MARCH 2012

tunnels & tunnelling INTERNATIONAL

58

24

Australasia

T&TI brings you the latest trends, trials and triumphs from the southern continent

Renovation

Varied requirements and mechanisation of works for safety, regulations and capacity

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Break the Victoria bottleneck

The park bypass box finished a year ahead of schedule, and the hotel jacked out of its way

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During construction of the longest tunnel in the world, the Swiss Gotthard Base Tunnel, four hard rock machines made by Herrenknecht excavated and secured a total of 85 kilometers of tunnels. The main breakthrough in March 2011 marks a milestone in the Champions League of mechanized tunnel construction. In July 2011, Spanish miners celebrated the breakthrough in the Calle Mallorca projects, after they had excavated nearly 5 kilometers of railway tunnel under the city of Barcelona passing beneath the world-famous Sagrada Familia, for example. London is tackling a giant mega-project. The new Crossrail railway line is to cross beneath London from east to west. A total of 8 Herrenknecht EPB Shields and Mixshields will be employed from 2012. In China, the expansion of high-performance railway networks is being advanced. Herrenknecht delivers large machines with diameters up to 13 meters for 18 challenging tunnel projects.

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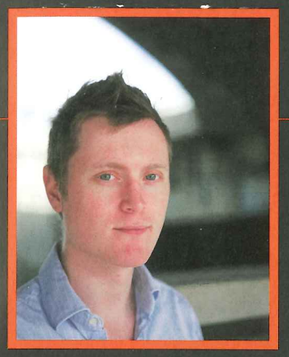

comment

Reform over revolt

Revolution is in the air once again as the Syrian Government battles rebel fighters. Following the coverage of this uprising has shown clearly that the Western media, by and large, backs an underdog and loves a revolt. It is rare, however, that a revolution will benefit either party; and careful reform is usually much more productive.

Rebels and revolutionaries frequently blight the tunnelling industry too.

It is safe to say that all tunnelling projects face opposition from inception. Heavy civil engineering works start with a problem, be it traffic jams, water shortages, sewer overflows and so on. Planners and designers, owners and politicians, work to find a solution. Consultation suggests tweaks and changes, or alternative approaches. Opponents (our rebels) deny the problem or the benefits of the solution.

Every tunnel project has its anti-tunnel rebel, usually branded 'Citizens Against…', or 'Say No To..' or similar. And this month's T&TI is not short of revolt stricken projects.

In Australia's Sydney the North West Rail Link (see page 34) is pushing into site investigation and design after a decade of fighting, one cancellation and a resurrection. Consultation lead to small changes in the project in the early stages of planning but as concrete plans were established, a revolt from the opposition party and a change of government lead to a total cancellation and the proposal of an entirely different transport project. A few years later and a political swing in the right direction and the project was reborn and is on track to solve transport issues in the Sydney suburb.

New Zealand's Waterview Connection in Auckland (see page 30) has survived a 'Tunnel or Nothing' rebel group that insisted the entire roadway be put underground – while readers may support the notion, the project would not have been financially viable so only the 'Nothing' option would have been left.

In Britain the High Speed Two rail project is fending off rebel group 'Say No to HS2' and has awarded contracts for a development partner and environmental overview services (see page 12). The project still has some way to go before it can be considered to have crushed the revolt.

There is a shining example of the success of reform in getting a project to completion this month too. In 2009 the New Zealand Government was struggling under the weight of the financial crisis and was looking for ways to save money. In the firing line was the Victoria Park Tunnel. But with some quick thinking and a reform to the projects tender conditions it was used effectively to stimulate the local economy. Spend on the project was increased, with a stipulation for no imported goods, and a preference for small to medium firms. Some 214 contracts worth a total USD 62M were issued, of which 80 per cent went to businesses in the local area. As well as boosting the local economy, the early availability of state funds meant the project was delivered a year early.

While revolts often expose real problems, revolution is rarely the solution.

Jon Young

Supporter of:

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contents

NEWS

5 **WORLD NEWS**
12 **BUSINESS NEWS**
14 **NEWS IN DEPTH**

TECHNICAL

16 **SQUEEZING GROUND**
TBMs in squeezing ground conditions

SPECIAL REPORT: AUSTRALASIA

22 **MARKET OVERVIEW**
When it all goes south
26 **MELBOURNE MAIN SEWER**
Historic Melbourne sewer replacement
30 **AUCKLAND WATERVIEW CONNECTION**
Auckland's big dig
34 **SYDNEY NORTHWEST RAIL LINK**
Breaking ground on tunnel pledge
38 **VICTORIA PARK**
Victory at Victoria

TECHNICAL

44 **EARTHQUAKE DAMAGE**
Earthquake damage in 'mountain tunnels'
49 **RENOVATION OVERVIEW**
Sustainability and safety – the role of renewal
54 **MECHANISED ENLARGEMENT**
On-line renewal and enlargement

BTS: CLEANER SEAS FOR SUSSEX

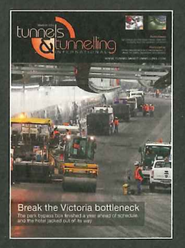
52 **BRIGHTON SEWER UPGRADE**
Final piece for Peacehaven

PEOPLE

62 **DEPLOYMENT: HARRIET RUTLEDGE**
Harriet on Hong Kong

DIRECTORY

63 **BUSINESS DIRECTORY**
65 **RECRUITMENT**
66 **BTS CORPORATE MEMBERS**
69 **DATES AND EVENTS**



On the cover:

Work on the Victoria Park project in New Zealand necessitated the temporary removal of a hotel

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Okayama submarine collapse

JAPAN

An under-construction subsea tunnel in Okayama, Japan collapsed last month with six workers inside. One managed to escape but two bodies had been discovered as *T&TI* went to press.

Initial searches were limited to 90 minutes by severe site conditions and it was not clear if water was continuing to enter the tunnel. Divers struggled with visibility in the shaft. A police spokesman said, "They were swimming into debris and into each other. There were also fears that the debris could cut the pipes on their dive gear."

According to the *Japan Times* contractor Kajima said the machine excavating the tunnel had been halted 50 minutes prior to the disaster. It added that the corporation could not confirm that an electrical problem had been reported prior to the collapse.

A Kajima spokesman told *T&TI*, "Kajima's focus is now on assisting the search and rescue operations for our missing workers on the project. We are working with the police and fire services among others and are fully cooperating with the investigation.

"We, Kajima, have started to investigate the cause of the accident ourselves but have not yet been able to clearly identify it. We have also not decided if we will disclose the results to the public."

Construction began on the 140m-long tunnel in 2010. It was designed to be U-shaped, 11m in diameter and 30m underground.

JX Nippon Oil and Energy Corporation operate Mizushima Refinery, which opened in 1961.

The surviving worker told police that he thought he heard a voice shout 'danger, leave' just before water came gushing in.

Herrenknecht's Guangzhou works hosts world leaders

CHINA

Herrenknecht's first China plant in Guangzhou hosted a visit by the Chinese Premier and German Chancellor on 3 February. Federal Chancellor Angela Merkel and Premier Wen Jiabao visited as part of Merkel's trip to China.

A Herrenknecht spokesman said the Chinese market generates approximately 20 per cent of sales by the Herrenknecht group. "To date Herrenknecht machinery has been used in 275 projects in China, mostly for inner-city tunnel construction," the spokesman added. "As many as 480km of tunnel tubes have been built over the past years, while a further 200km are being planned. In metro work alone, 172 machines have and are being used in 18 cities."

The spokesman credited the country's economic growth and increasing urbanisation for the figures. The Guangzhou branch was opened in 2002.

