North America as its official publication



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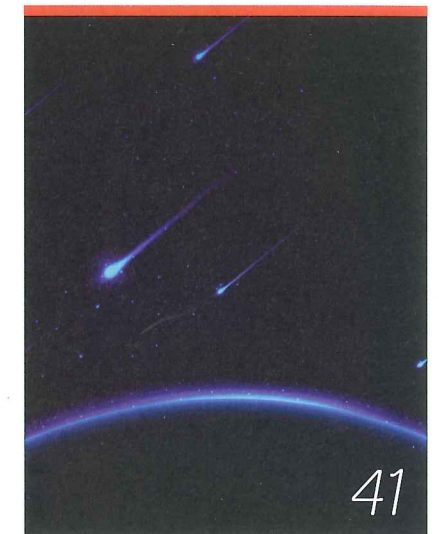
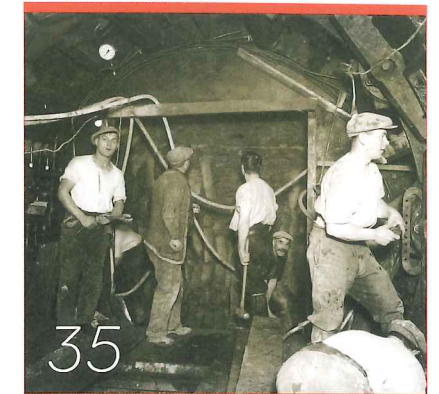
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Changing the attitude of 'your uncertainty is my risk' to 'we share risks' with a full understanding of uncertainty



Contributors

☺ **Colin Mackenzie**
Mackenzie, is a seventy three old retired engineer with over forty years tunnelling experience, all of it with contractors, and much of it on London Underground contracts. Tunnelling. He is an ex-chairman of the BTS.

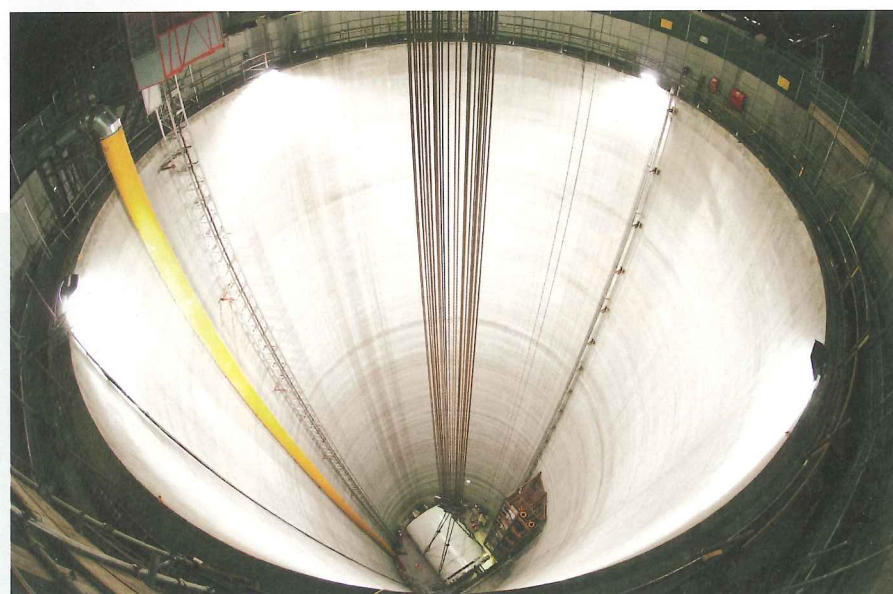


☺ **Yasuharu Hanaoka**
Hanaoka is a professional mechanical engineer working for Japanese TBM manufacturer Hitachi Zosen. He is overall general manager of the TBM design department as well as overall TBM business manager.



☺ **Haldun Kahyaoglu**
Kahyaoglu currently works as construction manager for client Qatar Rail on the Doha Metro project. He previously worked for McConnell Dowell in New Zealand. From his experience, he has decided to try and change attitudes to risk and estimation.





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UNION THREATENS CROSSRAIL ACTION

GREAT BRITAIN: Britain's largest labour union has threatened action against Europe's largest construction project, Crossrail, unless it reinstates 28 workers out of work following a contract that had been ended.

Unite accused contractors on Crossrail's Western Tunnels project of dismissing workers for raising safety concerns. The workers were employed by labour agency Electrical Installations Services (EIS).

Contractor Bam-Ferrovial-Kier (BFK) denied the claims and issued this statement: "Unite is wrong to claim that EIS workers at the Westbourne Park site have been laid off for raising safety concerns when in fact the EIS subcontract concluded last week [21

September] as their work to launch the TBMs had completed."

A spokesman for client Crossrail added that the workers were employed by EIS directly. Neither client nor main contractor was involved in the employment status of the workers.

In a letter from EIS director Ron Turner to Unite representative Harry Cowap, Turner expressed concern that the contract was cancelled to remove safety 'whistleblowers' from the project.

Turner detailed two alleged incidents of his employees raising safety concerns. One was that the TBM was overmanned, with 24 workers despite a safety refuge capacity of 20. Turner claimed that a member of BFK senior management subsequently banned the worker from

entering the tunnel or working on site.

Turner said the other worker took photos of rubble covering an 11kV power cable and was intercepted by the same member of BFK senior management while taking the printed photographs to his supervisor. The manager is alleged to have accused the worker of intending to release the photos on the internet, and removed him from site on the basis that the worker had no photography permit.

The Crossrail spokesman said that the photographer was suspended by EIS for neglecting to return his mining tally when leaving the tunnel, and so breaking site rules.

Turner says this was a third miner, and unrelated to the two incidents. BFK declined to comment further.

Clearwater alignment chosen

USA: The alignment for the Clearwater Program in Los Angeles, USA has been chosen. The tunnel only solution was selected in spring following the environmental impact report.

A spokesman for Jacobs Associates, which carried out the feasibility study, said: "The Sanitation Districts and the US Army Corps of Engineers, lead agencies for the project, analysed the potential impacts of each proposed tunnel alignment alternative before selecting the 18ft diameter (5.5m), seven mile long (11km) onshore-only tunnel alternative.

"The selected tunnel alignment begins at the JWPCP shaft site and extends south under Figueroa Street through Harbor Regional Park, continuing south under North Gaffey Street. The alignment turns west to follow West Capitol Drive, then follows Western Avenue southward until it connects with the existing ocean outfalls at Royal Palms Beach."

Chinese city starts work on 9km tunnel

CHINA: The Chinese coastal city of Xiamen began work

last month on a CNY 6bn (USD 949M) undersea tunnel linking the busy downtown island with its major industrial area of Haicang District, a strong centre for Taiwanese investment in the region.

The 9.03km two-way, six-lane tunnel will be built below the South China Sea. The bottom of the tunnel will be constructed 72.6m below the ocean surface. It is expected to be completed in 2016. The route includes a 6.26km crossing under the sea.

The tunnel is intended to reduce traffic issues currently experienced on the existing Haicang Bridge.

It is part of a planned network of highways to improve logistics in the region.

The client for the project is China's Ministry of Transport.

Butan headrace progress

BUTHAN: Excavation was completed last month on the headrace tunnel for the Punatsangchu One hydropower project in Bhutan.

The 8.9km long tunnel was excavated by Gammon India, for approximately 7.5km and Hindustan Construction Company for the remainder, around 1.5km.

Two adits were constructed

of 268m and 450m, and provided the only access and egress. A third adit was attempted, but had to be abandoned due to unfavourable ground conditions.

Heading work was completed on schedule after 24 months at a cost of USD 27.1M. A second headrace for Punatsangchu Two has also begun, with a length of 8.6km.

Breakthrough on London Power Tunnels project

GREAT BRITAIN: Tunnelling operations reached a major landmark on London Power Tunnels project with a breakthrough, it was announced last month.

The Caterpillar TBM Evelyn has dug almost 3km of tunnel below London and has now reached the reception tunnel shaft at the site off National Grid's Canal Way in Kensal Green in west London.

"The breakthrough at Kensal Green takes us one step closer to completing this essential project," said David Luetchford, head of cable tunnels at client National Grid.

"It's National Grid's job to connect people to the energy they use and this month's breakthrough is just one part of a much bigger story."

The next phase of digging



Above: The power tunnels interim breakthrough at Kensal Green before driving on to the substation in St John's Wood

operations will see Evelyn construct a tunnel to its next destination, National Grid's St John's Wood Substation.

Evelyn is digging 19km of the 32km London Power Tunnels project, which aims to provide an easy to maintain underground electricity superhighway and help ensure Londoners are kept connected to electricity supplies.

London Power Tunnels project is due for completion in 2018.

FIRST TBM FOR KORALM

AUSTRIA: The first of two TBMs for Austria's Koralm tunnel was delivered in late August. The tunnel will provide a new high-speed train route between Graz, Switzerland and Klagenfurt, Austria. The Aker Wirth machines will be in operation by the end of this year, the manufacturer announced last month.

The two telescopic shield machines each have a diameter of 9.93m. They will be used to create the main section, an approximately 18km stretch of tunnels, on the 32.5km long Koralm tunnel project.

Access to the underground construction work areas is a challenge, explained a spokesman for Aker Wirth. The only possibility is a 60m deep shaft, through which the main components of the machine will be transported and subsequently assembled.

"With this project, we can draw on more than 40 years of experience in hard-rock

tunnelling", said Hans Greve, vice president of mining and construction at Aker Wirth. "With our experienced employees, we are confident that we will successfully meet the complex challenges regarding logistics and underground assembly."

Robert Goliasch, machine engineer at ARGE Koralm tunnel construction lot two (Kat Two) added: "With the factory approval for the first TBM, we have reached a significant milestone. Together with our skilled personnel, we were able to be present during the assembly at the factory, to contribute to the installation and consequently to get to know the new TBM. As a result, we hope to gain time for the underground installation and for a speedy commissioning. The first performance tests have done justice to Aker Wirth's reputation as a manufacturer of high-quality machines for hard rock."



Amsterdam immersion completes

THE NETHERLANDS: The final element for the immersed tube section of Amsterdam's North South metro line was floated into place last month. A total of three elements were lowered into a 19m deep trench that had been dredged in the bed of the river IJ. The elements are roughly the same size at 140m long, 12m wide and 8m high. They are large enough to carry two train lines. The immersed

Above: Immersed section of Amsterdam metro line in place

section links the TBM driven tunnels cutting under the heart of Amsterdam south of the river and the complex works under the city's Central Station. Works on the crossing began in February. For a full report see Tunnels, July, pp. 47-50.

HS2 slammed for consultation failures

GREAT BRITAIN: The High Speed Rail Two (HS2) project

has come under attack after it was revealed that the analysis of the public consultation had failed consider hundreds of responses. In a commons written statement Transport Minister Norman Baker said the responses were omitted due to technical errors. The UK Government has already committed itself to phase one of the GBP 32bn HSR scheme (USD 52bn), running from London to Birmingham.

News briefs

USA: A man exploring tunnel and pipes under an old mill in downtown Minneapolis, Minnesota, was rescued last month after he became trapped. The man's companion was able to get out on his own and alert authorities. Crew had to travel 200ft (61m) into a passageway as narrow as 30 inches (762mm) in diameter under the Pillsbury mill building to reach the man. It took the rescuers about two hours to get him out.

UKRAINE: A tunnel network running from Ukraine into neighbouring Slovakia is being investigated by Ukrainian authorities. Ukraine's secret service, SBU, has revealed that it discovered a suspected smuggler tunnel running from the western Ukrainian border village of Mali Selmenci into Slovakia. There is concern that organised crime groups are smuggling people, weapons, drugs, cigarettes and other goods into the EU.

Karnaphuli tunnel feasibility study nears end

BANGLADESH: The feasibility study on the construction of the Bangladesh's first ever tunnel under the river Karnaphuli is at its final stage, Communications Minister Obaidul Quader told parliament in Dhaka last month.

The proposed tunnel will connect the southern part of Chittagong with Chittagong city as well as facilitating communication with the tourist city of Cox's Bazar.

"The construction work will begin by getting the necessary allocation of money as suggested by the feasibility study," Quader replied to the legislature's queries. "It is hoped that the construction of the tunnel will be completed within the next five years."

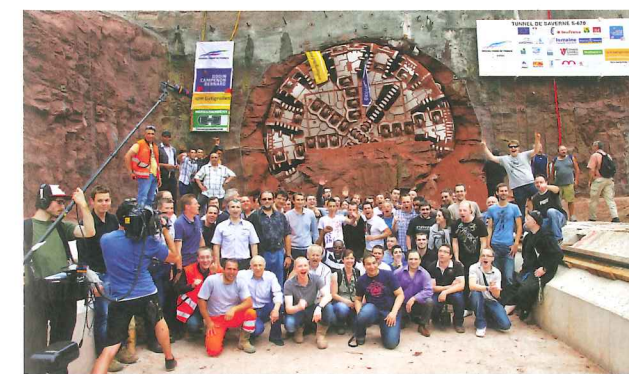
Hong Kong commissions west drainage tunnel

CHINA: The Hong Kong West Drainage Tunnel (HKWDT) has been commissioned, revealed HK Drainage Services Department (DSD) last month. The tunnel aims to significantly alleviate the flooding risk in areas including Central, Admiralty, Wan Chai and Causeway Bay.

The USD 3.4bn project, which started in November 2007, comprises an 11km-long main tunnel extending from Tai Hang to Cyberport, adding measuring 8km in total length, and 34 intakes at ground level.

Chief secretary for administration Carrie Lam said at the commissioning ceremony: "The largest flood prevention project of the DSD, the HKWDT's main drainage tunnel is the longest in Hong Kong and the largest in diameter. The tunnel can effectively intercept about 30 per cent of the storm water in northern Hong Kong Island for discharge into the sea off Cyberport, bringing the flood protection level of the drainage system in northern Hong Kong Island to new heights."

Co-officiating at the ceremony, Paul Chan, the secretary for development added: "The DSD has made remarkable achievements in the past 20 years in formulating flood prevention strategies and implementing related works. Taking the latest land development plan and various factors such as climate change into consideration, the department is now reviewing the drainage master plans throughout the territory in



METRO LINE PLANNED

FINLAND: The Helsinki City Planning Department has begun work on the local plan required for the proposed new rail line around the city centre. The proposed 7.2km long link features 6km of twin-tube tunnels with cross passages every 200m. The line will have just three stations, each with three entrances.

Dubbed Pisara, meaning teardrop, because of its shape, the line begins at the Pasila transport hub and heads south circling Helsinki's overground train terminus.

The Helsinki City Council will decide on the tunnel's local plan in 2014. The realisation of the plan also requires approval by the Finnish Transport Agency.

phases in order to identify further improvement works."

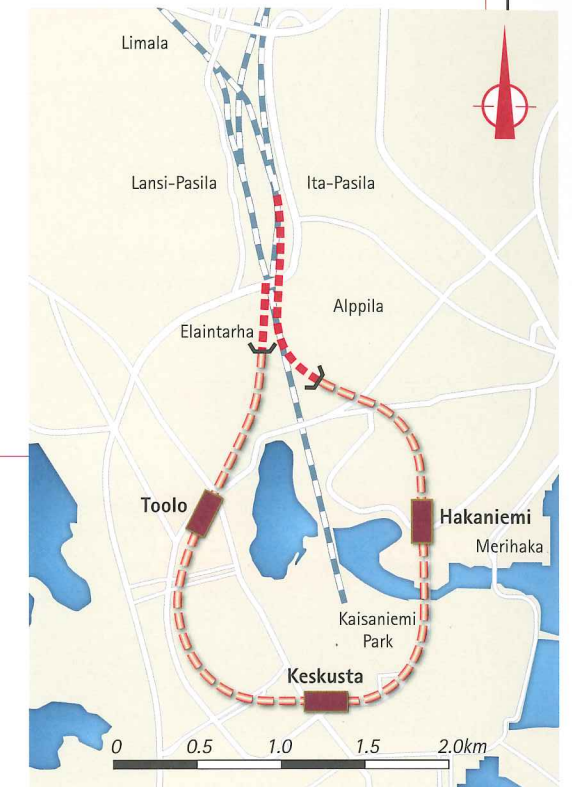
Early breakthrough at Tunnel de Saverne

FRANCE: The first tube has broken through on Tunnel de Saverne. The machine boring the high speed rail project in the Vosges Mountains in eastern France reached the western side two months ahead of schedule. Contractors Spie Batignolles TPCI and Dodin Campeon Bernard worked for client Resau Ferre de France.

The Herrenknecht machine that excavated the approximately 4km-long first tube began work in November 2011 and took seven months. It saw a daily best advance rate of 46m and a week best of 250m.

The 10.01m diameter machine was built as an open convertible EPB shield capable of excavating two soil types. The initial 200m of the drive

Right: The 7.2km line was dubbed Pisara after its teardrop shape



were in unconsolidated rock comprising sandstone and shell limestone. In closed mode it could drive through the prevailing geology of hard red sandstone then continue in open mode for the rest of the bore.

A Herrenknecht spokesman said, "This is the first time a Herrenknecht TBM with a convertible EPB shield has been used that can also handle the open hard rock mode with belt conveyor discharge."

Herrenknecht project manager Stephan Hanusek said, "The conversion went without a hitch, so the machine was ready again in a few days."

The second tube was due to begin excavation this month.

Tunnelling begins on Brisbane's Legacy Way

AUSTRALIA: Tunnelling has started on Legacy Way in Brisbane, Queensland,

Left: Early breakthrough on Tunnel de Saverne

following the recent launch of the first TBM, Annabel. Transcity, which is building the tunnel, announced the milestone last month.

Annabel will excavate the westbound tunnel. Work was expected to begin in June 2012, but ran behind schedule due to changes in legislation for tunnelling, the company said. Transcity incurred an AUD 250,000 (USD 259,400) penalty each day it ran late.

The second TBM, Joyce, which is being assembled on site, will start excavation of the eastbound tunnel later this year. It will take approximately 18 months for the TBMs to complete the journey from the western worksite at Toowong to the eastern worksite at Kelvin Grove.

The company is currently in negotiations with the council to extend that date.

Legacy Way is a 4.6km road tunnel that will connect the Western Freeway at Toowong with the Inner City Bypass at Kelvin Grove. It is scheduled to open in 2015.

FIRM DENIES HIRED THUG ATTACK

CHINA: A Chinese state-owned enterprise has denied that it hired more than 100 people to assault 40 workers who occupied a railway tunnel construction site in Anhui Province, China, claiming they were owed two months of wages, local media reported last month.

China Railway Sixth Bureau Group admitted that 80 of its workers got into a fight with protesting employees of

Xintong Company in late August. The firm told local media that its personnel had been blocked from working on the Bijia Mountain tunnel project since March, after the Xintong backed out of its contract to build more than 16km of tunnels for the project.

Xintong was subcontracted by China Railway Sixth Bureau Group to build 11 tunnels on a new railway linking Hefei in Anhui Province to Fuzhou in Fujian

Province. The contract was worth CNY 846M (USD 133.38M).

The China Railway Sixth Bureau Group claims it paid CNY 418M (USD 66M) to Xintong when it backed out of the project in February 2012 after completing just 7km of tunnelling works for the railway project.

China Railway Sixth Bureau Group said it will cooperate with the police investigation.

TBM preparations for Alaskan Way Viaduct

USA: Crews are cutting a launch pit to hold the world's largest diameter TBM for the Alaskan Way Viaduct Replacement project in Seattle, Washington. The launch pit will be 400ft (122m) long, with a width and depth of 80ft (24m). The 57.5ft (17.5m) diameter TBM (right) is currently being assembled in Hitachi Zosen's factory in Japan. It will launch just west of Seattle's stadiums. The machine is expected to begin digging in the summer of 2013.



Above: Assembly of the 17.5m diameter TBM for Alaskan Way

Green light on Georgia-Turkey tunnel

EURASIA: Georgia and Turkey have pledged to sign an agreement on the construction of a tunnel on the Akhalkalaki-Kars railway line of the Baku-Tbilisi-Kars route, local media in Turkey reported last month. The meeting between Jaba Ebanoidze, head of the Georgia Revenue Service, and Ziya Altunialdiz, minister for customs matters of Turkey, was held in Istanbul. The agreement allows the simplification of border crossing procedures with the freeing of imports into Georgia from all customs duties and to establish a temporary border checkpoint.

This document sets out to demonstrate that customs administrations have done everything to ensure that the construction of a railway tunnel is completed in the

shortest possible time.

The Baku-Tbilisi-Kars transport corridor project includes the construction of the Kars-Akhalkalaki railway branch with a length of 98km, of which 68km is in Turkey and 30km in Georgia. A 183km section of the Akhalkalaki-Marabda-Tbilisi railway will be reconstructed, which will increase the cargo carrying capacity to 15Mt every year.

London's Custom House station contract awarded

GREAT BRITAIN: The main construction contract for London's Crossrail Custom House station was awarded last month. Crossrail awarded

contract C520 to Laing O'Rourke. In line with European Union procurement rules the contract is subject to a 10 day cool off period.

The new station will be built on the site of the former North London Line station that closed to passengers in December 2006. The station will include a new ticket hall, an interchange with Docklands Light Railway (DLR) and step-free access between the street and Crossrail platforms.

Exhibit showcasing world's first underground park opens

USA: A free exhibition in Manhattan's Lower East

Side called 'Imagining the Lowline' opened last week. The exhibit demonstrates Arup's research into a proposal for the first underground park, the company announced.

The exhibit shows how the team's system for collecting sunlight and channeling it below ground can create an attractive public space and enable plant growth, the company stated. Arup has been heavily involved in the project since approaching the architects about partnering with them to provide technical services; the company has provided feasibility studies and innovative explorations of design possibilities.

The current exhibit transforms an abandoned warehouse into a life-size replica of the proposed Lowline. The main focal point is a 35ft (10.6m) wide canopy designed and executed by Raad Studio and industrial designer Ed Jacobs.

The canopy features six sunbeamer devices that reflect sunlight into a parallel column, then direct it down a highly reflective tube the canopy directs sunlight to a mockup park containing plants that can be cultivated in low light conditions.

Arup worked in collaboration with the canopy team and University of British Columbia physics professor Lorne Whitehead to model and test the sunbeamer devices and canopy materials in order to optimise the potential for sunlight collection and redistribution.

The Ground Support Company

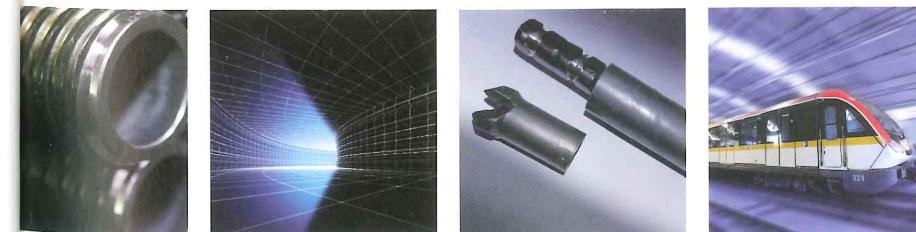


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The Ground Support Company

CROSTOWN CONTRACT

CANADA: Metrolinx has awarded the first of two tunnelling contracts for the Eglinton-Scarborough Crosstown tunnel, which involves tunnelling beneath Eglinton Avenue from the west launch shaft area at Black Creek Drive to Yonge-Eglinton station. The contract, worth CAD 320M (USD 328M), was announced last month by a Metrolinx spokesman.

Crosstown Transit Constructors, a joint venture of Obayashi subsidiary Obayashi Canada, US-based Kenny Construction, Canada-based Kenaidan Contracting and also Technicore Underground, won the contract to build the 6.2km tunnel, about half the underground portion of the Crosstown light

rail line. Work will begin in late 2012 using two TBMs.

"We are moving forward on the biggest investment in public transit in the City of Toronto," said Bob Chiarelli, Ontario's Minister of Transportation and Minister of Infrastructure. "This project will create tens of thousands of jobs and make it easier for commuters to get to work, school or appointments."

The CAD 4.6bn (USD 4.7bn) light rail transit, which will run about 19km from Black Creek to Kennedy station in the east, is expected to take about eight years to complete. About 11km of that is underground.

TBM gets ready for Singapore's Downtown Line

SINGAPORE: The first of six 6.65m diameter Robbins EPBMs is set for a massive undertaking for Singapore's Downtown Line, excavating contract C927 running between Bedok Park and Bedok Reservoir. The 62t cutterhead for the machine was lowered in August and the TBM is scheduled to begin excavation this month, the manufacturer announced.

"Assembling the machine was a challenge due to the small shaft opening," said Mark Passey, Robbins site manager. "This required assembling the shield in smaller sections than usual, and required the use of a purpose-built lifting adaptor to lower the cutterhead support and forward shield separately."

Two EPBMs will excavate contract C927 for contractor CMC di Ravenna of Italy, which will bore parallel 1.35km tunnels through alluvium consisting of cemented sandstone and beach rock. Four more Robbins EPBMs will excavate contracts C925 and C937 for contractor GS Engineering & Construction of South Korea.

Blast in New York subway

USA: A blast at a construction site for New York's USD 4.5bn subway expansion shattered windows, damaged a building

and forced a street closure, last month.

The Metropolitan Transportation Authority revealed that an error occurred as contractors were blasting a tunnel for the Second Avenue subway, which is planned to run up and down the east side of Manhattan. There was no structural damage to any surrounding buildings and no injuries were reported.

Some 132 inmates escape Mexican jail through tunnel

MEXICO: More than a hundred prisoners escaped through a tunnel from a jail in northern Mexico last month, setting off a massive search by police and soldiers in an area close to the

US border, local media reported. Authorities in Coahuila state said the 132 inmates fled the prison in Piedras Negras, a city across the border from Eagle Pass, Texas, through a tunnel that was 21ft (6.4m) long and 4ft (1.2m) in diameter, then cut their way through a chain link barrier and escaped onto a neighboring property.

Groundbreaking on Seattle light rail extension

USA: A groundbreaking ceremony was held at the site of the Roosevelt station in Seattle last month, marking the start of construction on Sound Transit's Northgate Link light rail extension from Husky Stadium to Northgate.

The USD 2.1bn extension will run mostly underground. Work is initially focused on demolition in the Roosevelt area, and Sound Transit will award a contract in 2013 for the construction of the twin-bore 6km tunnel from just north of Roosevelt station to University of Washington station. Tunnelling will begin in 2014 and the line is expected to open in 2021.

Breakthroughs on Russian oil pipeline and metro

RUSSIA: Two TBMs achieved project breakthroughs last month in Russia. Caterpillar TBMs in use on the Mostovik's oil project pipeline tunnel in Novorossiysk by the Black Sea, and a second for a metro tunnel in the city of Omsk in Siberia, Russia holed through (see photo, below left).

A 3.86m diameter EPBM bored the 3.224km oil transmission pipeline tunnel from Grushevaya oil depot to Sheskhari's oil depot.

The machine launched in February 2011, advanced under the 400m overburden of Mount Markhotskiy Ridge and broke out on 1 August 2012.

In Omsk, a 6.5m EPBM was used to mine a metro tunnel with total length of 1.56km. Mostovik inaugurated the TBM launch in June 2011, and the machine took a bit less than 14 months to break through on 6 August 2012.

The Omsk metro is expected to be in operation by 2016.



Above: The Caterpillar TBM broke through on the Omsk Metro

News briefs

GREAT BRITAIN: A tunnel under the River Thames in London, UK had to be shut last month after seven pedestrians reported breathing difficulties. Emergency services closed off the Greenwich foot tunnel and carried out a sweep of the area for any chemical spills. The tunnel was reopened after there were no elevated readings.

"Our relationship with Sandvik goes back a long way and I can honestly say that the Sandvik roadheaders have really met our needs: they are powerful, robust, and energy-efficient. Combined with Sandvik's comprehensive knowledge in tunneling, excellent service and solid technical support, I don't think one can find a better solution in mechanical cutting."

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STRABAG FACES LOW 2012 EARNINGS

AUSTRIA: Central and eastern Europe's largest construction company last month announced considerable falls in its figures for the first half of this year. Strabag has also recently disclosed a downward revision of its outlook for the full-year 2012, citing the causes as delays by public authorities in central and eastern Europe in dealing with claims, the cautious valuation of some construction projects and the ruinous price war in the raw materials business.

The earnings before interest, taxes, depreciation and amortisation (EBITDA) was down significantly from EUR 197.18M (USD 254.58M) in the first half of 2011 to EUR 16.14M (USD 20.8M) in the first half of 2012. "This is due above all to non-operating effects in the second quarter – the second-quarter EBITDA fell

from EUR 256.99M (USD 331.9M) to EUR 90.48M (USD 116.8M)," said a spokesman for Strabag.

"The unusually high other operating expenses include, among other things, damage compensation expenses in the amount of EUR 43M related to the ruling by an arbitral tribunal regarding the failed acquisition of the Cemex activities in Hungary and Austria – a ruling which Strabag has appealed – as well as noteworthy transfers of losses by consortia. The EBITDA was further burdened by a loss of associates resulting from the inclusion of an equity investment in a cement company in Central and Eastern Europe."

The group's output volume in the first half of 2012 fell slightly by two per cent to EUR 6,036.18M (USD

7,727.2M). The largest reduction was registered in Poland due to the end of the construction boom in that country. The company added that for some time a clear trend has been developing toward a reduction of the output volume in the transportation infrastructures segment with simultaneous growth in the other segments. Order backlog, for example, was two per cent higher, with large-scale orders in Italy and Germany.

"If we want to manage the future, we will have to create the best possible conditions for doing so," said Hans Peter Haselsteiner, CEO of Strabag. "Things will certainly become more difficult than we have been accustomed to. The challenge will be to position the group in such a way that we have the decisive competitive advantage, this is my task."

Normet appoints new managing director

FINLAND: Ola Woldmo, the former CEO of Woldmo Consulting, begins work this month as managing director of Normet Scandinavia. Normet announced the appointment of Ola during the summer.

Woldmo has over 30 years of experience in project management and as advisor for major civil engineering and infrastructure projects. He is an expert and advisor for rock mass grouting, rock support and sprayed concrete. In addition, Woldmo is a member of the Norwegian Tunnelling

Society's International committee and a frequent lecturer on seminars and rock support training courses.

Sandvik management shake up

FINLAND: Finland-based drilling equipment

manufacturer Sandvik has reshuffled its executive management. Anders Thelin, president of Sandvik Venture area of the group, with overall responsibility for research and development activities will retire. Tomas Nordahl, head of IT, sourcing and strategy will step into the role.

Olle Wijk, chairman of the research and development board and director of technology and research will assume overall responsibility for research and development. He will keep hold of his current responsibilities.

Wijk will also become a member of the group executive management team, which already includes Nordahl.

All changes will be in effect from 1 November 2012.

President and CEO Olof Faxander added, "I would like to take this opportunity to express my deepest gratitude to Anders Thelin, who over a period of 35 years has used his strong and committed leadership skills as the president of various business areas and as a member of group executive management to make a very tangible contribution."

Faxander complimented the decision over the appointment of both Nordahl and Wijk.

Share tracker

Company	August	September	Change (%)
Aecom (NYSE: ACM)	18.95	20.91	▲ 1.96 (10.34)
Atkins (LSE: ATK)	667.00	667.00	▶ 0.00 (0.00)
Balfour Beatty (LSE: BBY)	292.90	300.60	▲ 7.7 (2.63)
BASF Global (XETRA: BAS)	60.93	65.66	▲ 4.73 (7.76)
Bekaert (BSE: BEKB)	21.15	23.87	▲ 2.72 (12.8)
Bilfinger Berger (XETRA: GBF)	68.30	67.05	▼ 1.25 (1.83)
Caterpillar (NYSE: CAT)	88.94	89.12	▲ 0.18 (0.20)
Costain Group (LSE: COST)	218.00	249.50	▲ 31.50 (14.45)
Ferrovial (MCE: FER)	8.95	9.48	▲ 0.53 (5.92)
Hindustan Construction Company (BOM: HCC)	17.25	16.10	▼ 1.15 (6.67)
Hochtief (XETRA: HOT)	40.92	37.29	▼ 3.63 (8.87)
Morgan Sindall (LSE: MGNS)	634.00	684.00	▲ 50.00 (7.89)
Sandvik (STO: SAND)	96.60	94.10	▼ 2.5 (2.59)
Shanghai Tunnel Engineering (SHA: 600820)	7.80	8.27	▲ 0.47 (6.03)
Strabag (VSE: STR)	18.12	18.00	▲ 0.12 (0.66)
URS Corporation (NYSE: URS)	37.36	37.13	▼ 0.23 (0.62)
Vinci (EPA: DG)	34.85	36.78	▲ 1.93 (5.54)

Prices are taken on 12th of each month. NYSE is in USD. LSE is in GBP. STO is in SEK. BSE, EPA, MCE, STR and XETRA are in EUR. BOM is in INR. SHA is in CNY.

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GOVERNMENT SUPPORT

GREAT BRITAIN: Business secretary Vince Cable singled out tunnelling as a target industry for the Government to support and develop in the UK, in a new 'interventionist' industry strategy announced last month.

Cable highlighted key areas of industry that require a long term boost with ready access to funding, better skills and government contracts. This followed the publication of GBP

70bn worth of government contracts for the next five years, announced in April.

Construction and engineering are seen as key strategic industries where government action could have a real and early impact. Cable noted that tunnelling, in particular, was a British sector that needed to be developed ahead of the expected work boom in transport, water and energy projects.

Ampcontrol buys Primatec

AUSTRALIA: The largest privately-owned electrical engineering company in Australia has acquired an automation and process control firm. Ampcontrol announced its acquisition of Australia-based Primatec last month.

Ampcontrol provides electronic products and complete electrical solutions to the mining, tunnelling, infrastructure, utilities and energy sectors. Primatec specialises in automation, process control and software

solutions to the mining, industrial and utility markets.

Ampcontrol has acquired the business and assets of Primatec and the company will operate under the Ampcontrol Group as Ampcontrol Automation.

"The technology solutions provided by Primatec will be a significant value-add for Ampcontrol customers as they complement our existing products," Geoff Lilliss, Ampcontrol CEO said.

Clint Bruin, one of the founding directors of Primatec, added: "This is a great outcome for our employees and the business. We are looking

forward to being part of the Ampcontrol team and in a position to provide improved services to our customers. We have worked closely with Ampcontrol on a number of large coal mining projects in recent months and we believe our combined expertise will deliver a highly attractive solution for our customers in Australia and overseas."

Changes in board and brand at Bilfinger

GERMANY: Klaus Raps, who joined the company in 1986 and was appointed CEO of Bilfinger Berger on 2004, will resign his position in the executive board at the end of this year.