Martin Herrenknecht spoke about important Chinese and international projects, and showed the leaders a 6.95m EPBM that will be used on Dongguan Metro Line Two in the country's south.

Herrenknecht shown second from left; Merkel third and Wen fourth

Guerrilla retreat spurs investment

COLOMBIA

The retreat of Colombian guerrillas has freed territory giving contractor Construcciones El Condor of Medelin the confidence to seek investment for infrastructure work. The terrain of much of Colombia requires transport projects to include substantial tunnelling.

The same holds for hydropower work, which features very strongly in Colombia.

Bloomberg reported that Condor wanted to raise up to COP 200bn (USD 111M) through an initial pubic offering this quarter. There was a reported backlog of COP 1.3tn (USD 722M) worth of projects to be worked on. The South American country will need COP 99tn (about USD 55bn) of infrastructure development by 2021 according to a September report by the Colombian Transportation Ministry.

A surge in foreign direct investment has helped spark the fastest economic growth in five years as new areas of the countryside open up to oil and mining exploration after a decade of military victories over guerrillas.

Condor was one of at least five companies that said they may offer shares this year in Bogota, and construction in Colombia is forecast to be a driver for growth for the next five-10 years. Although Condor profits and revenue have dropped recently, highway projects are expected to bolster 2011 figures. Current Condor projects include highway work in the Putumayo and Narino regions of southern Colombia.

Future projects may well be delayed by politics, bureaucracy and heavy rains according to the Bloomberg report.

The Environment Minister, Frank Pearl, suspended Condor's work on a tunnel on 12 January for 90 days to review its environmental impact study. President Juan Manual Santos created a National Infrastructure Agency last November to streamline public bidding processes.

News in brief

Morgan Sindall to cool Green Park Tube Station
Morgan Sindall was last month awarded a GBP 9M (USD 14.2M) project to install a system to cool the platform areas at Green Park Station in London, UK. Eight air handling units will be fed from a series of boreholes. A Morgan Sindall spokesman said it will be the first time this type of system is used on the London Underground. The design phase was underway as *T&TI* went to press and the project will complete in summer 2012. Work will go at an accelerated pace to meet the summer deadline.

World at a glance

Project developments, milestones and challenges

NEW YORK, USA

Amtrak announced on 11 January that it will spend USD 15M during 2012 for planning and other pre-construction activities for the Gateway Program. Work on which will include a trans-Hudson River tunnel from New Jersey to New York.

The overall scope of the project includes building two additional tunnels under the Hudson River to access expanded terminal facilities serving New York Penn Station and the future Moynihan Station on the site of the former Farley Post Office. It also will replace and expand the century old Portal Bridge over the Hackensack River and increase from two to four the number of tracks between Newark and New York.

Specifically, the funding in 2012 will be used for planning, design and preliminary environmental review for project elements as well as to begin utility relocation for the Portal Bridge project, which is currently in the final design stage.

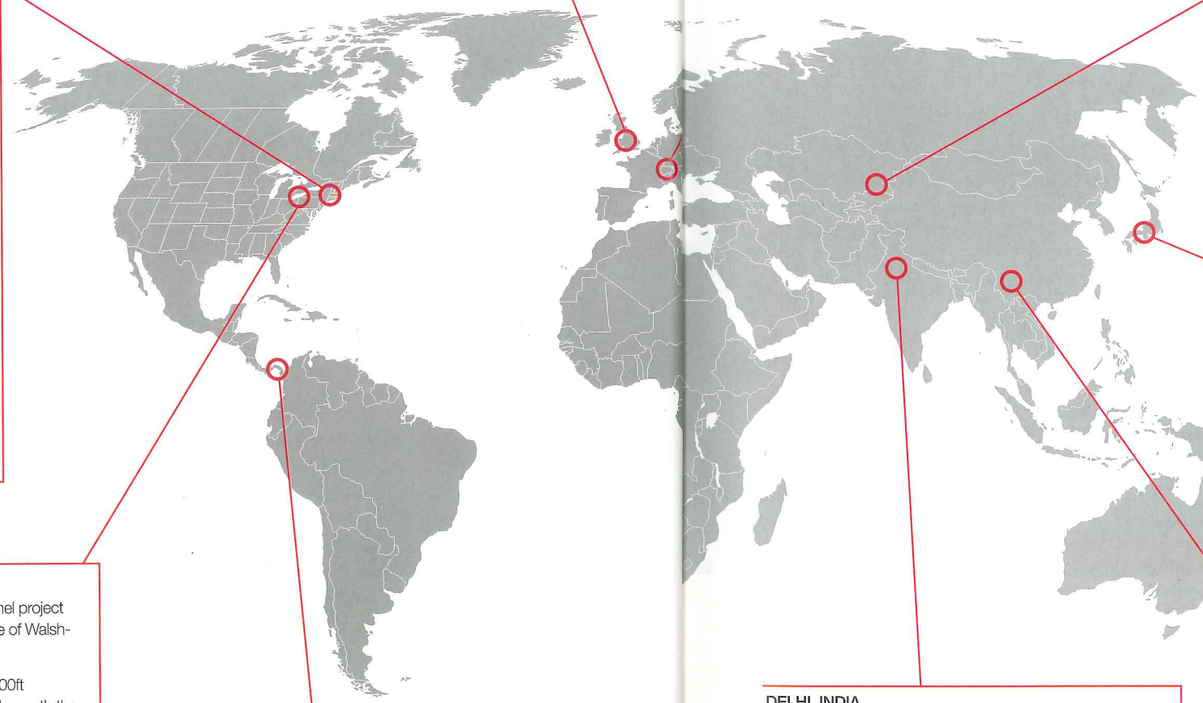
The announcement by Amtrak's president and CEO, Joe Boardman, came as part of the rail company's 2012 agenda, including "further integration and advancement" of Northeast Corridor planning efforts to improve the existing corridor and develop a high-capacity, next-generation high-speed rail system.

LONDON-BIRMINGHAM, UK

Environment and engineering survey work can now begin along the High Speed Two (HS2) alignment between London and Birmingham, UK. An access to private land agreement was reached with landowner representatives, which led to yesterday's announcement.

Work should begin in February to identify plants, animals and habitats. If necessary, HS2 will carry out detailed investigation of specific species.

HS2 said that it had also begun contacting individual landowners to arrange site visits. HS2 chief executive Alison Munro added, "I'm very pleased that we are able to get going with the next key stage of our work assessing, in much greater detail than we have been able to do up till now, the potential impact of the HS2 proposals on local sites.



LORAIN, USA

The Lorain, Ohio, city council approved a USD 55M sewer tunnel project on 23 January, including a USD 53M contract for a joint venture of Walsh-Super Excavators.

The 24ft diameter (7.3m) wastewater storage tunnel will be 5,500ft (1,676m) long, and will be excavated 112 to 187ft (34 to 57m) beneath the city. The finished diameter is to be 19ft (5.8m).

According to documents submitted to the Ohio EPA this summer, an open face rock TBM will be used to mine the tunnel with some pre-excavation grouting as need. The city also noted that it "expects that the primary tunnel lining system used underneath Lorain will entail steel ribs and skeletal wood lagging (or liner plates under certain areas) to both support advancement of the TBM and support of the tunnel crown, plus any additional needed sheeting and bracing to support the floor and sides of the tunnel."

Construction is expected to start in March and last for three years.

PANAMA

A 9.7m diameter Herrenknecht TBM began excavating the 6.4km-long subway for Panama City's Line One on 23 January. The project's contractor, an FCC-led consortium with Odebrecht, has a budget of more than EUR 1bn (USD 1.4bn) to build the subway line, and is currently assembling a second Herrenknecht EPBM, to be launched on the project in March.