The company has also announced that it changed its branding, and was no longer to be known as Bilfinger Berger. As of 25 September, the company has shortened its

Central bank rates

	Rate (%)
AUD	3.50
BRL	7.50
CAD	1.00
CHF	0.00
CNY	6.00
EUR	0.75
GBP	0.50
INR	8.00
JPY	0.10
NZD	2.50
USD	0.25

Rates are taking on 12th of each month.

name to 'Bilfinger' following a decision at the annual general meeting in May 2012. Raps joined the executive board in 2007 and is leaving the company by mutual agreement due to differing views on the company's business policy, a Bilfinger Berger spokesman announced last month.

The supervisory board of Bilfinger Berger has appointed Jochen Keysberg as a member of the executive board which will take effect as of 1 November 2012.

Keysberg has been with the company for over 15 years and has most recently been the head of executive management at Bilfinger Berger Ingenieurbau.

Oil price



96.99

The US Dollar value of a barrel of Brent crude oil as of September 2012

Values are taking on 12th of each month.

Currency tracker

	USD	EURO	GBP
1 AUD	1.045	0.811	0.649
Inverse	0.957	1.233	1.541
1 BRL	0.495	0.384	0.307
Inverse	2.019	2.603	3.253
1 CAD	1.025	0.795	0.636
Inverse	0.976	1.258	1.572
1 CHF	1.067	0.827	0.662
Inverse	0.938	1.209	1.510
1 CNY	0.158	0.124	0.098
Inverse	6.323	8.158	10.194
1 EUR	1.289	1.000	0.800
Inverse	0.957	1.000	1.250
1 GBP	1.611	1.250	1.000
Inverse	0.621	0.800	1.000
1 INR	0.018	0.014	0.011
Inverse	55.217	71.187	88.953
1 JPY	0.013	0.010	0.008
Inverse	77.861	100.381	125.433
1 RUB	0.032	0.025	0.020
Inverse	31.457	40.555	50.677
1 USD	1.000	0.776	0.621
Inverse	1.000	1.289	1.611

Values are taking on 12th of each month.

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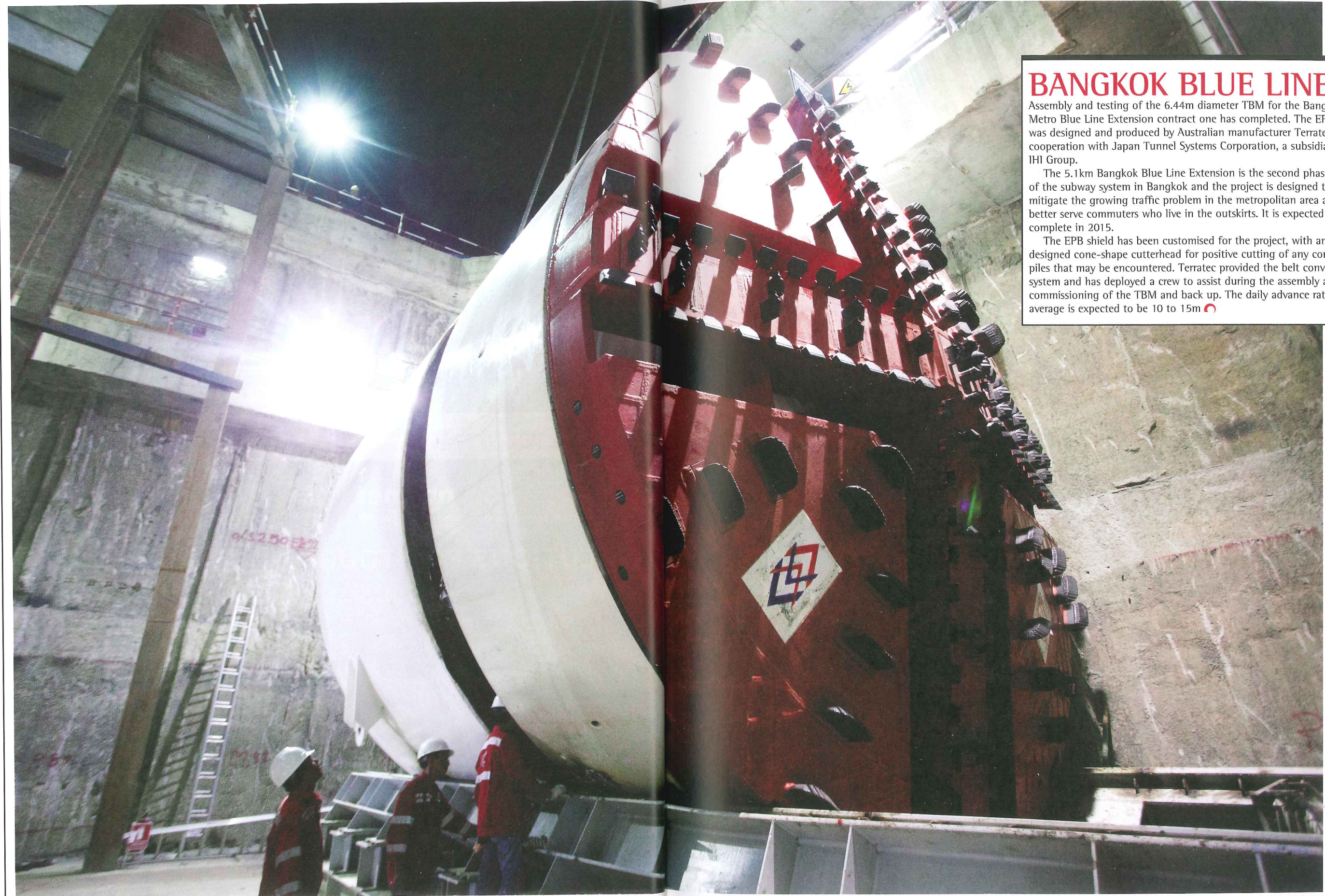


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Values are taking on 12th of each month.



BANGKOK BLUE LINE

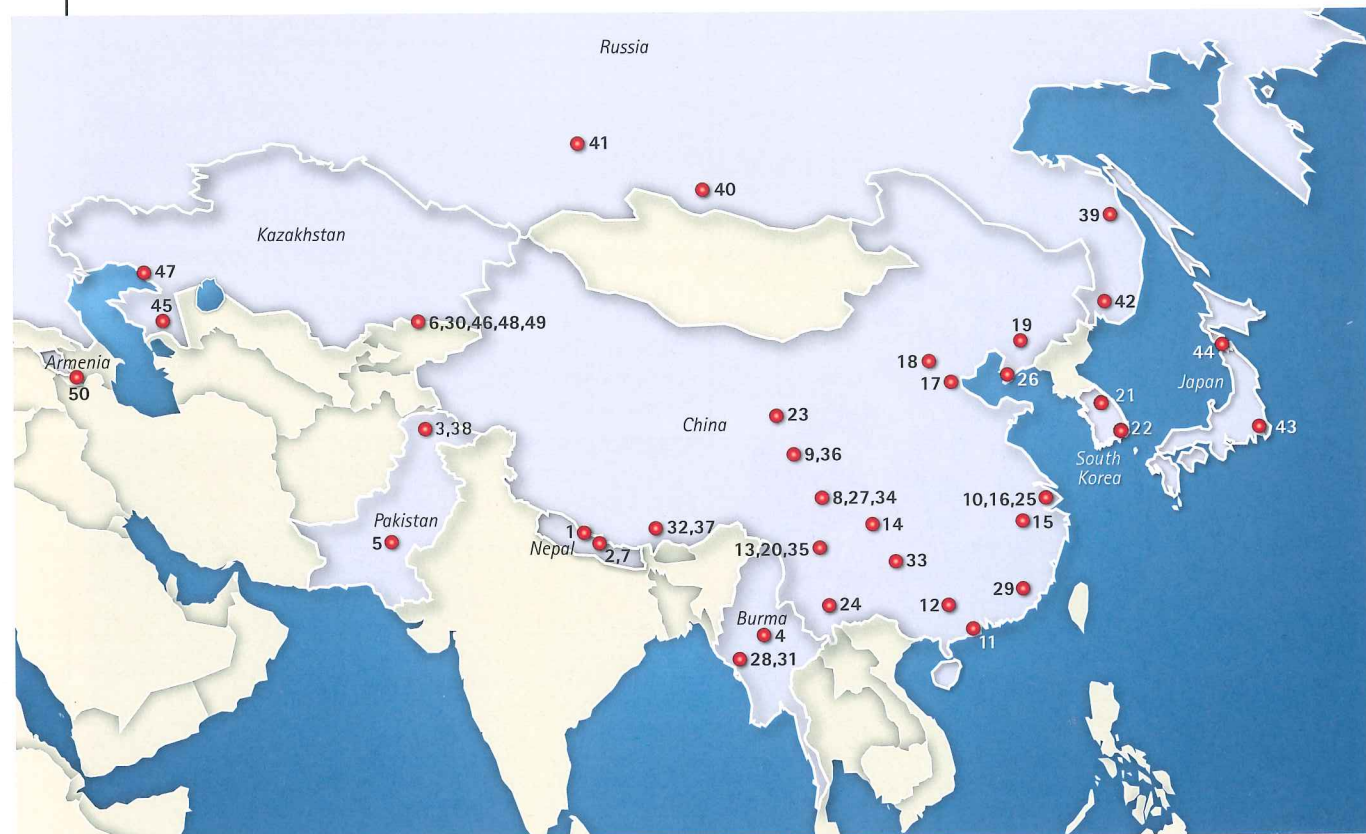
Assembly and testing of the 6.44m diameter TBM for the Bangkok Metro Blue Line Extension contract one has completed. The EPBM was designed and produced by Australian manufacturer Terratec in cooperation with Japan Tunnel Systems Corporation, a subsidiary of IHI Group.

The 5.1km Bangkok Blue Line Extension is the second phase of the subway system in Bangkok and the project is designed to mitigate the growing traffic problem in the metropolitan area and better serve commuters who live in the outskirts. It is expected to complete in 2015.

The EPB shield has been customised for the project, with an IHI designed cone-shape cutterhead for positive cutting of any concrete piles that may be encountered. Terratec provided the belt conveyor system and has deployed a crew to assist during the assembly and commissioning of the TBM and back up. The daily advance rate average is expected to be 10 to 15m.

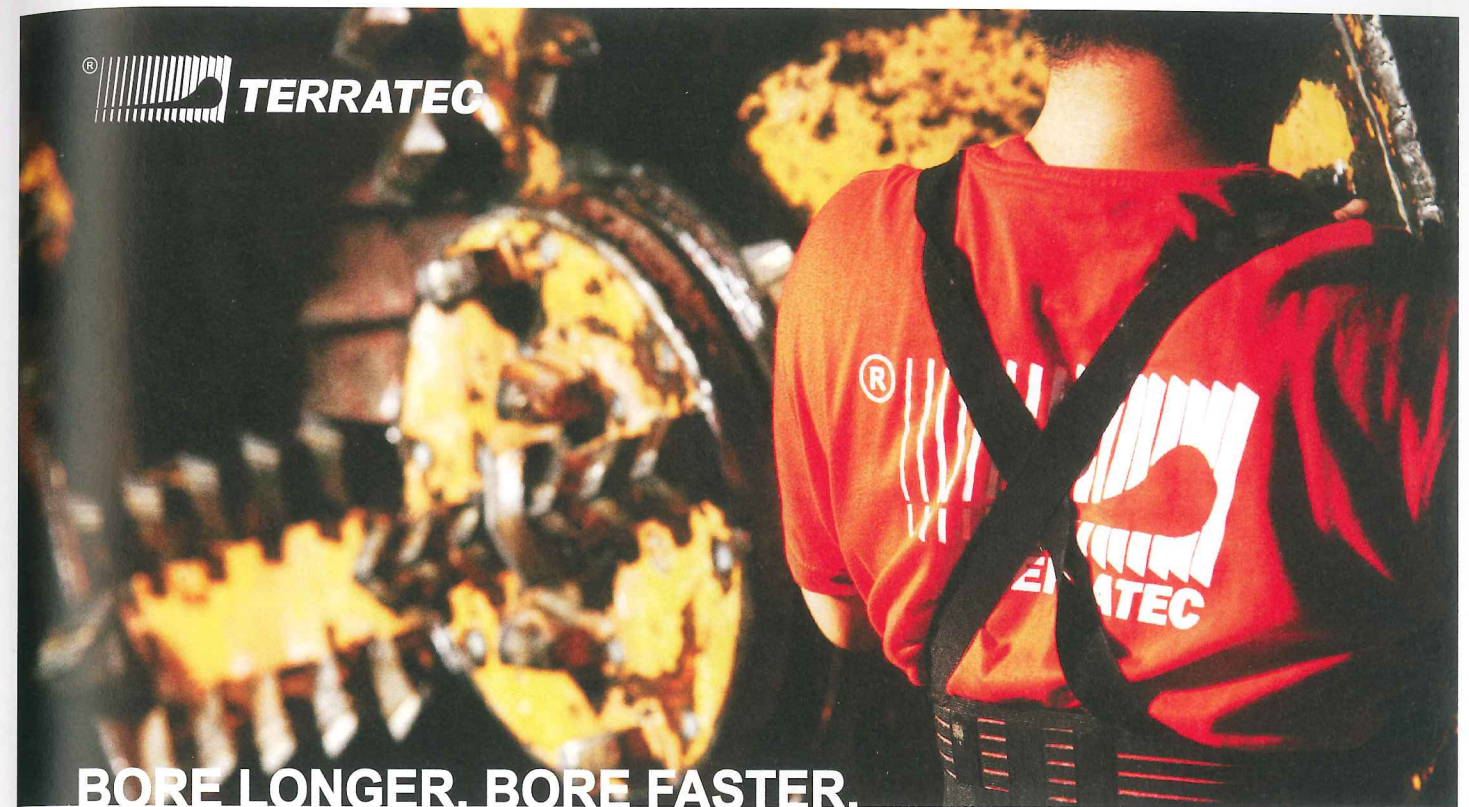
PROJECT MAP

A snapshot of work going on in Central and North Asia. The focus is unsurprisingly on Chinese metro



Key

- | | | |
|--|--|--|
| 1. Kathmandu-Tarai Fast Track Expressway | 19. Shenyang Metro | 36. Xian to Baoji High Speed Railway Line |
| 2. Sundarjal Water Treatment Plant | 20. Jinping II Hydroelectric Power Plant | 37. Punatsangchu Hydroelectric Power Plant Phase I |
| 3. Daral Khwar Hydroelectric Power Plant | 21. Donghongcheon Yangyang Expressway | 38. Golen Gol Hydropower Plant |
| 4. Muse-Kyauk Phyu Railroad | 22. Pohang to Ulsan Expressway | 39. Kuznetsvosky Railway Tunnel |
| 5. Nai Gaj Rockfill Dam | 23. Yintao Water Supply Tunnel IX | 40. Korshunovsky Tunnel Reconstruction |
| 6. Kambarata Hydropower Stations | 24. Xiangjiaba Hydroelectric Power Plant | 41. Boguchansk Hydro Electric Power Plant |
| 7. Melamchi Water Supply Project | 25. Suzhou Light Rail Line 1 | 42. Leopard National Park Tunnel Development |
| 8. Jinping Hydropower Station | 26. Dalian Bay Subsea Tunnel | 43. Nerima-Setagaya Underground Road Tunnel |
| 9. Lianghekou Hydroelectric Power Plant | 27. Guandi Hydropower Plant | 44. Yomogida Shinkansen tunnel |
| 10. Hangzhou Metro | 28. Tha Htay Chaung Hydroelectric Power Plant | 45. Uzen-Gyzylgaya-Bereket-Etrek-Gorgan Railway Line |
| 11. Shenzhen Metro | 29. Xiamen Haicang Undersea Tunnel | 46. Chilik River Hydroelectric Power Plant |
| 12. Guangzhou Metro | 30. Bishkek-Torugart Roadway Rehabilitation | 47. Mangyshlak-Bautino Railway Line |
| 13. Chongqing Metro | 31. Laymro Hydroelectric Power Plant | 48. Bishkek-Naryn-Torugart Road Rehabilitation |
| 14. Wuhan Metro | 32. Zangmu Hydro Power Plant | 49. Kambarata Hydropower Stations |
| 15. Nanjing Metro | 33. Huaneng Nuozhadu Hydroelectric Power Plant | 50. Aras Hydro-Electric Power Plant I |
| 16. Shanghai Metro | 34. Guandi Hydropower Plant | |
| 17. Tianjin Metro | 35. Huaneng Nuozhadu Hydroelectric Power Plant | |
| 18. Beijing Metro | | |