The machine was named Marta after Panama president Ricardo Martinelli's wife. It is expected to excavate at 16m per day.

BERN, SWITZERLAND

Warm drain water from the Lotschberg Base Tunnel is being used to feed Switzerland's first sturgeon and caviar farm, the 'Tropenhaus' at Fruitigen between the tunnel and Bern. According to local media, this was an idea of Peter Hufschmied, an engineer in charge of diverting the recently completed tunnel's drain water.

The warm water (20°C) can help grow and mature the fish so that it can be harvested at six years old. The wild sturgeon, also threatened by extinction, can take 20 years before reproduction. The water, which is too warm to discharge into the Kander River is also used to heat a tropical greenhouse. The Tropenhaus farm's branded 101 Oona caviar sells at about 60 per cent of the price of Beluga caviar from the Caspian Sea.

ALMATY, KAZAKHSTAN

The first metro line in the Kazakhstan capital of Almaty was opened in December after 23 years of construction. The smart, pristine architecture of stations and trains has led many to agree it has been worth the wait. Residents have reportedly visited just to admire it. Even a wedding was held during a trip on its 8.5km single line.

Construction was halted with the dissolution of the USSR, to be resumed in 2005. The line has seven stations, four at deep levels and three sub-surface, which feature marble floors, intricate mosaics and even stained glass windows. The estimated cost was around USD 1bn.

The project contractors, JSC Almatymetrokurylys, have a long history of underground works including metros in Krasnoyarsk and Kazan, tunnels on the Baikal-Amur railway, various underground facilities in the cities of Novosibirsk, Moscow and Tashkent and mining in Kasakhstan. Plans exist for an expansion of the Almaty metro system to a total of 45km.

OSAKA, JAPAN

An acceptance test for a 3.09m-diameter 'compact shield type' EPBM was due to be held at Hitachi Zosen's Sakai Works in Osaka, Japan on 23 February.

The project destination was the Dai-ni Yatagawa trunk storm sewer project phase three in Tokyo, Japan.

The TBM will arrive at the project site this month to excavate the 989m-long tunnel for contractor Okumura Corporation under client, Tokyo Metropolitan Bureau of Sewerage.

The shield was designed with two articulation joints with a maximum articulation of 14.5 degrees to execute curves with a 15m radius. It was also built in three body parts: front, middle and rear. This will allow the machine to commence excavation with only the front part in the shaft.

DELHI, INDIA

The Delhi Metro Rail Corporation awarded two more major civil engineering contracts for phase three of the project in January. One was a tunnelled section while the other was elevated.

The tunnel contract went to a JV of Larsen & Toubro and Shanghai Urban Construction Group for construction of stations and tunnels between Mandi House and Jama Masjid. The 3.3km section will involve three cut and cover stations, each separated by around 2.5km of TBM-driven tunnel.

Five civil tenders had been awarded prior to these, the first in June 2011. Construction began shortly after.

YUNNAN, CHINA

The Xiushan Tunnel was completed on 10 January. The project in Yunnan Province, China forms part of the eastern line, the Yuxi-Mengzi Railway, of the Pan-Asia railway project.

The 1.3km tunnel was considered a 'first-level high-risk tunnel'. Tonghai County in Yunnan is famous for complex, changing geology. Tunnelling encountered frequent bursts of water and mud. Construction took 1,000 workers six years to complete. Total investment for the railway will hit CNY 4.5bn (USD 703M). It will become operational later in 2012.

The eastern line will run for 141km. It will enable greater trade between China and ASEAN nations. State news agency Xinhua reported in 2006 that rail transport could only meet 30 per cent of transportation demand for trade with the bloc.

US approves border tunnel crime bill

USA

The US Senate unanimously approved a bill on 30 January meant to combat illegal tunnel activity along the US-Mexico border. The Border Tunnel Prevention Act of 2011, sponsored by Dianne Feinstein (D-CA) and Jon Kyl (R-AZ), provides law enforcement and prosecutors with additional tools to locate tunnels, and identify and punish criminals.

According to Feinstein, as the border has become more secure, criminals have sought new ways to go around and under checkpoints.

"These passageways are much more than simple holes in the ground, some of them feature elevators, electric rail tracks, and even a hydraulically controlled steel door," Feinstein said. "Border tunnels can be used to transport drugs, weapons, or people and present a serious threat to our national security."

The bill makes the use, construction or financing of a border tunnel a conspiracy offense. In addition, illegal tunnelling will be classified as an offense eligible for Title III wiretaps even when there are not drugs or other contraband to facilitate a wiretap. Companion legislation has been introduced in the House and is pending action.

"Of the 135 illegal tunnels uncovered over the past decade, all but one have originated in Mexico, and exited in Arizona, California, or Texas," said Kyl. He added, "I urge the US House of Representatives to approve legislation so that federal authorities can step up their efforts against this growing problem."

On 28 January Mexican authorities uncovered tunnel activity in Nogales, Sonora. The entrance to the tunnel, which had not yet been completed, was found in a home just blocks away from the US border.

US authorities also unearthed a cross-border tunnel in November that federal officials described as "the most sophisticated tunnel we have ever found".

Sedrun lags Gotthard final concrete push

SWITZERLAND

At the start of the year nearly all of the Gotthard Base Tunnel had received its final lining, apart from portions of the deep Sedrun Multifunction Station and the adjacent East Tube where work has now been accelerated. Railway equipment is being installed in the East Tube of the Erstfeld and Amsteg sections from the north portal and in the Bodio West Tube test section from the south portal.

Work was stepped up at Sedrun to complete concreting including increasing aggregate production from two to three shifts.

Four lining trucks are being used in the East Tube.

IEM calls for compulsory graduate engineer exam

MALAYSIA

The Institute of Engineers Malaysia (IEM) last month called upon the Government of Malaysia to introduce an engineering competency exam.

The 'Fundamentals of Engineering Examination' (FEE) would ensure all graduates from accredited universities, Malaysian or international, can demonstrate an understanding of engineering principles. An IEM spokesman said, "As a professional institution and learned body, IEM firmly believes that the quality of engineering graduates cannot be compromised and the introduction of the FEE will go a long way to ensure that engineering graduates possess the minimum competency on engineering principles. The IEM is willing to offer its assistance in implementing the FEE.

"A person may apply to sit the examination when in the final year of a degree programme or after graduation, before registration with the Board of Engineers Malaysia as a graduate engineer," the spokesmand added.

"This examination will ensure that graduates of foreign engineering degrees have achieved the same standard."

Connaught cofferdams

GREAT BRITAIN

Crossrail announced last month that cofferdams will be placed in the Connaught Passage, water will be pumped out and a dry construction area created to allow workers to dig down to the tunnel for cut and cover enlargement works.

Crossrail originally intended contractor Vinci to remove the existing steel linings and back fill the entire section with concrete firm. Enlargement would then be carried out by boring through the concrete to allow Crossrail trains to pass through.

Connaught Tunnel project manager Linda Miller said, "The central section of the Connaught Tunnel is in a poor structural condition. To ensure we can undertake the tunnel enlargement work as safely as possible we have now decided to drain a section of the Royal Docks and then dig down into the tunnel.

"This will be the first time the tunnel has been exposed from above ground since its construction in the 1870s. While we will be using modern techniques, we will be using a similar cut and cover approach that was used to build the original tunnel which saw the tunnel constructed first with the docks then built over the top."

A Crossrail spokesman said, "Connaught Tunnel in the Royal Docks was built in 1878 and was part of the North London Line until 2006. The tunnel will be extensively refurbished as part of works to construct Crossrail's new Abbey Wood branch.