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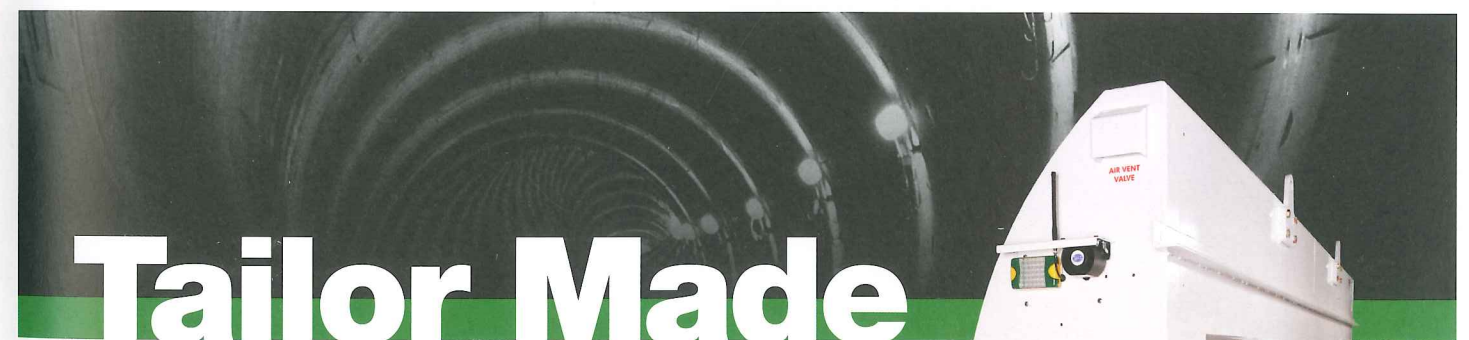
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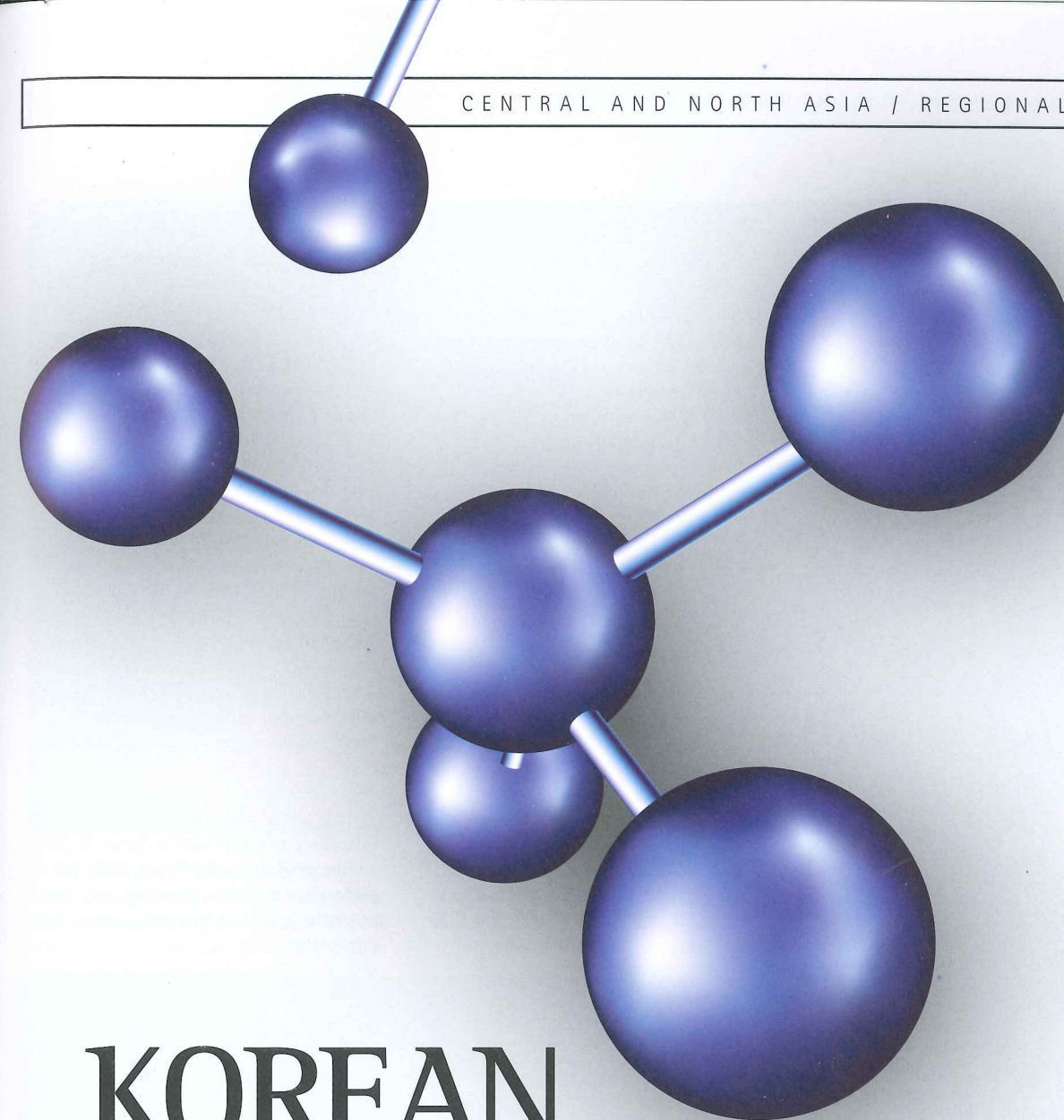
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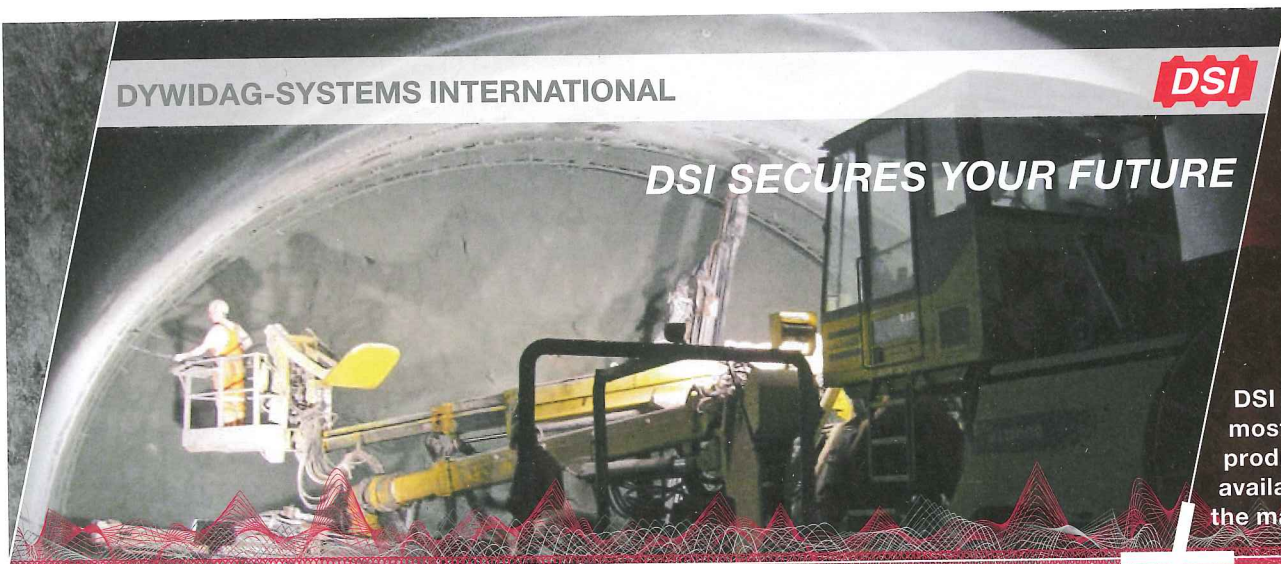
KOREAN CONNECTIONS

Following a drive worthy of any alpine highway, and a respectful shuffling-off of shoes in favour of the site office sandals, **Alex Conacher** speaks to Young Sam Kim, site manager for contractor Samho

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LOW, STEEP mountains covered in brown spiky trees pimple the landscape surrounding Gyeongju City in South Korea. In the far south east of the country, some 370km away from the capital, Seoul, Gyeongju was the ancient capital of the Kingdom of Silla, which ruled around two thirds of the peninsula from the seventh to ninth century. »

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





The heritage site sits halfway between the major port cities of Pohang to the north, and Ulsan to the south. The under-construction Pohang – Ulsan Expressway will link these two economic centres of the southeast of South Korea. The whole project will require some 60km of tunnels.

South Korean contractor Samho was founded in 1976 and has 20 to 30 tunnelling projects under its belt, with half a dozen ongoing. One that it is currently working on is division seven of the Pohang to Ulsan expressway. Samho is executing works client Korea Expressway Corporation.

All 7.5km of the division is in twin tunnels and the site is located 137m above sea level on Tohamsan (literally: Mount Toham).

GEOLGY, DRILLING AND BLASTING

There are five divisions in Korean geologic thinking. Rock runs from 'very good' with a rating of one, down to five for 'very poor'. The rock in this project runs across three types and is mainly heavily fractured granite including shale. It is a highly complex environment.

"At the moment we do not have much data on tunnelling conditions, and everything depends on the experience of engineers"

The face is 14.16m wide and 9.17m high, with another 12m apart. A 118 hole drill pattern has been used and blasting is performed seven times per day. Blasting throughout the night is made possible by the remote location of the project site.

With a drop in rock quality from Korean rating three (around 1-10 according to the Q Index) to five (less than 0.1), a top heading and benching approach has been adopted.

Because of the fractures, and following a tunnel roof collapse in June, a reduced drilling depth has been put in place after umbrella grouting. Another potential issue is a fast penetration rate into softer rock.

3.8

The maximum achievable drill depth, which had been managed twice as *Tunnels* visits site

2.5

The average drill depth as *Tunnels* visits site

Above: Figure 1, the site situation on the new route between the major port cities

Right: The approach to the site was barren as *T&T* visited site, and winter was ending



The RD525 drifter can penetrate faster than the Axera in hard rock with a high accuracy, hence the mentioned rate improvements (see box, p.26). If the drill speeds up in softer rock, accuracy is lost and there is the possibility of overbreak and underbreak. The RD525 drill was designed to be able to recognise the rock formation, and then it is able to reduce speed automatically to compensate for this effect.

The maximum depth of 3.8m had been executed twice on the project as *Tunnels* visited, while normal rounds consisted of depths of two to 2.5m.

Lining

The sprayed concrete lining was installed by a Samho subsidiary and was designed to cope with 1,800t of water per day. Wet shotcrete was used for a double shell lining and applied by a Samho subsidiary. Concrete was batched on site.

Rockbolting

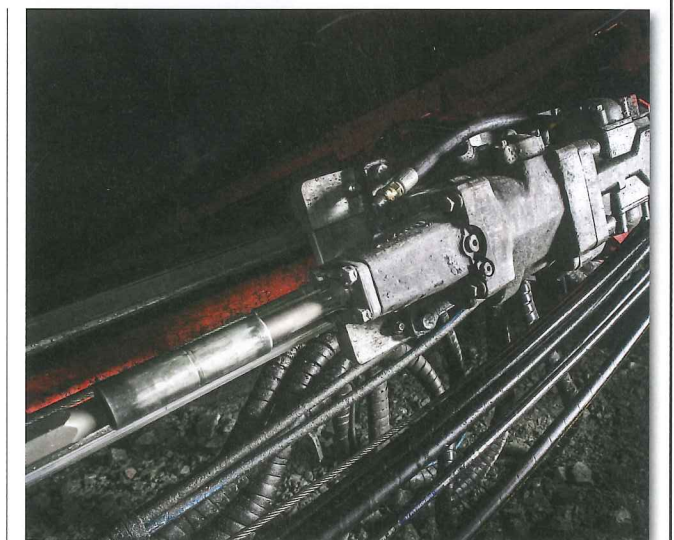
The resin rockbolts used are 32mm in diameter and 4m long and are manufactured by a local Korean company. Placement is 1.5m apart in more competent rock, and 2m apart in less. The original design was to use some 20,600, but now every round is bolted due to the instability of the rock.

LANDSCAPING

Rock excavated is used for construction, and the site claims 100 per cent of material is recycled. Tohamsan is in a protected national park area, and is under-developed for this reason.

1800

The tonnage of water the tunnel lining was designed for originally



Above: Behind the driver's seat in a DTi jumbo

Right, top: Samho is gathering data on tool consumption

Right, bottom: The new iSure drilling software plans bores without marking the face



Smart jumbos in Korea

Young Sam Kim has seen an increase in tunnelling work in Korea to the point where there is always something happening and Samho's plant is at a premium. "The Dti allows more efficient, faster drilling so it can be moved to the next site more quickly," Young adds.

The Sandvik DT1130i on site is the third intelligent jumbo in the country and it was brought in to replace the Axera T11 DATA that was in use previously. With an HLX5 drill the Axera achieved drill times of two hours. The DT1130i has achieved 1.5 hours with an RD525 drill. The switch gives a higher maximum percussion rate, increasing from 67Hz to 74Hz, the manufacturer claims that this and a stabiliser has given test results showing a 17 per cent higher penetration rate and longer tool lifespan compared to the HLX5.



Samho
삼오개발/상호개발

3

The number of smart jumbos constructed by Sandvik currently operating in Korea

As a result, even supplying the site with 40t trucks has resulted in complications.

Just down the road from the site, a bridge has had to be completely strengthened by Samho from its original 30t capacity.

All such works have had to be permanent improvements.

ALL ABOUT DATA

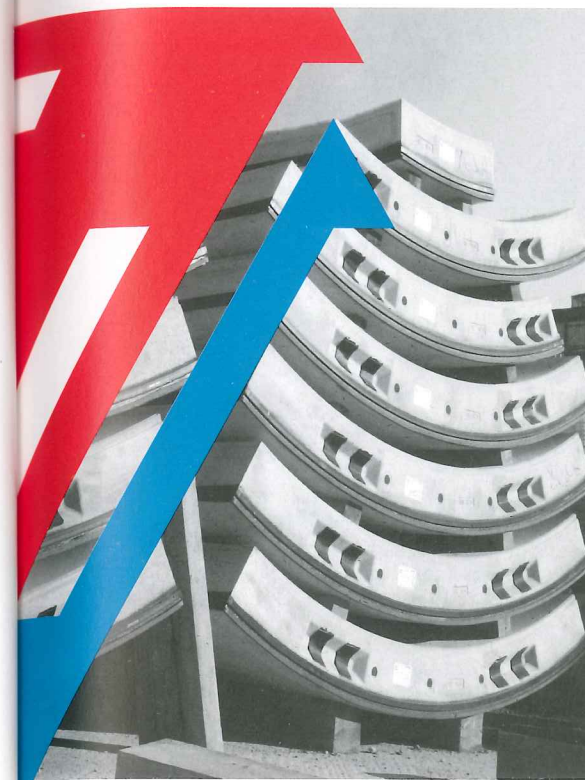
"One of the biggest challenges we are facing on this project, and one that we are trying to improve on across all of our tunnelling activities, is data," says Young Sam Kim, Samho site manager. "At the moment we do not have much data on tunnelling conditions, and everything depends on the experience of our engineers, which we hope to change."

Young adds that there is now a focus to increase our datalogging activities, and build up a database for use on future tunnelling projects. And it's not just conditions that are missing from spreadsheets.

An idea of tool consumption and timescale will of course be crucial for accurate costing, and future tendering activities in Korea. "And elsewhere, of course," he adds. "We have no tunnelling experience outside of Korea yet, but we are eager to expand abroad"

Above: Young Sam Kim outside of the pristine site office

Left: The tunnel portal lies some distance from the site office



www.datwyler.com

Sealing Technologies

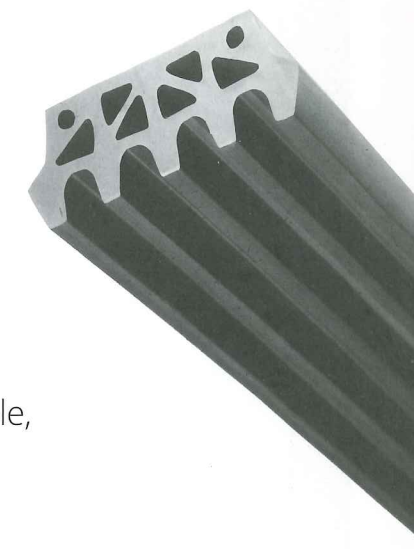
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The Israel Light Rail

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Tender No. 017/2012 – Pre-Qualification

For the Design-Build of NATM Tunnels for the Tel-Aviv LRT Red Line Project (the "Tender")

Following the Invitation for Pre-Qualification in relation to the design and construction of NATM Tunnels for the Red Line Project published by N.T.A. – Metropolitan Mass Transit System Ltd. ("NTA") on June 21st, 2012, NTA amended several Pre-Qualification Requirements. For further information please refer to Addendum no. 3 published on NTA's website at: <http://www.nta.co.il/site/en/neta.asp?pi=464>.

Itzhak Zuchman
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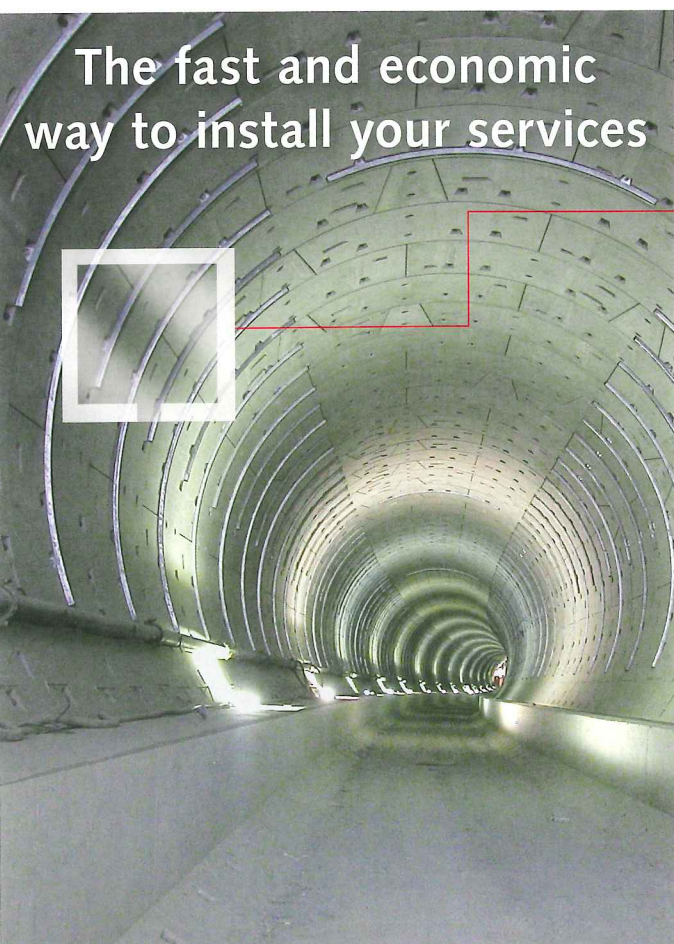
HIGH PRESSURE SEA CROSSING

A slurry TBM is cutting through the sands deep under Zhanjiang Bay, China, to provide a crucial water link to an island steelworks. A tight schedule and a 42m head of water are upping the pressure on the project. *Tunnels* editor Jon Young visits the site

IT IS everybody's first time in the mad dash to complete an undersea tunnel off the southern coast of China. A vital water link is needed to regenerate the largely vacant island and boost the region's economy. East Sea Island will eventually host a massive steelworks and accommodate the 20,000 workers expected to flock to the island. The island lies in Zhanjiang Bay, which is home to China's first modern port, the enormous 39 wharf dock.