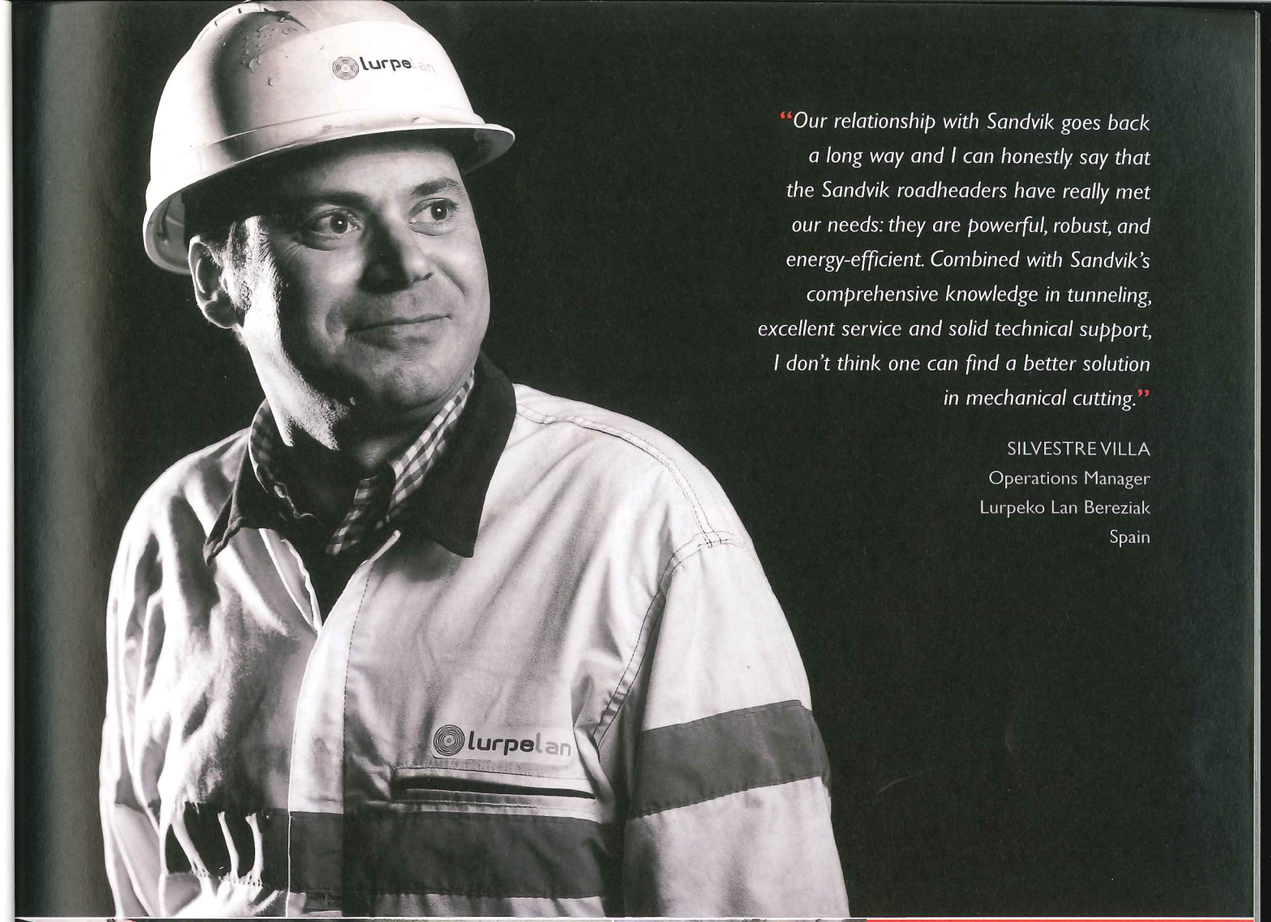
"Sections of the existing tunnel are in a poor structural condition. In 1935, larger ships began scraping the bottom of the Royal Victoria Dock, which sits above the Connaught Tunnel."

News in brief

POMT spoil storage solved

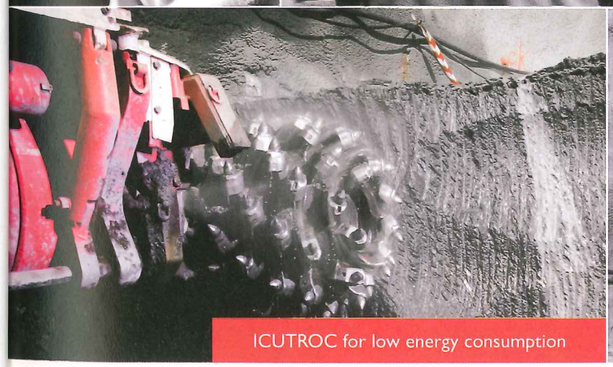
Florida's Department of Environmental Protection issued a permit to the MAT Concessionaire building the Port of Miami Access Tunnel for depositing spoil on Virginia Key in December.

Testing of spoil produced since the TBM began boring in November proved the rock to be clean. Up to 214,075 cubic metres can be deposited by the contractor. Spoil will be used for a restoration project.



"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."

SILVESTRE VILLA
Operations Manager
Lurpeko Lan Bereziak
Spain



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Odebrecht's swish monument to metro

BRAZIL

A new monument to tunnelling was placed outside the Oderbrecht's Brazil plant honouring completion of lots one and two of Sao Paolo Metro Line Four. A plaque recognises Seli technical personnel and engineers for their work in carrying out the excavation. Work was completed at the end of 2009.

A Seli spokesman said, "This recognition has special significance as it serves as further confirmation of the quality of their work and symbolises the trust their clients place in their technical and operational expertise."

The project called for the realisation of a metro tunnel of 6.4km with a diameter of 9.5m to join the stations of Faria Lima and Joao Teodoro, along Line Four.

The client was the Via Amarela consortium led by Oderbrecht. Seli won the EUR 29M (USD 38.4M) contract for a two-year excavation.

Squirrel tunnel rehab works contract awarded

USA

The Pennsylvania Department of Transportation (PennDot) chose the firm Michael Baker Jr. to provide construction inspection and construction management services for the Squirrel Hill Tunnel rehabilitation project in Pittsburgh.

The project includes updates to the electrical, lighting, control and ventilation systems, as well as addressing structural repairs to the walls and arched ceiling, installation of a water line, and other construction within the 4,225ft (1,288m) long tunnel.

Thomas Donatelli, assistant vice president of Pittsburgh Construction Services said, "We have the experience that is essential to coordinate complex highway, bridge and tunnel construction projects simultaneously within a busy metropolitan area which includes a vast number of commuters."

The tunnel rehabilitation will increase vertical clearance to reduce the number of delays due to over-height trucks; lighting improvements will be made to allow motorists to maintain highway speed through the tunnels; and an upgrade to the fire suppression system will add to the safety improvements.

The work is expected to complete in summer 2014.

Ahmadinejad promotes Iranian tunnellers

IRAN

Iranian President Mahmoud Ahmadinejad has been promoting Iranian tunnelling during a tour of South America.

A spokesman for the Iranian embassy in Colombia said the tour was designed to boost bilateral trade and find new opportunities for Iranian tunnelling and dam companies. Iranian trade with the region has reportedly been surging and the country is setting up new embassies. "Our government is simply trying to diversify its trading partners and promote more 'South-South' collaboration."

Iran has announced more than 200 joint industrial projects with Venezuela alone, according to official US sources.

Amendments to Queensland code of tunnel practice

AUSTRALIA

The Tunnelling Code of Practice 2007 for Queensland, Australia will be amended. The Australasian Tunnelling Society (ATS) announced in January that the Queensland Government had approved changes in areas such as emergency planning, risk management, air quality, diesel emissions, fire, explosion and communications.

The ATS and Workplace Health & Safety Queensland will provide a workshop on the development and implementation of these changes on 12 March in the Hawken Auditorium, Engineers Australia, 447 Upper Edward Street, Brisbane at 2pm.

Visit www.engineersaustralia.org.au/qld/events to register.

News in brief

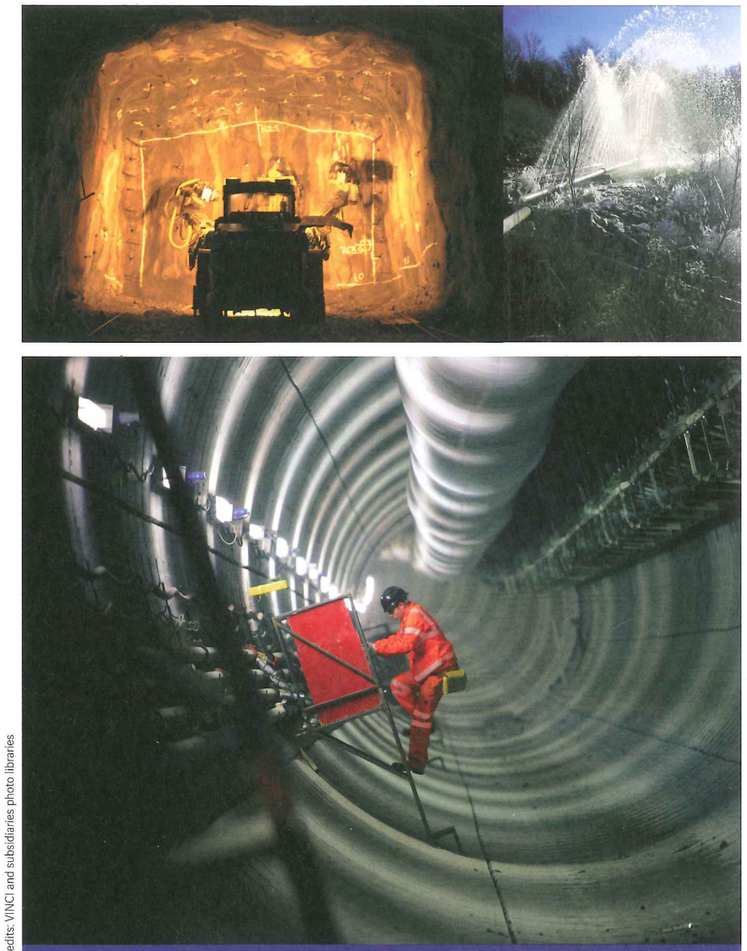
Fehmarnbelt industry day
An 'industry day' will be held to increase interest in the Fehmarnbelt crossing between Denmark and Germany. Due to be held in Copenhagen on 21 March, client Femern said on Monday it hopes the event will attract international contractors to the EUR 5.5bn (USD 7.32bn) project and increase competition.

Sandvik turns 150
On 31 January, it was 150 years to the day since Goran Fredrik Goransson's company was formed in Sandviken, Sweden. An anniversary flag was hoisted and a fireworks display celebrated the company's milestone.

Farringdon fundraising
Costain Laing O'Rourke's joint venture at the Farringdon Station project in London, UK has donated USD 9,600 to charity. Charities included the Osteopathic Centre for Children, City of London Road Safety, Global Generation, St Bartholomew's Hospital and Foyer Federation. The money was raised while promoting 'near miss' reporting on sites.

Concrete completed at Devil's Slide tunnel
Workers poured the final concrete pavement for the roads inside the Devil's Slide tunnel in California on 2 February. Owner Caltrans expects the project finish before the end of 2012. The project comprises two tunnels beneath San Pedro Mountain, 9m wide and 1,280m long.

Provincial governor visits Hong Kong MTR
Zhu Xiaodan, governor of Guangdong Province, visited MTR last month for an update on the Express Rail Link to Guangzhou and Shenzen. It will be completed in 2015.



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CH2M Hill as High Speed Two development partner...

GREAT BRITAIN

CH2M Hill was named development partner for the next phase of UK high-speed rail line, High Speed Two (HS2). HS2 made the announcement last month and added that a team of about 80 people would be created to fulfil the GBP 70M (USD 110.1M) contract.

A HS2 spokesman said, "They will project manage the professional services companies who will carry out the design, environmental and land referencing work for the London to West Midlands line. CH2M Hill's expertise will ensure that the work is fully integrated and delivered on budget, on time and to the required quality."

Chief executive of HS2, Alison Munro said, "Now that HS2 is up and running, it's time to bring new people on board and I'm very pleased to welcome CH2M Hill as our development partner for the next phase of this exciting project.

"They will bring their highly regarded experience of working on HS1 and Crossrail, two major UK infrastructure projects that have direct relevance to our work."

The appointment was confirmed on 3 February after the 10-day standstill period required by EU procurement regulations, which allows unsuccessful bidders to challenge the decision.

The procurement procedure began at the end of July 2011.

...while Arup takes on a service role for environment overview

GREAT BRITAIN

Arup last month won a contract for the provision of environmental overview services for the UK's HS2 rail link. Supported in its role by URS Scott Wilson, the GBP 7M (USD 11.1M) award was the first 'Lot Three Environmental Services' contract awarded by the client.

Arup will coordinate and provide 'technical leadership' to the winners of the remaining four packages to produce an overall environmental statement from their impact assessments.

The four remaining impact assessment packages to be awarded under lot three will cover: natural environment, such as biodiversity, water, geology and visual impact; historic environment, such as built heritage and archaeology; built environment, such as townscape, traffic and transport, waste and planning policy; and finally community, such as noise, air quality, property and agriculture. The contract began in February and will last until the end of 2013.

Arup global rail leader Colin Stewart said, "Arup has been working with HS2 since May 2009, conducting the initial route engineering studies.

"We are very pleased to be helping implement the next stage of this project and to help make integrated, high speed rail a reality for the UK."

Bilfinger Berger sees net profit jump

GERMANY

Bilfinger Berger (BB) announced last month it had met all finance-related goals for 2011. Net profit increased from EUR 284M (USD 376M) in 2010 to EUR 394M (USD 521.7M) with a resultant dividend per share increase of EUR 0.9 (USD 1.2). The scale of the increase was largely due to the sale of Valemus Australia to Australian construction group Lend Lease in the first quarter.

A BB spokesman said, "Austerity measures initiated by the public sector will lead to weaker demand for civil engineering. Regardless of this development, output volume in the business segment will decline following the completion of a major project and reach the magnitude that has been planned for some time.

"The improved risk structure and the increasing focus on higher margin activities will allow for a further increase in the EBITA margin [which had a 21 per cent increase from 2010 to 2011 for the construction business segment]."

Total EBIT grew six per cent to EUR 361M (USD 478M). Output volume increased five per cent to EUR 8.5bn (USD 11.2bn).

BB announced future targets: output volume increase of 50 per cent by 2016, net profit doubled and over EUR 1bn (USD 1.32bn) invested in the acquisition of companies.

The full report can be read: www.bilfinger.com/en/Press/Press-Releases/2012/listing/Preliminary-report-on-the-2011-financial-year

Neighbour losses hit Skanska

SWEDEN

Losses in its construction business units in Finland and Norway have cost Skanska SEK 520M (USD 76.8M) in the fourth quarter of 2011.

As a result of reviews of operations and project portfolio in those countries by new management there has been a cost of SEK 350M (USD 51.8M), chiefly attributed to write-downs of building projects and provisions in southern Finland and Estonia SEK 320M (USD 47.3M) plus write-downs of land and other assets in Estonia. In Norway the revision and restructuring of construction resulted in write-downs and provisions of around SEK 170M (USD 25.1M).