Jon Young
Based in London, Jon has been editor of *Tunnels* since 2009



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A view down the four per cent gradient of Zhanjiang Bay Tunnel

It is the first time the tunnelling crew crossing Zhanjiang Bay has used a slurry TBM. And the first time the machine's manufacturer has ever built one. Tunnelling crews are racing to meet a tight construction schedule with breakthrough penned for this month.

The tunnel will carry water south from Wuchuan, located north of Zhanjiang, to feed the steel works being constructed on East Sea Island. The entire water transfer scheme is 26.4km long. The tunnel is needed to cross Zhanjiang bay and is being driven from East Sea Island, northwards 2.7km.

The designer specified a minimum overburden of 22m. This means the ideal alignment sees the tunnel launching from a shaft that ends a little above the rock layer. Then drops on a steep gradient of around four per cent under the bay to a total depth of some 60m. It then rises almost equally as sharply and ends in a reception shaft excavated on Nanshan Island.

The geology is made up of stayed clays, middle coarse sand, gravelly sand and fine silty sand. The sand is quartz.

SHAFT EXCAVATION

The launch shaft on East Sea Island is cut 26.5m deep and the reception shaft on Nanshan Island reaches 28.5m. The bottom of each shaft is at the same depth below sea level. There were two limiting factors on the shaft depths, the height of the rock layer, which would have been costly to excavate through and the water pressure.

David Han is project manager for US-based TBM manufacturer Robbins. He explains that the shaft depth was limited to ensure the safety of the TBM launch. As the ground has a high water pressure



"The ground occasionally becomes sticky, the contractor adds sodium carbonate to reduce viscosity"

Above: Figure 1, the site is near the first modern port in China

Below: The TBM slurry system is monitored near the launch shaft

the TBM must launch through a seal in the shaft wall. The deeper the shaft, the higher the pressure, and the greater the stress on that seal.

Excavation on the launch shaft started in December 2010. It was completed in July 2011. The retrieval shaft started construction in August 2011 and was due for completion in August this year. Shi Quinghua, chief engineer for contractor Guangdong Hydropower Engineering explains that the reception shaft is founded in a much less stable geology, which



slowed construction. The launched shaft is excavated in stayed clay while the reception shaft, to the north, is excavated in an unstable sand.

Piles were driven to beyond the full depth of the shaft. Excavation then began and as the shaft was excavated a secondary lining was cast for final support. The initial piles on the launch shaft were driven 37m deep for a finished shaft depth of 26.5m. In the poorer geology on the north side the piles had to be driven 52m deep for a finished shaft depth of 28.5m. The secondary lining was installed as the shaft was excavated within the piled ring. The piles and the secondary lining are made of reinforced concrete.

THE MACHINE

As this is the first slurry machine Robbins has manufactured, the company partnered with Mitsubishi Heavy Industries Mechatronics Systems (MHI-MS) of Japan, which supplied the slurry system.

The contractor chose a slurry TBM for the project because, project manager Liang Mindong says, the system is safer in the sandy ground conditions, where an EBPM could cause a collapse of the ground above by removing soil faster than the machine advances. A sinkhole would be a major problem for the project as it could lead to the flooding of the machine.

The slurry also offers the cutterhead some protection

26.4

The length in kilometres of the entire water transfer scheme

against the abrasive quartz sands. Muck removal is simplified using a slurry system in the tight launch shaft as all of the earth can be shifted through the slurry pipes.

The machine has an outside diameter of 6.26m and a shield thickness of 45mm. Three rows of wire brushes are fitted to the tale of the machine to prevent the six bar of pressure escaping down the side. The annulus space is filled with a single component liquid grout. The machine has 20 sets of thrust cylinders giving a thrust of 46,000kN. The high power is needed to overcome the high pressures at the face. It has a working torque of 5,442kNm and a maximum torque of 5,896kNm. The cutter head is a spoke type with plates and a 30 per cent opening ratio.

The cutter tools include discs, knife edge bits and cutter bits.

The machine is fitted with a two chamber man lock in case crews need to access the cutterhead. So far the project

Below: The first slurry machine manufactured by Robbins



Land of opportunity

The People's Republic of China is the second largest economy in the world. In 2011, mainland China's Gross Domestic Product (GDP) reached a total of USD 7.2tn and GDP per capita amounted to USD 5,351, according to data firm Timetric.

China is the most populated country in the world with 1.35 billion people in 2011, up 0.48 per cent from the previous year. The urbanisation rate rose to 51.3 per cent in 2011, the first time in history the figure has been above 50 per cent. China is also the second largest country by territory (9.6Msqkm). This urbanisation is driving the need for underground infrastructure.

China has maintained strong economic growth in the past few decades, recording an average annual rate of expansion of 9.9 per cent since the launch of reform and opening up in 1978, which included market-oriented reforms and stronger foreign economic ties. Investment is the key driver of China's economy. Gross capital formation rose to a peak of 49.2 per cent of total GDP in 2011, while household consumption accounted for 34.9 per cent. The government is aiming to shift the economy from investment- to consumption-led growth.

China's construction sector flourished and became the key driver of the economy during the last ten years. Investment in real estate development rose to nearly CNY 6.2tn (USD 0.987tn) in 2011 from CNY 2.5tn (USD 0.398tn) in 2007. Floor space of new started construction increased to 1.9bn sqm from 945.9M

sqm during the same period. The rapid growth of China's construction sector is reflective of the country's urbanisation and industrialisation progress, which requires the expansion of factories, housing and infrastructure networks.

Soaring property prices in 2010 induced concerns of a property bubble, and the government subsequently implemented a series of property market restrictions with the aim of increasing affordability and deterring speculative behaviour. These measures have led to a moderation in China's annual economic growth, down to a three-year low of 7.6 per cent in Q2 2012.

Infrastructure construction has been a major driver of growth, particularly since late 2008, when the government implemented a CNY 4tn stimulus package, within which 45 per cent was to be invested in public transportation and the national grid. Investment in public transportation rose to CNY 2.7tn in 2011 from CNY 1.28tn in 2007, while investment in the production and supply of power, gas and water rose to CNY 1.46tn from CNY 907bn during the same period.

As a percentage of GDP construction is on the increase. It was 6.6 per cent in 2010, 6.8 per cent in 2011, forecast at 7.3 per cent in 2012 and growing to 8.5 per cent by 2016.

The growth in construction is partly driven by the growth in public transportation investment. In July it was up 13.7 per cent year on year according to Timetric.



has not needed any interventions.

THE LAUNCH

The TBM was delivered on 1 August 2011. The machine was originally intended to be delivered in February but at that point there was no road to site that could take the large trucks needed to haul the machine components. The machine was assembled, tested and on 17 November last year was launched.

The machine was lowered into the shaft and seated on a steel cradle for launch. A launch frame was constructed that moved forward with the TBM as it pushed into the ground. This allowed the contractor to keep the congested launch shaft free of segments until the machine was through the shaft lining. According to Liang, this is the first time the method has been used in China.

Above: Despite the construction of a missive grout launching block and the use of a seal, the high pressure of the water inevitably escaped into the shaft

Chief engineer Shi explains that the high surrounding water pressure meant that it was impossible to totally seal the shaft. He explained that: "Some water is entering the shaft but it is at an acceptable level." The shaft structure was successful in preventing water ingress but when the TBM launched through the side of the shaft the seal was unable to completely hold back the water. A small, 3kW pump is in place to remove water from the bottom of the shaft, while crews work on a mesh platform a few meters above the floor.

To control the water during the launch of the TBM, a 25m wide, 12m deep grout injected block was cast from the surface. The grout block was the initial 12m of ground that the TBM cut through on breaching the shaft.

THE LINING

The tunnel is segmentally lined using 1.5m long, 450mm thick segments in a five plus key arrangement. The thicker-than-usual segments were needed to cope with the high pressures. The lining has an outer diameter of 6,000mm and an inner diameter of 5,100mm. Each segment is cast on site and then allowed to cure in a cooling pool before being stacked, coated in waterproofing, lowered down the shaft, drawn through tunnel, erected and bolted into place.

The hydraulic design institute that prepared the designs for the tunnel prepared a very robust specification,

building in many redundancies according to the contractor. For example, the rubber gasket between the segments that is placed to hold back the high water pressures is supported by a second sealant that is cast in the joint once the segments are in place.

This rubber paste sets in the joint in case the primary sealant fails. A pump system is being installed in the tunnel upon completion to cope with any water ingress that occurs during the operation of the tunnel.

THE DRIVE

After launch the contractor took a slow and steady approach to excavation so the crew could get accustomed to the machine and its behaviour. An average of four rings a day, or 6m per day, was achieved initially. But this ramped up to four to six rings per 12-hour shift, or 12 to 18m per day, once through the launch process.

The contractor is on a tight schedule so has to press ahead 24-hours a days and avoid as much downtime as possible. Maintenance is limited as much as possible with the aid of wear detection on the cutter discs and some cutterhead components. The crew typically needs to shut down the machine once a week.

The machine can progress four rings before excavation work stops to allow

52

The depth in metres piles had to be driven for the 28.5m shaft in the poor geology to the north

5862

The maximum torque of the Robbins slurry machine in kilo Newton metres

Below: Segments were immersed in a cooling pool to facilitate curing following demould

"A launch frame was constructed that moved forward with the TBM as it pushed into the ground. This kept the shaft free of segments"

slurry lines and other support lines to be extended. It takes the operators about eight hours to extend the lines. Gate valves positioned along the slurry line allow a section to be parted to insert the extension piece.

A bentonite slurry was used during the launching of the machine as it cut through the shaft wall and grout block. Beyond launch no additives are typically used, water is sent to the face and the mud slurry is pumped back, loaded into trucks and the truck dump the grey coloured slurry on the land surrounding the site.

In the high summer temperatures the slurry quickly dries and the land surrounding the steel works is changed from a vibrant red and orange to a cement like grey.

Along the route the ground has occasionally become sticky and risks clogging the system so the contractor adds sodium carbonate to help reduce the viscosity.

With no one above other than boats, subsidence is not a big concern for the project. Nevertheless, the material being excavated is measured against the advance of the machine to ensure that no over excavation is occurring. However, a sinkhole would be a major problem for the project as it could lead to the flooding of the machine.

There is no requirement for probing or pre grouting. The machine is fitted with a boulder-collecting gate to deal with any boulders that are encountered on the drive.

The TBM is due to breakthrough this month and the tunnel would become operational by the end of the year



1 mm

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

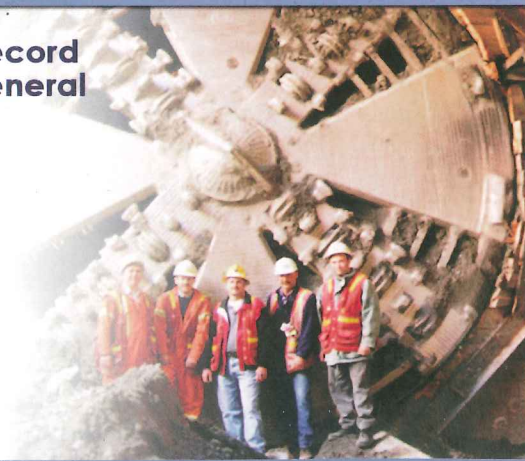


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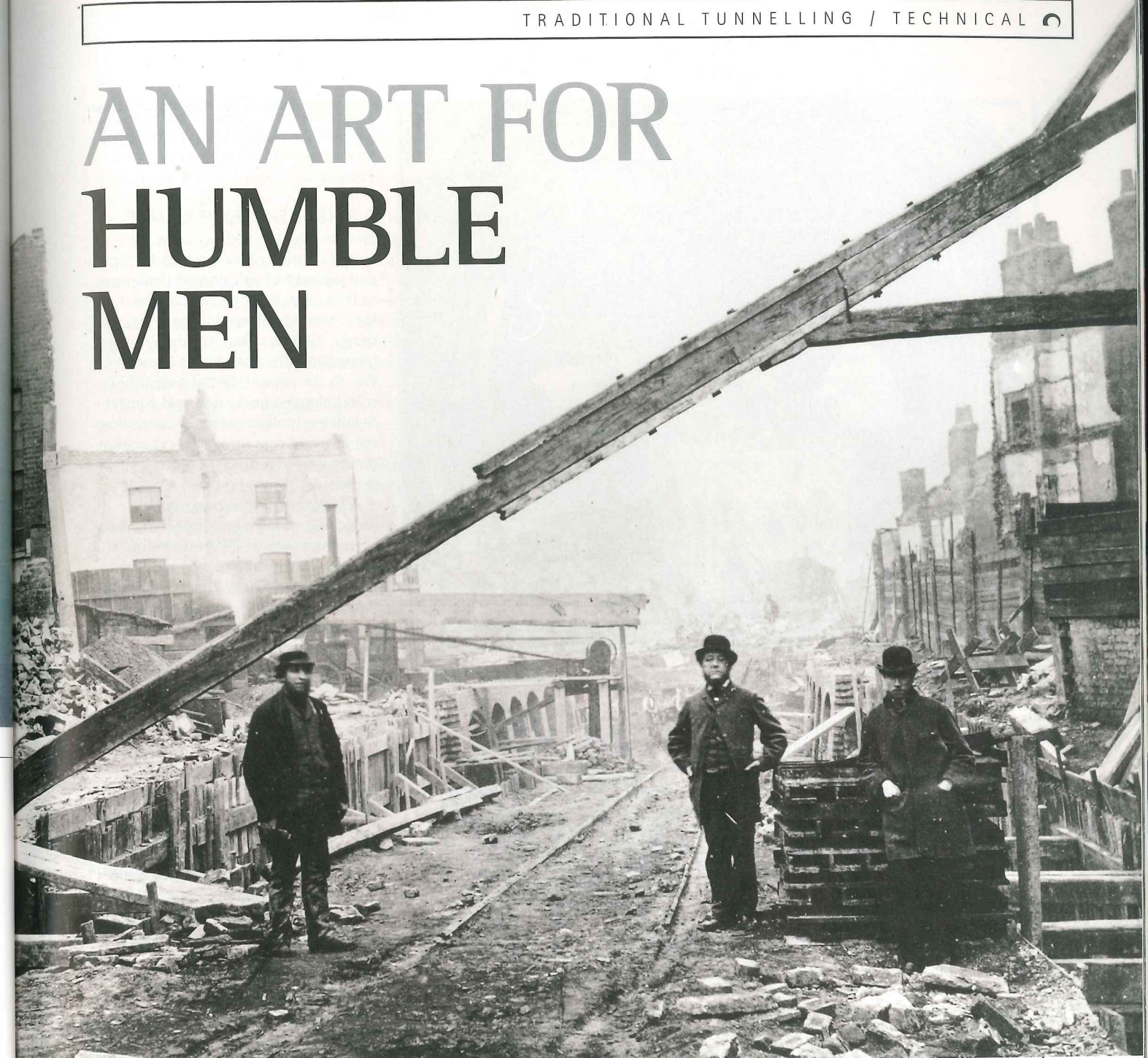


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AN ART FOR HUMBLE MEN



Tunnels revisits the traditional methods. Hand mining and its health and safety related concerns are well known, while the traditional soft ground timber supports are increasingly forgotten, as the old methods get pushed aside by the march of mechanisation. **Alex Conacher** reports

Above: Cut and cover construction on the Metropolitan Railway extension to Kensington. A working site has been cleared, and excavation work has begun on the retaining walls of the cutting, in the trenches on either side. The effect of the work on nearby properties is clearly visible. Circa 1867. LONDON TRANSPORT MUSEUM

TRADITIONAL TUNNELLING is a vague term that can lead to confusion. Often it refers to hand mining regardless of the tunnel lining, in some countries such as Japan it can refer to excavation by semi-mechanised TBM (see page 41) as opposed to a closed shield, and sometimes it can refer to the means of support during excavation.

With regards to hand mining, it is never used for excavations of serious length in modern tunnelling, purely for economical reasons in an age of mechanisation. Tunnel finishing work on the periphery with a spader, or interfacing a new tunnel into an old system, is more likely for the space might



be too small, or too awkward for a small hydraulic excavator to be used effectively.

Other factors limit its work even for small-scale, restricted use. The most obvious are the health and safety implications of having men working directly on the ground. This opens workers up to falls of ground; possible working in close proximity to heavy machinery; manual operation of hydraulic equipment with the burden of lifting it, possibly over head, opening the miner up to risks of falling equipment or balance issues that can endanger fellow miners. The risks are there to be seen.

VIBRATION IN HAND MINING

When *Tunnels* last looked into handwork in a technical focus specifically targeted at hand mining (*Tunnels*, September 2011), the focus was immediately shifted to Reynaud's Phenomenon; the infamous and most apparent symptom of Hand Arm Vibration Syndrome – White Finger.