News in brief

Geneva electro-mechs
The Vesenaz cut-and-cover highway tunnel in the municipality of Collogne-Bellerive, Switzerland, is the subject of a contract notice advertised by Geneva cantonal government for various electrical installations. Seven lots are available. Deadline: 19 March. Contact: bassem.haddad@etat.ge.ch

Atlas Copco in top 10 sustainable companies
Atlas Copco was ranked at number 10 in the World Economic Forum's list of the world's top 100. Judgement was passed on criteria such as revenue versus total consumption of energy and water. Atlas Copco was unranked in 2011 but on the list for the five previous years. A spokesman said the company was proud to see its development recognised.

B&V water president calls for New Deal

USA

Cindy Wallis-Lage took the presidency of Black & Veatch's global water business last month. Wallis-Lage called for a new focus and investment in the water industry.

She said: "We will see increased investment in water and electric infrastructure throughout the world. This will have a rippling effect in the water industry on supply and demand, quality and reliability and flood control. It will also impact environmental and security issues.

Wallis-lage was previously executive managing director of technical solutions for Black & Veatch. She added, "We know that investment in infrastructure creates jobs and boosts the economy. In the US, the New Deal in the 1930s and the American Recovery and Reinvestment Act of 2009 shared a goal of increasing jobs and improving the economy through public works spending on construction. Today, the world needs a New Deal type of approach for aging infrastructure."

A US Environmental Protection Agency report found that capital investment required for US drinking water was USD 91bn in 2010 while only USD 36bn was put forward. The World Bank has estimated that an annual investment of USD 180bn will be needed globally for water infrastructure until 2030.

Wallis-Lage brings 25 years of industry experience to the role. She is a licensed professional engineer with a bachelor's degree in civil engineering from Kansas State University and a master's in environmental health engineering from the University of Kansas. She has served on committees for the Water Environment Federation and International Water Association.

Hip Hing relocates

HONG KONG

Hip Hing Construction relocated its head office to Chevalier Commercial Centre, Kowloon Bay, Hong Kong. A Bai Sun ceremony was held to celebrate completion with directors of the company presenting incense sticks, burning joss papers and cut roast pigs together. The ceremony is for prosperity and good fortune.

Hip Hing managing director Chu Tat-chi uncovered the company's logo at the entrance to the building to officially open the office on 9 February.

Above: Hip Hing's Bai Sun ceremony

Kawasaki's nine months

JAPAN

Kawasaki Heavy Industries released its financial results for the nine months ending 31 December 2011. Net sales increased from JPY 870.5bn (USD 11.09bn) in the previous year to JPY 906.3bn (USD 11.5bn). Operating income increased from JPY 38.7bn (USD 492.9M) to 47.3bn (USD 602.5M) and net income grew from JPY 28.1bn (USD 357.9M) to JPY 33.7bn (USD 429.2M).

The company saw decreased cash flows, with a drop from JPY 33.5bn (USD 426.7M) to JPY 16.1bn (USD 205.1M) in operating activities, JPY 78.1bn (USD 994.8M) to JPY 61.2bn (779.5M) in financing activities and JPY 35.8bn (USD 455.98M) down to JPY 34.3bn (USD 436.9M) in cash and cash equivalents at the end of the term. Investment activities increased by some 24 per cent from JPY 41.5bn (USD 528.6M) to JPY 51.4bn (USD 654.7M).

The announced forecast for the full year ending 31 March 2012 expected to see net sales of around JPY 1.3tn (USD 16.6bn), operating income of JPY 50bn (USD 636.9M) and net income of JPY 26bn (USD 331.2M).

Strabag betters forecast

AUSTRIA

Strabag exceeded its expected output forecast for 2011 by EUR 0.3bn (USD 396M). The total EUR 14.3bn (USD 18.9bn) output figure was up from EUR 12.8bn the previous year.

The order book stood at EUR 13.4bn (USD 17.7bn), down nine per cent on the level at the end of 2010. A Strabag spokesman said that the company should see output in 2012 roughly equalling that in 2011. The spokesman added, "Even if uncertainties regarding the actual economic environment – economic growth in the individual markets, the height of public spending, and the financing environment for our clients – make planning difficult, Strabag [will see] relatively stable results for the 2012 financial year."

News in brief

SAK Construction adds two to business team
SAK Construction has recruited Gerald Addington and Cary Shaw to its business. Addington was made general manager of the central rehabilitation division for the US-based pipeline rehab and tunnelling services contractor, while Shaw joined the business development and marketing team.

New director for India capital's metro
Jitendra Tyagi has been appointed the new director of works of the Delhi Metro Rail Corporation (DMRC). He has more than 29 years of Service in various disciplines of civil engineering. He has vast experience on Indian Railways. He joined DMRC in April 2004. In Phase – III he will be in charge of consultancy for the Yamuna Vihar to Mukundpur corridor of Line Seven of the project.

Yongnam Holdings CEO's possible Securities and Futures Act infringement
The Singapore police began an investigation of steel fabricator Yongnam Holdings CEO, Seow Soon Yong. The police required him to 'produce certain documents' after they found reasonable grounds for believing him to have committed an offence. Seow Soon Yong disputed the allegation and said he would cooperate fully with the Commercial Affairs Department's investigation.

New executive vice president for Lemminkainen
Jouni Pekonen was last month appointed executive vice president of Finnish contractor Lemminkainen. The move will be effective as of 19 March. Pekonen was previously at Rautaruukki, Andritz Group and Metso.

Sany of China to buy Putzmeister

Construction machinery manufacturer Sany Heavy Industry based in Changsha, China is to take over the concreting specialist Putzmeister of Aichtal, Germany. The move will proceed subject to regulatory approvals. Putzmeister described the move as a merger in which both partners benefit substantially from the combination. Both agreed not to disclose the purchase price but a value of about EUR 500M (USD 660M) has emerged.

Putzmeister described the deal as the largest Chinese-German transaction to date, and also the first time that a company in the 'Mittelstand' (small to medium sized company) engineering backbone of the German economy has merged with a Chinese company. Putzmeister claimed it would benefit from greater financial strength to secure growth prospects and competitive advantage, whilst Sany acquires cutting-edge technology and a strong distribution and service network outside of China.

The investment by Sany has a large financial input from the Chinese private equity company CITIC PE Advisors (Hong Kong) as a minority shareholder, allowing the 100 per cent purchase of Putzmeister. Morgan Stanley acted as financial adviser to Putzmeister.

Sany is a large Chinese producer and market leader in concrete pumps in China. Aichtal will become Sany's new international HQ (excluding China) for concrete machinery, while Sany will concentrate on operations in China, handling Putzmeister as a premium brand.

Karl Schlecht, the founder of Putzmeister, commented, "Sany is one of the few large Chinese conglomerates that is personally operated by the founder [Liang Wengen], who is also the majority shareholder. In fact, Wengen is one of China's most successful entrepreneurs. He not only shares our entrepreneurial spirit, but also Putzmeister's visions and corporate values." The entire proceeds of the transaction will be transferred to the benefit of Karl Schlecht Gemeinnutzige Stiftung (99 per cent) and Karl Schlecht Familienstiftung (one per cent).

Above: Liang Wengen (right), chairman and founder of Sany talking to Yu Laishan, executive governor of Hunan Province at Sany's works

Wengen, chairman of Sany, also commented, "With this merger Putzmeister and Sany will create a new and global market leader for concrete pumps. Putzmeister will remain as an independent brand with its own management within the Sany group. We are looking forward to working with the Putzmeister management that makes this business so successful." Wengen tops Forbes China rich list.

Last year Putzmeister employed 300 people and generated about EUR 570M (USD 751.4M) in revenue. It has a long-standing marketing agreement with the Sika Group for the marketing of concrete spraying systems and, in May last year, announced a distribution agreement with GHH of Germany and MineMaster of Poland for drilling jumbos, rock-bolting rigs and load-haul-dump vehicles. These two companies also form a global alliance with Schmidt, Kranz & Co.

A spokesman for Putzmeister explained that as Putzmeister has been acquired as a whole, the deal includes Putzmeister Iberica, which handles most tunnelling and mining marketing, as well as subsidiary companies Lancy and Allentown. The spokesman added, "The same is true for contracts regarding the co-operation with Sika. The contracts are still valid. As of today there are no plans for any adaptations."

Sany Heavy Industry was founded in 1994 as a private company. It has about 70,000 employees in over 150 countries.

This will not be Sany's first move in Germany as it claimed the previously largest investment of a Chinese company in Europe (EUR 100M – USD 131.6M) with a 2009 agreement to open an research and development centre near its facility in Cologne, Germany.

A major competitor of Putzmeister, Cifa of Italy, became part of the Zoomlion engineering manufacturing group, also of Changsha, China in 2008. The Putzmeister statement indicates that the presence of German directors on the Chinese board, and vice versa, may follow a similar operating structure. Norbert Scheuch will remain as Putzmeister CEO and will join the Sany executive board.

Maurice Jones

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NTA
The Israel Light Rail

NTA - Israel Metropolitan Mass Transit System Ltd

Tender No. 060/2011

For the Design Build of the At Grade Sections, the Depot and all Rail Systems for the RED LINE (the "Tender")

1. NTA Metropolitan Mass Transit System Ltd ("**NTA**") is a government owned company in charge of the design and construction of the mass transit system in the Tel Aviv metropolitan area.
2. The Red Line is a Light Rail Transit (LRT) system and is the first line of the Tel Aviv metropolitan area mass transit system to be implemented.
3. The overall length of the Red Line is approximately 23 kilometers, of which approximately 12 Kilometers are At Grade areas and 11 Kilometers are Underground.
4. NTA intends to pre-qualify interested international suppliers who will be issued with Tender documents. The subject of the tender will cover 3 areas of the proposed Red Line Works to include: Transit Systems, At Grade sections, and the Depot:
   - 4.1. The Transit Systems for the entire Red Line (23Km) and the Depot shall include inter-alia communication and control systems, signaling and control systems, electrical systems (high voltage), Catenary Systems, fire detection systems ,Traffic Management Systems, Passenger Information systems ,CCTV & Intruder alarm systems and track.
   - 4.2. The At-Grade sections shall include all civil works for the LRT, including the technical rooms along the line. The scope of the works shall include inter-alia all Civil and fixed Mechanical and Electrical systems at these areas.
   - 4.3. The purpose of the Depot is to serve as the operation and maintenance center for the Red Line, and as such the proposed scope of the works shall include all necessary heavy and light maintenance buildings, office building, Secondary control centre, Depot control centre and the stabling area for the fleet. The scope of the works shall include inter alia all civil engineering and fixed mechanical and electrical works necessary to facilitate the operation of a Depot for the size of fleet proposed for the Red Line. The scope will include but will not be limited to the provision of services for Train Jack, wash plants, paint shops, wheel lathe, training systems –Cab simulators and maintenance management systems.
   - 4.4. NTA reserves the right of adding a maintenance contract for all, or part of the equipment supplied under the scope. The NTA decision will be incorporated in the final request for tender or in an addendum to same. The maintenance contract with NTA might be assigned to a third party O&M contractor.
5. This notice serves to provide advanced information about the proposed prequalification of potential interested suppliers for the Systems At Grade and Depot package.
6. Interested parties are to note that proposed package will have inherent interfaces and coordination with a number of other packages to be tendered (such as the Rolling Stock, the UG Stations, O&M etc').
7. NTA wishes to retain an international contractor to provide the services that will be further described in the Prequalification and Tender documents. Set out below is the proposed procurement timetable. This is intended as a guide and whilst NTA does not intend to depart from the timetable, it reserves the right to do so at any stage.

Target Date	Activity
Q2 2012	Pre-Qualification Questionnaires (PQQ) Issued
Q3 2012	Invitation to Tender (ITT) Issued
Q2 2013	Contracts Awarded.

8. An updated notice will be published together with the publication of the Tender Documents.
9. From time to time NTA might publish updates regarding this package at its website under www.nta.co.il/site/en/neta.asp?pi=464 or under ftp.nta.co.il (login ftpuser17, Password Sdag@13)
10. All queries regarding this Tender can be addressed to the Tender mail box at: SDAG_Tender_060_2011@nta.co.il (Link: SDAG_Tender_060_2011@nta.co.il)
11. It is hereby clarified that if a contradiction is discovered between this advertisement and the Tender documents, the content of the Tender documents shall prevail over the contents of this advertisement.

Itzhak Zuchman
CEO
NTA

www.nta.co.il

ASHKENAZY ZALSMAN / Bss

TBMs in squeezing ground conditions

Marco Ramoni of Basler & Hofmann and Georgios Anagnostou of ETH Zurich review their own research work on TBM tunnelling in squeezing ground. Part one of their contribution illustrates the specific problems and discusses possible countermeasures, while part two (to be published in the April issue of *T&TI*) will introduce practical design aids for the planning engineer

Renovating and restructuring the cutterhead for the Herrenknecht TBM at Gotthard's Faido section, which suffered major ground squeezing

The expression squeezing ground is commonly used with reference to large deformations of the opening after excavation. If an attempt is made to hinder the ground deformations, a high ground pressure may develop upon the tunnel support endangering its structural integrity.

Conventional tunnelling offers adequate solutions for coping with squeezing ground. In fact, it is well known that a suitable amount of over-excavation in combination with deformable lining systems (e.g. steel sets with sliding joints) allows large convergences to be accommodated without violating the clearing profile, thereby reducing the ground pressure acting upon the tunnel support to a manageable level.

The space available for ground deformations in TBM tunnelling is very limited, due to the fixed geometry and the limited flexibility of the tunnelling equipment (TBM and back-up). As tunnelling experience shows (Ramoni and Anagnostou, 2011a), even relatively small convergences of 10–20cm may lead to considerable difficulties in the machine or in the back-up area, thus extending the range of geological conditions falling under the definition of 'squeezing ground' to rock masses which would be more or less unproblematic in conventional tunnelling (e.g. hard but highly fractured rocks encountered at great depth).

Difficult conditions such squeezing may slow down or even obstruct TBM operation (see Figure 1, below). Operating a TBM near or even at its operational limits over frequent tunnel intervals or longer tunnel sections may have a major impact on the economic viability of a TBM project. An assessment of the technical feasibility as well as, more generally, the proper planning of a TBM drive is therefore of paramount importance in squeezing ground.

Specific problems

Squeezing behaviour may become problematic at different distances behind the tunnel face (Ramoni and Anagnostou, 2011a). There are potential hazards both for the machine area and the back-up area. The TBM may be blocked in squeezing ground due to a sticking of the cutter head or a jamming of the shield (see Figure 2, right). Jamming is also possible with respect to the back-up equipment (see Figure 3, right). Other potential problems in the back-up area include inadmissible convergences of the bored profile and damage to the tunnel support (see Figure 4, right).

The performance of a TBM is the result of a complex interaction between the main system components ground, tunnelling equipment (TBM and back-up) and tunnel support. The advance rate influences this interaction too and is not only a result of it. The assessment of critical situations – such as TBM operation in squeezing ground – requires proper identification of the relevant interfaces as well as an in-depth understanding of the manifold interactions within the system components. As the number of interfaces and interactions is high and there may also be conflicting requirements, this is only possible by applying an efficient mapping system and a systematic approach using system engineering tools – as in the case of Ramoni and Anagnostou (2010b).