This is an issue that has not so much divided the UK tunnelling industry as placed the Health & Safety Executive

"Keep the ground under control at all times. Never let it move, impose yourself on the ground before it can impose itself on you"

(HSE) on one side, and experienced contractors on the other. The prevailing thought seems to be that while vibration is a risk, it is not one that applies overly to the tunnelling industry. When tunnellers use a hand tool, it is for short periods and not for prolonged exposure times as are experienced by road breakers or ship riveters.

However, the legislation is in place and was made an enforceable matter around ten years ago in the UK by the HSE. Elsewhere in the world, ISO 5349 on mechanical vibration is frequently used to provide limit values for hand miners,

40

The number of tonnes of axial thrust a Military Trestling Column and a 12x12in Douglas Fir full timber can carry

Above: Work in progress within a Greathead shield on the Southgate Extension of the Piccadilly line. 1 January, 1931. LONDON TRANSPORT MUSEUM

and sometimes worker protections are symptom-led (HAVS progresses increasingly quickly with further exposure).

A SCIENCE OF EXPERIENCE

London Clay has possibly been the most extensively used geology for the development of soft ground timbering in the world. Work on the London Underground has run in stages for nearly 150 years, from the days in the immediate aftermath of the Crimean War to the present. In this time it has seen linings of brick, steel and concrete. A working understanding of controlling the face and supporting the excavation during work has developed over many decades of observation.

With the advent of mechanised tunnelling, soft ground tunnelling has been given over to TBM excavation with an immediately erected and grouted precast concrete ring. The temporary support of timber is not needed in such an environment, or so runs the common line of thought. There is a possible risk that the knowledge gathered over the years will be lost, or at least not understood first hand by a new, computer-aided generation of tunnellers.

TIMBERING

The term timbering, as implied, comes from the timbers that were traditionally used as the material for the supports. This was due to the suitability of timber as a lightweight material with "excellent" load-bearing capabilities. Structural steel sections have also been used where loads and stress were particularly high.

A NEW GUIDE ON TRADITIONAL TIMBERING

The British Tunnelling Society (BTS) is in the process of publishing a new guide for traditional timber work in soft ground tunnelling. Written by retired contractor Colin Mackenzie, it delves into the main points of temporary tunnelling support in London Clay, identifying the particular challenges that render the techniques given suitable for many other types of clay. It does not delve into long-term support, highlighting the plastic behaviour of London Clay that develops as a squeezing load over decades. Temporary supports, covering 'short-term' loads, are designed to the requirements of support for "days, weeks and, very occasionally, months".

The guide also covers typical component specifications for the various timber section sizes, and diagrams drawn in the traditional style relating to

Mowlem guideline

In his guide, Mackenzie says, "Mowlem – the oldest company in the business, with roots going back well over a hundred years – had already built a substantial proportion of the tunnelled sections of the London Underground network, and had the drawings to prove it. These were contained in a large, highly prized volume known as the Mowlem Bible."

The book contained no calculations and standards to which engineers should do their calculations were not given, in particular what loadings were to be applied. This was an issue in passing knowledge on to the younger engineers, and so as a result discussions were held.

The senior engineers produced the following guidelines, which are contained within the Timbering Guide:

- Timbering is temporary work and should be designed accordingly. If it doesn't creak and groan a bit when under load, it's been overdesigned and money has been wasted.
- The principle purpose of headboards is to protect face workers from falls of blocks of clay from the roof. Headboards should, therefore, be capable of carrying six feet of clay.
- The purpose of the combination of face-legs, poling boards, walings, struts, soldiers, kickers and Military Trestling is to keep the whole face under control. The timbering for each stage of face excavation, working down the face, frame by frame, should be capable of supporting a block of clay (a 'greasyback wedge') sliding frictionlessly out of the face. The Military Trestling to the rear of the advancing face should be capable of carrying all combinations of the loads from the walings and struts.
- For the top frame, the dimensions and hence the mass of the block should be determined by drawing a line sloping upwards at an angle of 45 degrees to the horizontal from the foot of each face leg (usually around 6ft tall at the centerline of the face) to intersect a line drawn upwards at 15 degrees to the horizontal



Colin Mackenzie, author of the guide

from the top of each face leg.

- This procedure should be repeated for each subsequent frame (usually 4ft tall).
- Short duration horseheads, generally, should be designed to carry at least 25 per cent of the solids overburden. Longer duration horseheads, including those in stations, and in concourses between parallel stations, should be designed to carry at least 40 per cent of the soils overburden. Horseheads in stations and concourses, and in other tunnels over 14ft id, should be constructed from Military Trestling components. In other circumstances, horseheads may be constructed from 12x12in baulks of first quality Douglas Fir. A Military Trestling Column and a 12x12in Douglas Fir full timber sould each be considered capable of carrying a 40t axial thrust when appropriately constrained.
- All timbering is to be pre-loaded by the use of good quality 'pages' to tighten the timbering on to the excavated surface of the clay which it is meant to support. (A 'page' is a timber wedge, usuall 6in or 9in wide, tapering from approximately 0.75in to zero over a length of 9in, cut from good quality semi-hardwood such as oak).
- All horseheads are to be pre-loaded by the use of pairs of 12in oak 'folding wedges'. (A pair of folding wedges consists of two wedges of equal taper placed one on top of the other so that the upper surface of the pair is parallel to the lower surface. The thick ends of the wedges are hammered simultaneously to provide a lifting force perpendicular to these surfaces:
 - An ancient and timeless method of producing very substantial forces)
 - 'Pre-loading is a vital aspect of timbering philosophy and practice, the maxim being: "Keep the ground under control at all times. Never let it move. Impose yourself on the ground before it can impose itself on you".

projects over the past 50 years, with full procedure details listed beside.

Author

Colin Mackenzie is a retired civil engineer with forty years of experience contracting in the UK. He earned a degree in civil engineering from University of Aberdeen in 1961.

He moved to Mitchell Construction working on the Awe Hydroelectric Project in Argyll, Scotland before travelling to London in 1964 to work for John Mowlem on the Victoria Line. Over the next 24 years he reached the position of director of civil engineering responsible for tunnelling activities and worked across the UK before moving to Amec Civil Engineering in 1988 as director responsible for tunnelling, where he remained until his retirement in 2001.

In his career he has received the Telford Gold Medal and the James

50

The number of tunnelling years timber guide author Colin MacKenzie has in his experience

Clark Medal from the Institution of Civil Engineers, as well as the Sword of Honour from the British Safety Council. He is a former chairman of the BTS and held a position on its committee for some nine years.

British Tunnelling Society interest

The BTS was formed in 1971 as a learned society of the Institution of Civil Engineers to provide a forum for discussion on tunnel related matters. In its own words, it also publishes industry guidelines and codes of practice, conducts design and construction training courses.

Traditional timbering techniques that emerged from decades of underground construction in London Clay, for the London Underground metro system, are no longer widely used. Mackenzie has written the Timbering Guide from a position of experience, and the BTS plans to publish the resulting document as an aid to the new generation of tunnellers who are perhaps less familiar with the traditional methods, concerns and requirements.

MODERN DEVELOPMENTS

Mackenzie points to a loss of separation of piecemeal payments between less demanding machine work and more

Compulsive reading

The BTS has commissioned the production of a guide to good practice in the use of traditional timbering in soft ground tunnelling. The man tasked with writing this document is Colin Mackenzie, a tunneller of 50 years. The BTS could not have made a better choice. He is one of our most experienced and knowledgeable tunnellers and we are fortunate that he willingly passes on that knowledge for the benefit of the less experienced amongst us.

In compiling the timbering guide Mackenzie has drawn upon his own experiences of the use of timber in constructing tunnels and stations on the Victoria, Piccadilly and Jubilee lines of the London Underground all of them built in London Clay. Whilst the Victoria and Piccadilly Lines drew extensively on the use of traditional timbering, the Jubilee Line saw the introduction of the then novel use of sprayed concrete lining (SCL) for primary and secondary support. Now of course, the use of SCL is commonplace and as Crossrail construction gets into full swing we will see extensive use of SCL where once timbering was used. We are unlikely to see again a fully timbered break up for the erection of a station shield or for driving a crossover tunnel. Having said that, the use of timber is not dead.

The existing assets of London Underground are full of nooks and crannies and it is a massive network of tunnels and underground spaces in constant need of maintenance, repair and upgrade. Much of this work, particularly upgrades, is still undertaken using traditional timbering techniques. Overbridges, link passages, staircases and the like, all needed to improve passenger flow, or for improved access/egress (safety considerations) are being designed as 'square work' using timber. Not without change or modification however, timber is now used in conjunction with sprayed concrete and whereas full timbers (300mm x 300mm) and half timbers (300mm x 150mm) had been used previously, these members are now likely to be steel.

All of these current works are of course fully designed. How do these designs compare with the traditional timbering of the 1980s, 1970s and 1960s – and earlier, as set out in Mackenzie's Guide. As Mackenzie points out "...there is little evidence of a consistent timbering design philosophy having existing within the tunnelling industry...". Young engineers did however have to design the timbering by calculation although to what standards and to

what loadings? Who knows, most of these works were carried out before the introduction of formalised quality assurance systems. What the tunnellers of yesteryear did have was drawings, volumes of them show the detail and construction sequences of timber supported excavations and these would be added to by engineers, agents and project managers as they developed timbering for their own projects. What they did have was, (from MacKenzie again), "...project agent and his general foreman, both of whom had extensive timbering experience...". Similarly the mining gangs carrying out timbering works would be very experienced.

This begs the question where are the miners and engineers now, who have the knowledge and expertise to carry out complicated timbering works? Decades have passed since this sort of work was routinely undertaken and many (perhaps most) of the men who did this work have retired or, one way or another, have left the industry.

Perhaps there will have to be a new learning process for miners and engineers to handle a Crossrail mini boom, albeit a much-reduced one, in traditional timbering. If so Mackenzie's guidance will be a very good place to start. Throughout the guide, the reader is reminded that timbering is a learned skill that should be led by experienced engineers and miners. Above all the following mantra is hammered home; "... Always tighten your timber onto the ground. Never give the ground a chance to move...".

Good advice, and better still for all tunnellers, no matter what they are doing; "...keep the ground under control at all times. Never let it move, impose yourself on the ground before it can impose itself on you...".

MUCH TO LEARN

In writing this commentary I am very aware that it will be read by my elders and betters (and perhaps youngers as well) who know more than I do and much more than I say. For in a tunnelling career spanning more than 40 years I have had scant acquaintance with heavy timbering, a gap in my knowledge which I know is shared by many. It's not too late and the BTS Traditional Timbering Guide will make compulsive bedtime reading.


David Donaldson
Chairman, Donaldson Associates

Guide distribution

The preparation of the guide has been funded by the BTS as a result of which it will be distributed free to all members of the BTS as a standalone accompaniment to an issue of *Tunnels* in the near future.

demanding handwork.

There is pressure, he says, to drive handwork payments even higher, increasing the cost of traditional working methods "at the very time that modern developments such as compact electro-hydraulic excavators, lighter structural support components and spheroidal graphite ductile cast iron segmental tunnel lining are available to make the work less arduous and more cost effective".

Speaking to *Tunnels*, he adds, "A good rate is possible with the system – the spheroidal graphite cast iron segments deal with the final loading. It is not like sprayed concrete lining where you have a primary and secondary lining" 



Left: Pick and shovel tunnelling being used for the diversion of the Northern City line at Highbury; the men work within a 16ft (4.9m) diameter hand shield. 20 August 1964. LONDON TRANSPORT MUSEUM



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Japan-based Hitachi Zosen has been manufacturing TBMs since 1967. **Yasuharu Hanaoka** of the manufacturer's industrial machinery business unit notes the decline in the open, semi mechanised shields that the company did brisk business within previous decades, as closed EPBMs and slurry machines have come to prominence. He explores the technology, and gives a recent example of a 'traditional method' shield in operation

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Yasuharu Hanaoka
Joined Hitz in 1982 as a mechanical engineer and now manages TBM design



IN JAPAN, as elsewhere, shield tunnelling began with the hand digging shields. The shield served simply to protect workers excavating with shovels. This soon led to the shields being equipped with a backhoe, or a roadheader type loading machine to help with excavation and transfer muck into the shield. The hand digging and later semi mechanised shields are referred to as 'traditional methods' in Japan.

Before the birth of shield tunnelling in Japan, there was a lot of work all over the country, but very little in urban environments. At around the same time Hitachi Zosen began manufacturing shield machines, shield tunnelling was adopted with alacrity. This was especially so in urban areas for metro construction. Although today there is no practical plan to construct a new metro, or extensions to existing metros in Japan (so tunnelling is driven by other sectors).

LIMITATIONS

A technical weakness and limitation of the technology compared to closed shields is the increased threat of ground settlement or collapse. Also, if operator skill is poor, the contractor cannot keep to the tunnel alignment. Otherwise, dust scattering can compromise the working environment.

Both of these weaknesses can be offset with correct and complete ground conditioning by the contractor, in which case there will be no such limitations. Where ground conditioning cannot keep the integrity of the ground or hold back water, this is of course an inappropriate method.

In Japan, compressed air is very rarely used, due to health and safety concerns, so ground conditioning is essential to make the ground steady across the entire cross section, for the entire length of the tunnel.

FLEXIBILITY

Although closed machines are not just limited to a circular cutting shape, there is less limitation on cutting section options when an open machine is used. This is because it can be equipped with a boom-style excavator that can move freely around the shield section.

This also extends to overcutting. While a closed shield is limited in overcutting range as it can only push copy or reamer cutters out from the cutterhead, an open machine can overcut freely via its loading machine or by hand mining.

354

The number of open shield machines delivered by the manufacturer to date

8

The number of open shield machines delivered since the year 1990, with manufacturing beginning in 1967

Below: Figure 1, Shinjuku Station in the Shinjuku region of Tokyo



So the open, semi mechanised shields are selected when special circumstances dictate. A closed shield may also struggle on projects where the TBM will encounter obstacles that will need to be removed; make a connection into an existing structure; make an extremely sharp curve or for the construction of a rectangular or horseshoe shaped cross section tunnel.

Although these machines are rarely adopted in Japan, there are many recent tunnel projects in severe conditions such as those mentioned above that would be appropriate for this technology.

ORDERBOOK OBSERVATIONS

Hitachi Zosen have delivered 354 units of these machines so far. But since the 1980's, closed shields have rapidly gained popularity. The major reasons are that closed TBMs have high safety and higher efficiency compared to open shields. Though, because the latter has freedom to choose the excavation cross-section, is small in cost, and has the high adaptability to various conditions, it is adopted occasionally even today.

No units have been sold since 2006, with 16 of the last 20 years seeing no orders. The record year was 1973 with 47 orders.

In general, open type is a circular semi mechanised machine (equipped with labour-saving excavation machinery). Also, we often deliver the TBMs with a full turning excavator for high-speed construction.

SHINJUKU STATION

Shinjuku Station is one of the major stations in Tokyo, Japan. Traffic, commerce and companies are concentrated around the station and the vicinity is plagued by severe traffic jam and lack of a transfer function.

Client the Ministry of Land, Infrastructure, Transport and Tourism, decided to sponsor maintenance of a connection point for public transportation, replace a viaduct and construct an underground walkway binding the new subway Fukutoshin-Line near Shinjuku Station's south exit.

Of this walkway, 114.5 of 233m of which was underground, a semi-mechanised open TBM was adopted by contractor Konoike-Aisawa JV to bore the Tuffaceous clay with associated ground improvements.

The walkway was opened in May 2010, and linked JR Shinjuku Station Southeast entrance plaza with Tokyo Metro's Fukutoshin Line Shinjuku-Sanchome station, and brings bright and comfortable space with its 6m width.

"An intermediate machine, between open and closed, could show the technology's raison d'etre"

The tunnel passed through a small space. To ensure an adequate earth covering of 6-7m, considering the economic value of the cross-section, a rectangular shape for the tunnel was adopted. It measured 7,820mm by 4,720mm (shield od), and was an arched complex cross-section.

Furthermore, the excavation length was extremely short. The owner calculated that if they employed a closed TBM, the construction cost per meter would be overly expensive, so an open type TBM, which is inexpensive in comparison, was chosen.

Machine features

This shield body has a rectangular shape, and each side curved. This machine digs a tunnel face with two loading machines installed to the right and left, makes a space, pushes into the space, and builds the tunnel.

Its driving stroke is 500mm per advance. To prevent collapse and ground subsidence, the excavation section is being subjected to ground improvement. But to protect workers from the collapse of small landslides caused by drilling, the top of the shield body is equipped with seven movable hoods. After excavating the top, the movable hoods are pressed against the tunnel face immediately to form the roof, to ensure the safety of drilling at the face.

In addition, working platforms extended and retracted by hydraulic cylinders have been installed at the front of the body to be used during ground improvement and removal of some 60 existing piles.

In order to prevent the collapse of the ground while the shield machine stops, eight face-support hydraulic jacks are arranged to push a plate against the tunnel face.

Furthermore, the shield machine is equipped with movable sleds at the bottom of the front body for the attitude control (to prevent a nose-down). Movable sleds are also effective in correcting rolling of the machine caused by the rectangular cross section because the sleds are placed on the right and left.

Equipped with these facilities and



30

The number of years of TBM design experience that Hanaoka has under his belt

30

The mega Newton total thrust capacity on the Shinjuku Station open shield

equipment, this machine had a length of 6,500mm, and weighed 200t.

Since the gap between ground and viaduct was only 4.5m, the TBM had to be divided and lowered into the shaft by a small size overhead crane. There was a limit to size and weight of the divided TBM. The shield was divided into 12 blocks weighing up to 13t.

Features of the loading machine

The loading machine is a dedicated backhoe for semi-mechanized TBMs. It has a high capacity to break through the tunnel face. Two machines are equipped at the right and left side of TBM's face to cover the whole flat cross section.

The backhoes have four operations, - boom up/down; boom left/right; arm protrude/draw and bucket scratch/dump. Each machine is operated independently of the other making simultaneous work possible.

Operations are controlled by joystick and the speed can be controlled freely, which allows the efficient excavating of the large section.

Features of the segment erector

Two segment erector devices were equipped, capable of complex functions, such as swinging of the arm and rolling of the clamp, are installed symmetrically in order to erect a rectangular ring consisting of eight segments.

Construction of the tunnel was completed successfully in a high-risk environment.

CONCLUSIONS

In Japan, the adoption of these machines is limited to construction under special conditions - very short tunnel length, existing obstacles, and complex line-shape and/or cross-section.

However, they are also appropriate in many situations because a visible excavating face lowers the risk of the TBM being stuck by obstacles and ground improvement in tunnel face. So, Hitachi Zosen believe that the system's value will continue in the future as a traditional machine type. It is basic, not 'old'.

This author believes that although contractors and clients do not consider the possibility of excavating a long tunnel by open shield, an intermediate machine, between open and closed, could show the technology's raison d'etre.

Although it is only used in special conditions at the moment, It would be good to see the flexibility of the open type leading to its being developed and changed constructively, in which case it will be adopted far and wide

Above: Figure 2, the breakdown of TBM orders by type, showing the clear decline of open TBMs

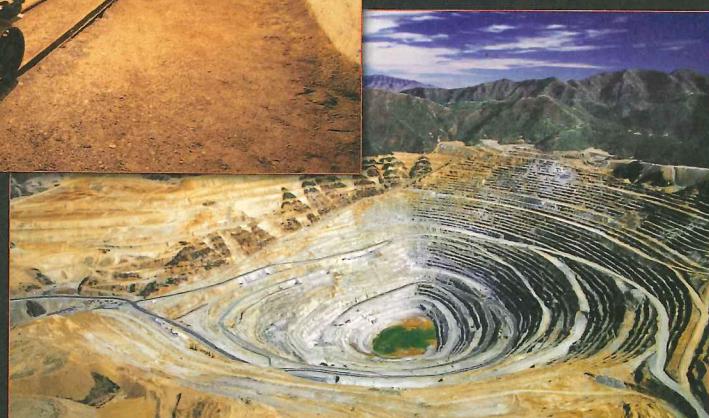
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THE PROFIT IN RISK

Many if not all underground construction projects involve unforeseen ground condition claims in spite of all efforts. These efforts are mainly directed to stop or manage claims. The main issue is still the perception of uncertainty and risk. This paper is presented by Haldun Kahyaoglu, of Qatar Rail

Haldun Kahyaoglu
Worked as a construction manager for Macdow
at the time of writing this paper



UNDERGROUND PROJECTS all over the world draw attention from the public and the media not only for their complexity and high profile; but more importantly for the reservations surrounding the cost of the projects.

It is not a myth that underground projects generally suffer from cost and time overruns.

It does not, however, necessarily follow that a project suffering from cost overrun must also suffer from time overrun or vice versa.

Researchers, authors, public agencies,

investors and investment banks have studied the subject of overruns in publicly funded projects including underground projects. An extensive literature on this subject exists and it expands over time as cost and time difficulties increase too.

It is therefore important to examine the cases from the literature in order to gain an understanding of the level of the overruns and the reasons for them.

Many, if not all, construction projects

suffer from cost and time overruns in one way or another. There are many reasons ranging from ground conditions to escalation of material prices, changes in specifications to changes in legislation. Flyvbjerg, et. al. (2002) assert that high-speed rail is the most prone to cost underestimation, followed by urban and conventional rail respectively. Similarly, cost underestimation appears to be more frequent for tunnels than for bridges. This suggests that the complexities of technology and geology might have an effect on cost underestimation.

Hence, it is clear that the first criteria to check in claiming for an overrun are the estimations or budgets allowed for a particular project. Although, many government agencies and investment bodies have different and complex estimation structures for estimating and budgeting the projects.

Large numbers of agencies, contractors, consultants and experts are involved at all stages of the project and have extensive experience in their fields. A large number of cost and time estimates are carried out before the contract is signed. The client and his experts and consultants, or the contractors, carry out estimates for the same project using all available tools such as historical data, local experience, methodologies, schedules, productivities, innovative solutions, commercial and also any business incentives.

And yet projects frequently run over time and over budget. Flyvbjerg, et. al. (2002) state:

- In nine out of 10 transportation infrastructure projects, costs are underestimated.
- For rail projects, actual costs are on average 45 per cent higher than estimated costs
- For fixed-link projects actual costs are on average 34 per cent higher than estimated costs
- For road projects, actual costs are on average 20 per cent higher than estimated costs
- For all project types, actual costs are on average 28 per cent higher than estimated costs
- Cost underestimation exists across 20 nations and five continents; it appears to be a global phenomenon.
- Cost underestimation appears to be more pronounced in developing nations than in North America and Europe (data for rail projects only).
- Cost underestimation has not

45

The average percentage costs are higher than predicted on rail projects

20

The average percentage costs are higher than predicted on road projects

- decreased over the past 70 years. No learning that would improve cost estimate accuracy seems to take place.
- Cost underestimation cannot be explained by error and seems to be best explained by strategic misrepresentation, i.e. lying.
 - Transportation projects do not appear to be more prone to cost underestimation than are other types of large project.

Table 1, below shows several transportation projects from Europe. The table clearly shows cost overruns between eight per cent and 116 per cent. However, it also shows that unit cost for three railway projects, the Paris to Lille TGV, the Madrid to Seville AVE and the Lyon to Marseilles TGV are between EUR 8.57M (USD 10.8M) and EUR 11.82M (USD 14.94M); In contrast for the ICE Frankfurt to Cologne line is EUR 33.98M (USD 43.8M). Although the cost difference may be due to many other factors, the effect of the ratio of tunnel length to total length (the ICE Frankfurt to Cologne line is 12.3 per cent and while the other three projects range between 3.2 per cent and 3.6 per cent) may also impact on total cost.

Florio (2009) lists the main causes of errors in cost estimation, which include delays in implementation, as changes in project specification and design, changes in quantity and prices, technological risks, underestimation of expropriation costs, changes in safety requirements and changes in environmental requirements. Although geological risk or overruns due to unforeseen conditions are not included in the main causes of errors in this classification, both of these are mentioned as major factors in Flyvbjerg, et. al. (2002).

Another example is from the Neue Eisenbahn-Alpentransversale (NEAT) project in Switzerland, which involves extraordinary tunnels such as Gothard Base Tunnel, Ceneri

"Epistemic uncertainty is subjective uncertainty. And aleatory uncertainty is randomness"

Base Tunnel and Lotschberg Tunnel. The project also suffered from cost overruns of 53 per cent of which nine per cent is accounted for by geology according to a report published by Swiss Office of Transport (2009).

Figure 1 (page 47) shows the cost overruns for the tunnels in Seattle Area. According to a report by the Straightline Institute [4] one in four recent tunnels in the Seattle area was completed within budget. The report concludes that the savings for the Mount Baker Tunnel can be attributed largely to two factors. First, labour and materials were cheaper than

Table 1. Forecasts and actual costs (in Million Euro) for some projects in Europe (Modified after Florio, 2009)

Project	Length of Project (km)	Total Length of Tunnel (m)	Tunnel Type	Total construction costs		Cost Overrun (%)
				Forecast	Actual	
ICE Frankfurt - Cologne	177	21722	Bored	2784	6015	116
Madrid - Seville AVE	470	16030	Bored	3263	4029	23
Lyon - Marseilles TGV	367	13187	Bored	4015	4338	8
Paris - Lille TGV	333	10700	Cut and cover	2666	3334	25
Eurotunnel	50	50000	Bored	2702	4568	69
Oeresund Fixed Link	7.85	4050	Immersed	1795	2924	63
Magdeburg Waterway Crossing	0.918	0		2064	2435	18

Source: Kahyaoglu

Case one: project RT-01

This is a motorway project with a cost of more than USD 220M which includes two NATM tunnels with twin bores and each carrying three traffic lanes. Excavation cross sections range between 120m² and 150m² depending on the use of invert. The client undertook the preliminary design and geotechnical report. However, the contractor who was very experienced with similar tunnels was responsible for completing the design of the portals as well as shop drawings for the tunnels. The client provided rock mass classification, based on ÖNORM B 2203 (Austrian Norm). However, Q and RMR systems were also used by the designer to validate the distribution. The project used a measure and value contract and the rock mass classifications needed to be signed off by representatives of the engineer after an inspection with the contractor.

Table 2 (page 48) shows the rock mass distribution provided in the contract, as estimated by the contractor and the as-built situation for a 500m long tunnel. It is worth noting that a major part of the client's estimate was based on A class whereas the contractor's was mainly based on B class, which proved to be the case during construction. The reason for the designer's inaccurate estimate was mainly due their site investigation and interpretation of site results. Since the tunnel was under a hill and rock mass was exposed in outcrops, no borehole were made. This was also partly due to access issues in the densely forested land. The information gathered from outcrops alone was enough to make an assessment. Q and RMR values have never been reassessed based on the effect of excavation. The behaviour of the rock mass was not considered and index based rock mass classifications (i.e. Q and RMR) were used only to assess ÖNORM B 2203 classes which are mainly behaviour based. The contractor visited the site and made visual investigations, collated all data together with the methodology and made its own estimation. Although the contractor estimated that the dominant class would be B1 (fractured rock with low deformations and loosening), actual rock conditions were more on class B2. The lineament observed was believed to be a fault zone by both the designer and the contractor and classified as C1 and C2. However, it was classified as B3 during the excavation. This example shows that the uncertainty was not in the parameters or the information used but rather it was the evaluation of those parameters and the information and the perception of the rock mass behaviour based on the past experience in similar tunnels.

expected because the US economy experienced a recession after the project costs had been estimated. Second, the soil conditions were relatively well understood in advance of the cost estimates, in part because an adjacent tunnel (the roadway for the original Interstate 90) had already been dug beneath the Mount Baker neighbourhood in 1940.

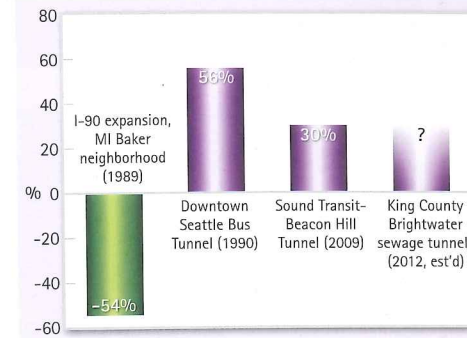
Many other examples regarding cost overruns can be provided but they all lead to same question: why are the same mistakes are being continually repeated? There are three main possible reasons (Flyvbjerg, et. al. 2003): Inadequate data on which the project is based, optimistic bias, and cost analyses are systematically and significantly deceptive. The discussion up to this point has only been about comparisons between the original budgets prepared by the clients and the final cost after the project completion. When the project is tendered and the bids received from the contractors, prices may be over or under that which is allowed. However, this is only a temporary situation and the most important is the price at the final completion of the project. The difference

between the initial and final price and the reasons for this difference will further be analysed in this paper.

Further discussion on the low budgets allowed by the clients is not within the scope of this project. However, the following factors should also be taken into account when low budgets prepared by the clients are discussed:

- Clients may intentionally approve tight and low budgets and schedules in order to make the consultant and the contractor believe that funds are more limited
- Clients, particularly those influenced by politicians, may try to minimise the budget and schedule in order to secure the approval of the project.
- Historical data may be highly biased since the prices for each contract is based on the current economical situation when the bid price is placed, economical situation of the winning contractor, competition, business decisions and fluctuations in the material prices.

Romero, et. al. (1997) pointed out that the differences between the 'cost'



Above: Figure 1, cost overruns for tunnels in the Seattle area, USA

as calculated by the consultants and the clients and the 'price' as calculated by the contractors are the constructability issues, risk and competition since cost estimation based on production type calculations should not differ. However, it is the author's opinion that there should be other factors that mainly drive the differences between the cost and the price. The main factor is uncertainty, which causes either excessive or insufficient figures when preparing budgets, or changes project price based on different perceptions.

UNCERTAINTY AND DIFFERENT PERCEPTIONS OF UNCERTAINTY

Many famous and 'scary' terms are involved in underground work contracts such as unforeseen, unforeseeable, foreseeable, uncontrollable, unpredictable, disclaimer and risk. They are all the end products of uncertainty which is generally unavoidable in geology and geotechnics. Uncertainty is categorised as either epistemic or aleatory. Der Kiureghian, et.al (2007) provides definitions for those terms:

The word aleatory derives from the Latin alea, which means the rolling of dice. Thus, an aleatoric uncertainty is one that is presumed to be the intrinsic randomness of a phenomenon. Interestingly, the word is also used in the context of music, film and other arts, where a randomness or improvisation in the performance is implied. The word epistemic derives from the Greek episteme, which means knowledge. Thus, an epistemic uncertainty is one that is presumed as being caused by lack of knowledge (data).

Epistemic uncertainty and aleatory uncertainty can be referred as subjective uncertainty and randomness respectively. According to Der Kiureghian, et. al

Table 2. Relationships of different parameters with origin and effect on productivity

Item	Description	A	B	C	D	E
1	Lateral extent of geological features	x		x	x	
2	Lithology	x		x	x	x
3	Strike and dip of discontinuities	x		x		
4	Presence of water	x	x	x		
5	Total discharge	x	x	x	x	
6	Groundwater regime	x		x		
7	Permeability	x		x		
8	Presence of gas	x			x	
9	Water chemistry	x				x
10	Behaviour in fault zones	x		x		
11	Stress condition	x		x	x	
12	Cavities	x			x	x
13	Fault zones	x			x	
14	Weathering	x	x	x	x	
15	RQD	x	x	x	x	
16	Extent of temporary support	x		x	x	
17	Groutability	x	x		x	
18	Drillability	x	x		x	
19	Ripability	x	x		x	
20	Distribution and description of rock mass classes	x	x	x	x	
21	Overbreak	x	x	x		
22	Contaminated soil or water	x			x	x
23	Assessment of pumping rates	x			x	x

For explanation of columns see text page 50.

(2007) uncertainties are characterised as epistemic, if the modeller sees the possibility of reducing them by gathering more data or by refining models. However, if this possibility does not exist, uncertainties are categorised as aleatory.

Examples of an aleatory uncertainty are: the uncertainty in timing of activation or movement of a fault or landslide (regardless of their locations are whether known or not); the exact profile of the tunnel after blasting (regardless the geology and blasting technique); the exact number and size of boulders along the tunnel alignment; the fluctuation in the cost of construction materials, and changes in legislation. Examples of epistemic uncertainty include the

34

The average percent by which fixed link project costs are higher than estimated costs

uncertainty in the dip and strike of a fault crossing the tunnel (which may become known if further investigation is carried out); the amount of water discharged into the tunnel when a water bearing strata is penetrated (the amount can be identified if permeability is known accurately); excessive rates of corrosion due to groundwater chemistry (due to improper or missing testing). It is clear that more knowledge, information and data reduces the epistemic uncertainty whereas the same does not apply to aleatory uncertainty. Other factors in reducing epistemic uncertainty are the probability of occurrence and the scale effect.

Although there are many controversial opinions regarding the distinction between uncertainty, and that risk and uncertainty have been used as if equal terms for many years, many researchers have separated the terms. Brooke, (2010) commented on one of the well known but disputed works by

Item	Description	A	B	C	D	E
24	Face stability		x	x	x	
25	Failure modes		x	x	x	
26	Stiffness of materials		x	x	x	
27	Particle size distribution		x	x	x	
28	Round lengths		x	x	x	
29	Stand up time		x	x	x	
30	Shear strength		x	x	x	
31	Shotcrete stickiness		x	x	x	
32	Cutting operation (TBM, D/B) mode		x	x	x	
33	UCS		x		x	
34	Moisture content		x		x	
35	Unit weight		x		x	
36	Presence of boulders, sizes, etc.	x			x	
37	Impact on buildings		x		x	x
38	Settlement on the surface		x		x	x
39	Degradation of materials when exposed			x	x	x
40	Behaviour of rock in response to excavation method			x	x	x
41	Swelling and squeezing capacity			x	x	x
42	Support system			x		
43	Presence of timber, shells, etc.			x	x	
44	Quartz content	x			x	
45	Abrasivity	x			x	
46	Bulking factor	x			x	

Source: Kahyaoglu

Case two: project WS-01

Four pipeline tunnels with a cross section of about 40m². Total length is more than 4,000m. Tunnels were mainly located in metabasalt, metagraywacke, schist and marble. However, the last tunnel was mainly within granite and granodiorite. The client did no site investigation but provided geotechnical profiles with the distribution of excavation classes. Excavation and support was designed by the client with three different classes. The contract was measure and value and the standard contract clause shifted all risk for the changes in the distribution of support classes to the contractor. Excavation and support were paid separately per linear metre of the tunnel in any particular support class. The design and construction was mainly following NATM. While Support Class One (SC1) has only rock bolts, wire mesh and shotcrete (out of cycle), SC2 has the same support only the number of bolts and shotcrete thickness increases while round length decreases about 35 per cent. However, SC3 is heavily supported using rock bolts, shotcrete, wire mesh and steel sets. Tunnel excavated in SC3 should also have an invert and forepoling as temporary support. SC3 represents 10 per cent of all tunnel length and mainly assigned to zones at either end of the tunnels and SC1 and SC2 represents 57 per cent and 33 per cent of the total tunnel

length respectively. Approximate RMR values for the support classes have been shown in Table 3 in order to give an idea about the rock mass quality. It may be expected that different rock support classes will have different prices. Table 3 shows that the contractor allowed a significant premium to his prices in order to level prices for different support classes. One factor was the geology. The contractor visited the site and observed extensive jointing, folding and faulting which would affect the excavation and the progress. Hence, the contractor had the opinion that SC1 and SC2 do not differ practically. Due to the rock conditions, the contractor also estimated that the overbreak would be significant and this will not only increase his direct cost but would also have direct impact on shotcrete quantity and time since the specification called for a final shotcrete layer. The necessity of concreting the invert, leaving a rough surface would also lead to cost increases. Access conditions were also a factor.

The most important lesson is the necessity of having a complete geological and geotechnical report, which should identify areas with potential problems and include an evaluation of the rock mass behaviour. The pricing structure should allow contractors to address concerns without adding large premiums.

Frank H. Knight (1921) on risk and uncertainty.

According to Brooke, (2010); Knight's commonly accepted definition is that risk refers to outcomes that can be insured against, and uncertainty to outcomes that cannot be insured against. Brooke, (2010) also adds that uncertainty refers to all instances where only subjective estimates of future outcomes are possible.

According to Luce, et. al. (1957), reproduced after Riabacke (2006), 'risk' occurs where each action leads to one of a set of possible specific outcomes, each outcome occurring with a known probability whereas 'uncertainty' occurs when actions may lead to a set of consequences, but where the probabilities of these outcomes are completely unknown. A risky situation is thus a situation where the outcome is unknown to the decision-maker. Although they are used interchangeably in practice, the terms risk and uncertainty will be used as separate terms, and as defined by Luce, et. al. throughout this paper. The main reason for this is that the risks can be defined since they exist as a probability, while uncertainty cannot be measured in terms of probability.

An example of this is that probabilistic analysis of a TBM project under certain conditions can provide probabilistic information and knowledge about a new project for the contractor. Hence, certain aspects of the new project are risky but not uncertain. Conversely, perched aquifers over a tunnel which is constructed by conventional methods are an uncertainty since the behaviour and impact of perched aquifers based on their potential occurrence, size, location and extent are unknown by the contractor. However, uncertainty can be interpreted with a certain 'degree of belief' or subjective probability based on experience. Degree of belief, however, does not imply being arbitrary but should be based on some knowledge. Figure 2 (see page 50) provides examples to visualise the difference among the terms since the perception of uncertainty is the core subject of this paper.

Assume that two tribes named A and B living on either side of the mountain decide independently (since they do not have any form of communication and they are unaware of each other) to tunnel the mountain to reach the other side. They start at the same time and drive tunnels in opposite directions

70

The number of years that have seen no decrease in underestimation

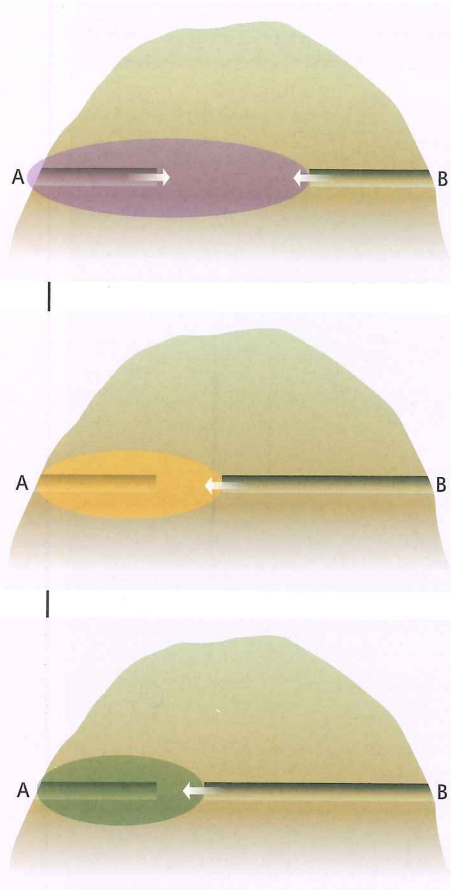
as shown in 2a. Although they do not know that the mountain has a syncline, they are able to record and track the geology as they keep driving. Hence, based on already completed sections of the tunnel, Tribe B recognises that cyclically encountered strike and dip of the strata will continue in the rest of the tunnel and they can identify the risks based on that knowledge, although it is a total uncertainty.

The risk area which is actually an uncertainty is shown as hatched area in Figure 2a. Now assume that Tribe A temporarily stops tunnelling while Tribe B continues and hits the centre of the structure where they probably faced water, then continues and observes that a strike and dip of the same strata changes in a way that indicates they may be connected as Figure 2b. At this point, Tribe B has a degree of belief in the strike and dip of the strata as well as excavation conditions and behaviour

Table 3. Pricing for support classes project WS-01

Rock Class	Contract	Contractor's Estimate (%)	As-built (%)
A1	0.3		
A2	54.4	2.7	
B1	36.5	65.3	
B2	5.3	23.0	80.7
B3			19.3
C1	2.5	3.5	
C2	1.0	5.5	

Source: Kahyaoglu



Above, top to bottom: Figures 2a, 2b and 2c, known unknowns and unknown unknowns in the tribal example

of the rock mass for the remaining tunnel length. When Tribe B continues excavation further (Figure 2) they observe and confirm that their belief has been correct and the rest of the tunnel length becomes a risk which can be identified and quantified. Interestingly, for Tribe B this has become an area of risk based on data, information and knowledge, but for Tribe A, it remains an uncertainty.

Therefore, it is clear that someone's uncertainty can be another's risk. This is the essential point in the perception and pricing the projects. Higher profits are earned where there is uncertainty and conventional profit margins are earned where there is risk. This theory has been established by Frank H. Knight (1921), reproduced by Brooke (2010), who stated that "if the future is risky, no profit can be earned if all the alternative possibilities are known and the probability of occurrence of each can be accurately ascertained". Hence, the contractors first try to identify the uncertainties and the risks when they obtain the contract documents including geological and geotechnical reports.

Aleatory uncertainties remain aleatory for every party. However, epistemic uncertainties are further analysed by the contractors based on their knowledge, past projects, data available to them and local experience. As a result, some epistemic uncertainties become risks according to the degree of belief for the contractors; and they use that advantage in pricing the project.

INTERDEPENDENCE OF GEOLOGICAL AND GEOTECHNICAL PARAMETERS

The initial stage for checking the tender documents for a tunnel is obviously the contract delivery method and contract conditions because these two items affect the whole process. The next stage is to consider all geotechnical reports, which may include geotechnical factual reports, geotechnical design reports, geotechnical interpretive reports and geotechnical baseline reports. Either some or all of these may be provided as part of the contract documents. However, it is not unusual to encounter tenders with only a simple geological summary and a bill of quantities. The contractors may choose to get the reports checked, interpreted and evaluated by external consultants in addition to their own in-house checks. If the construction method has not been defined by the client in the tender documents, the contractor's first action is to identify a resemblance between the new project and previous projects. This process is considerably less difficult if the contractor has worked in the same geography and geology in previous projects. This initial conceptual stage also guides the process of analysing the reports with respect to the importance and complexity of parameters which vary for different methods of construction.

Although there are many parameters involved in geological and geotechnical reports for any underground project,

"However, it is not unusual to encounter tenders with only a simple geological summary and a bill of quantities"

some of them have more weight than others in terms of method selection and costing. All models and parameters will be used to calculate the productivities as well as any short and long term effects. However, this is not an easy task since the parameters are interrelated and complex. Furthermore, different methods

will require different parameters to be checked. As an example, particle size distribution is important for a tunnel excavated by slurry machine whereas it has much less importance if the same tunnel is excavated by conventional methods. Another example is the effect of strain bursting which can be controlled by using the distressing effect of blasting in a rock tunnel whereas this approach may not be that easy when a TBM is used.

Table 2 (page 48) shows the development of productivity based parameters together with the parameters that have long term effects. This is only one example showing some possible parameters but a range of other parameters and models may differ for each case. It only shows where parameters are originating from and which parameters directly affect the productivity, with long term risks. The meaning of the table's letters are given below:

- A. Related with geology
- B. Related with geotechnical parameters and rock mass classification
- C. Related with excavation and support system
- D. Directly affects productivity
- E. Directly affects long terms risks

It is clear from the table that while some parameters have direct impact on productivity, others only have indirect effects. Therefore, the cost estimation will mainly be based on the productivities (directly affected by those parameters) and a premium will be allowed for long term affects if those effects are not offset either by insurance or by the client.

The example in Table 1 shows only the main part of the process. Method and procedures adopted during investigation stage, scale effect, inherent pitfalls and limitations of classification

systems were also analysed as part of this process.

CASE STUDIES

Several case examples are summarised (see boxes throughout article) in this article in order to show how geological and geotechnical reports are processed,

Table 4. Rock classification for Project RT-01

Item	RMR	Direct Cost (Euro)	Overhead and profit margin (%)	Factored Cost (Euro)	Premium (Euro)	Price (Euro)
SCI	50-60	19.7	35.0	26.6	24.4	51.0
SC2	30-40	22.4	35.0	30.2	24.4	54.6
SC3	15-25	42.6	35.0	57.5	0.0	57.5

Source: Kahyaoglu

and uncertainties and risks are identified by the contractors during the tender and project execution stages. Names and details including costs of the projects have been intentionally modified. Two case studies in this paper explain the concepts of uncertainty, degree of belief and risk. There are many other projects in the literature that may be analysed with the same concept. Riemer (2006) reports that Q-rating to the phyllites of the Kali Gandaki headrace tunnel in Nepal had given a rating of $2 < Q < 50$ for 84 per cent of the tunnel and led the engineer to consider an unlined tunnel which was rejected by the owner on the basis of experience with other tunnels in similar rock. Eventually, rock mass performance observed during construction of the tunnel mainly corresponded to a rating in the range of $0.4 < Q < 1.0$.

This example also shows the importance of the understanding of epistemic uncertainty and degree of belief.

The geological environment in

which the tunnel was constructed was modelled by the designer, with certain classification but the degree of belief of the client based on its past experience led to decision to line the tunnel which proved to be the correct decision during tunnel construction.

CONCLUSION

Although this paper cannot address all possible causes of time and cost overruns, it may be helpful to consider another perspective of costing tunnel projects from the point of view of the contractors, the mostly silent party.

Although there are very standard conclusions that are known to the industry such as realistic geotechnical reports, good site investigation, risk sharing, no disclaimer clauses and partnership, the following factors should also be considered:

- a. Clients should disclose past project experiences to the bidders and should not hide the risks.
- b. Parameters and information in the reports should be classified according

to their effects on productivity considering potential construction methods. This will assist in providing more knowledge and data.

- c. Clients should give the bidders an opportunity to comment on the gaps, omissions and insufficiencies in geotechnical reports.
- d. Commentary on possible rock zones should be provided.
- e. If excessively high baselines compared to available data are selected, the bidders will think that either the tests are faulty or the client has certain information that it does not want to disclose. This will cause the bidders to add premiums on their prices.
- f. If rock mass classification systems such as RMR and Q are used, it is important to provide all data used to calculate the index values rather than reporting the index value only.
- g. Commentary on rock mass behaviour is very important.
- h. Baselines should be measurable and verifiable otherwise they will not have significant bearing on pricing
- i. If unconventional techniques are proposed as a part of the project a detailed description including risks and potential construction techniques should be provided.
- j. A bill of quantities or pricing should be selected in a way to reflect the complexity of the geology. Single pricing under one rock class with a wide range rock mass quality will lead to a higher price than narrow ranged rock mass classification.
- k. Scale effect should always be considered even evaluating the response of the tunnel to excavation.
- l. Clients should take into account other factors, such as market conditions, business drivers and competition when tendering the projects.

All efforts should be directed to change the attitude of 'your uncertainty is my risk' to 'we share risks'. It is important to know that a greater amount of information will help to reduce epistemic uncertainty.

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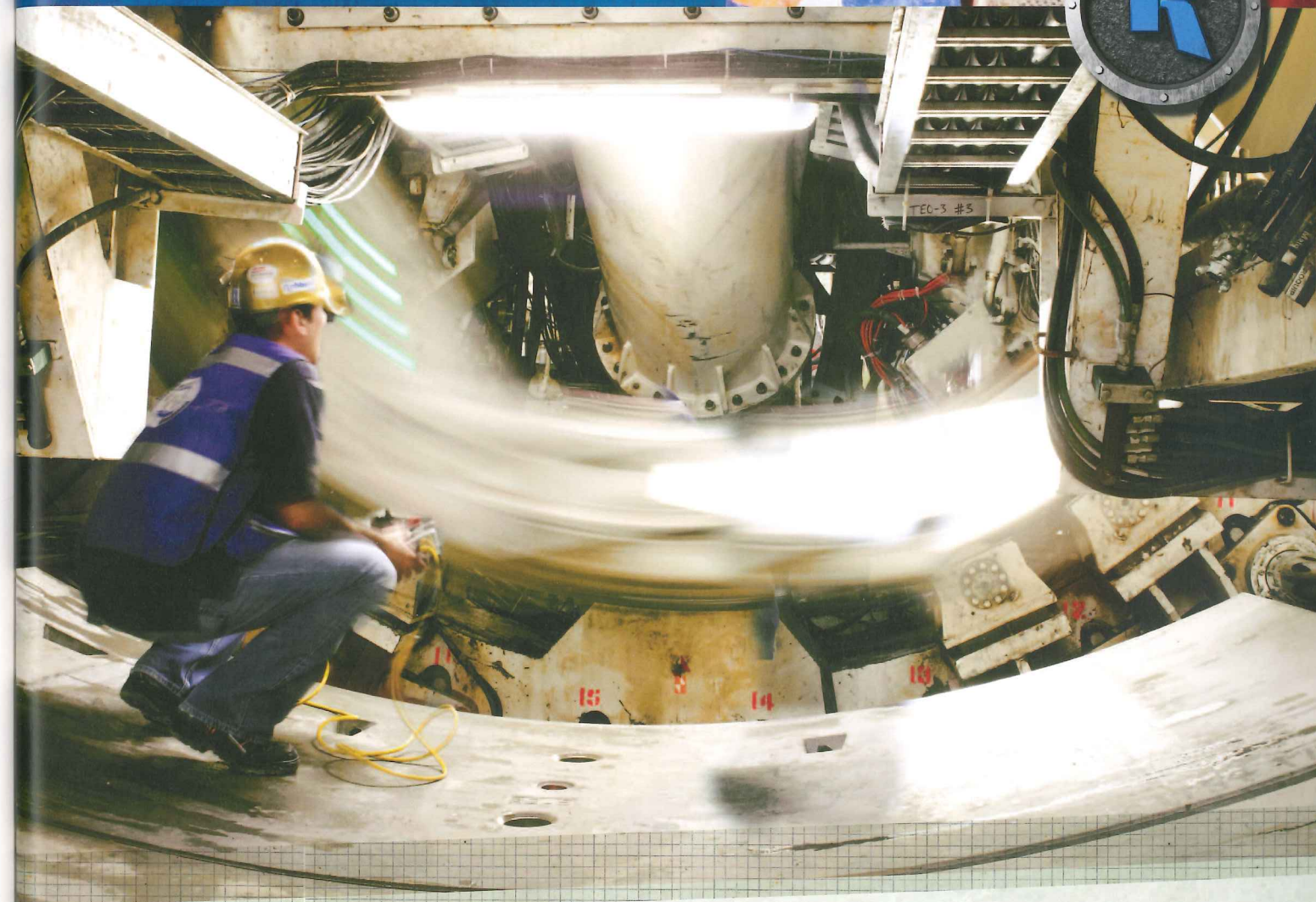
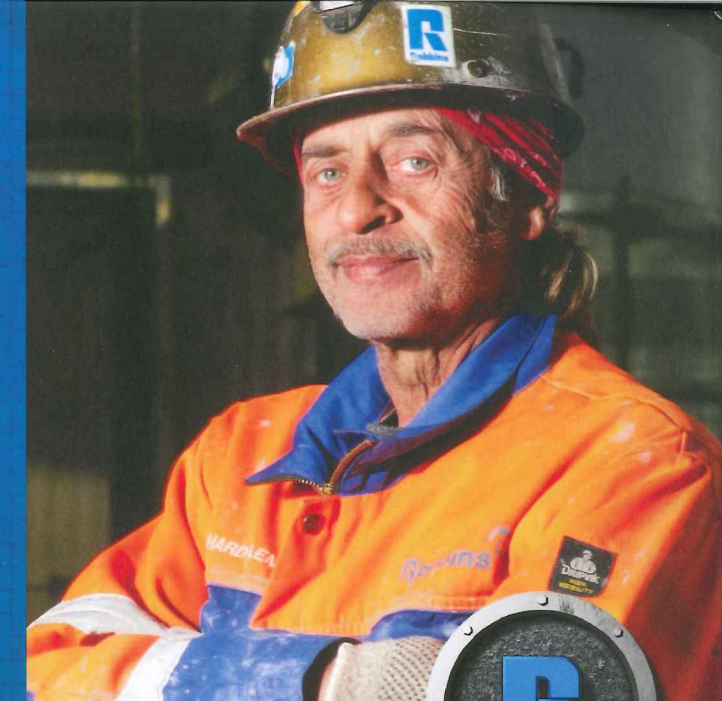
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