Moreover, the TBM types are different with respect to the thrusting system, the type of tunnel support, the presence of a shield, and the achievable advance rate. Consequently, different hazard scenarios have to be considered depending on the machine type.

Below: **Figure 1, single shielded TBM jammed in squeezing ground (Arrowhead Tunnel, USA, Ø = 5.82m). Support measures built during hand-mining to free the TBM. Picture courtesy of Brian Fulcher, J.F. Shea Construction**

Gripper TBMs

In the case of time-dependent ground behaviour, which is very common for squeezing conditions, a ground pressure may develop upon the machine during a standstill. In order to resume TBM operation, the thrusting system must be able to cope with the forces acting upon the cutter head and the shield. In order to move the TBM forward, the effective available thrust force must be higher than the frictional resistance (static friction). For restarting the rotation of the cutter head, the effectively available torque must be high enough to overcome the frictional and the rolling resistance of the cutter head. If the ground is weak and offers insufficient resistance to the grippers, the effectively available thrust force and torque will be lower than the installed ones, thus reducing the capability of the thrusting system.

Similar considerations apply when the TBM is boring, the main differences being that in this case, (i) the required thrust force includes the boring force (i.e. the force with which the cutter head is pushed against the working face) and, (ii) sliding instead of static friction has to be overcome. In weak ground, boring thrust force is generally low, while torque demand may be very high.

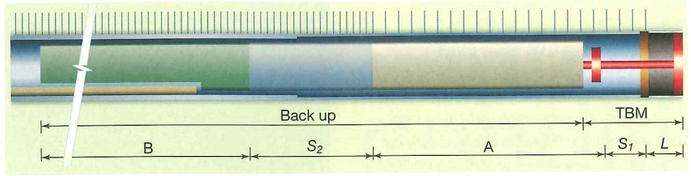
The locations where support installation is possible (S1 and S2 in Figure 5, page 18) are determined by the design of the tunnelling equipment: in the machine area and later in the back-up area at a distance of 30–60m behind the tunnel face (Maidl et al., 2001). Interventions outside these two sectors are not, as a rule, possible (this is a major difference between TBM tunnelling and conventional tunnelling, where interventions are possible practically wherever and whenever required).

In gripper TBM tunnelling, the zone between the first and the second support installation point (zone A in Figure 5) is particularly critical. In order to reduce the risk of problems in this area, the installation of a greater quantity of tunnel support may be needed in the machine area, thus leading, as a rule, to a slower TBM advance. Therefore, the selection of the type, quantity and location of support application represents an important

Above: **Figure 2, Single shielded TBM jammed in squeezing ground (Uluabat Tunnel, Turkey, Ø = 5.00m); the picture shows the ground, the shield (right side) and the segmental lining (left side) during operations to free the TBM. Picture courtesy of Werner Burger, Herrenknecht**

Above: **Figure 3, Jamming of the back-up equipment of a gripper TBM in squeezing ground (Gotthard Base Tunnel, Faido Section, Switzerland, Ø = 9.43m). The picture shows the converging ground touching the frame of the back-up trailer. Picture from Bockli (2008)**

Above: **Figure 4, Inadmissible floor heave and damage to the tunnel support in the back-up area of a gripper TBM (Gotthard Base Tunnel, Faido Section, Switzerland, Ø = 9.43m). Picture: Flury and Piller (2008)**



Above: Figure 5, Layout of a gripper TBM (Ramoni and Anagnostou, 2010b)

operational decision for a gripper TBM drive. As long as tunnel stability and working safety are not endangered, a trade-off between the excavation progress and the quantity of tunnel support to be installed just behind the shield is quite conceivable. Deciding to apply as little as possible tunnel support in the machine area, in order to proceed more rapidly, results, as a rule, in a lower support stiffness and bearing capacity and this may lead to problems in zone A, which may also slow down the TBM advance rate.

Single shielded TBMs

Single shielded TBMs are longer than gripper machines. As the shield surface exposed to the squeezing pressure is larger, a higher frictional resistance has to be overcome. The disadvantage of a longer shield is, nevertheless, outweighted at least to some extent by the fact that single shielded TBMs usually have a higher installed thrust force than gripper TBMs. Furthermore, as a rule, single shielded TBMs offer the advantage of a higher advance rate in poor quality ground and this too leads in general to a lower rock loading of the shield.

Instead of being thrust forward via grippers, single shielded TBMs are jacked against segmental linings. The structural design of the segmental lining plays an important role, as its bearing capacity (together with the design of the TBM) limits the effectively available thrust force and torque. The quality of annulus grouting near to the shield is also important, as a deficient backfilling of the segments may reduce the capacity of the segmental lining to handle the jacking loads.

Double shielded TBMs

Double shielded TBMs operating in the so-called 'gripper mode' install the lining simultaneously with the boring process and therefore, all other parameters being equal, achieve a higher performance than single shielded machines. In the case of time-dependent ground behaviour, a higher advance rate is advantageous with respect to the amount of shield skin friction to be overcome. Nevertheless, comparative studies should take account of the fact that double shielded TBMs are in general longer than single shielded TBMs, particularly for small diameter tunnels.

Furthermore, in weak ground, bracing by the grippers may become impossible. The operation mode has to be changed to the so-called 'auxiliary mode', where the machine jacks against the segmental lining. It is then no longer possible to install the segments simultaneously with the boring (unless a hexagonal segmental lining is applied). Depending on the machine design, unstable ground may also impair the extension and closure of the telescopic joint, thus necessitating single shield mode operation. In both cases (auxiliary mode and single shield mode), the same remarks apply as for the single shielded TBM, and the potential advantages of the double shielded TBMs mentioned above will be lost.

Countermeasures

If the geometry of a critical zone is known, the first option is to try to reduce the length of the tunnel crossing the zone by selecting another alignment. Other options to be evaluated may include the pre-treatment of the ground (from the TBM or from a pilot tunnel) or a conventional excavation of the critical zone (from an intermediate point of attack).

In general, the number and length of the critical tunnel stretches is an important influencing factor with respect to the technical feasibility and cost of a given measure (or package of measures) to counter squeezing. In the case of singular short fault zones, it is even possible to accept the risk of TBM jamming (and to plan possible TBM freeing works in advance). In the case of a very long section through squeezing ground, the possibility of selecting a larger boring diameter for the entire tunnel is also an option.

Design of the tunnelling equipment

In order to be able to cope with squeezing ground, the specific design of the tunnelling equipment (both the TBM and back-up) is very important.

Thrusting system

Nowadays, TBM technology allows for the installation of high thrust force and torque. According to the TBM technical data collected in Ramoni and Anagnostou (2010a), shielded TBMs with a boring diameter of about 10m can be equipped with a thrust force of up to 150–200MN and a breakout torque of 30–40MNm. As a rule, the thrusting system of gripper TBMs can exert a lower thrust force and torque (30–35MN and 10–15MNm, respectively). This is because the achievable reaction forces are restricted by the bearing capacity of the ground surrounding the grippers.

Cutter head

In order to facilitate unlocking, the cutter head should be rotatable in both directions. A moderate amount of squeezing can be accommodated by using one to three extendable gauge cutters.

This solution allows an increase in the boring diameter of up to 30cm (Wolff and Goliasch, 2003). However, this technology is not yet well developed and is of very uncertain value – at least for applications in long reaches of squeezing ground (ITA, 2003). Trouble-free application appears to be possible only in soft rocks. Timely decision-making during construction is another critical aspect. The determination of the right time-point for the start of the complicated overboring procedure is not easy under work site conditions.

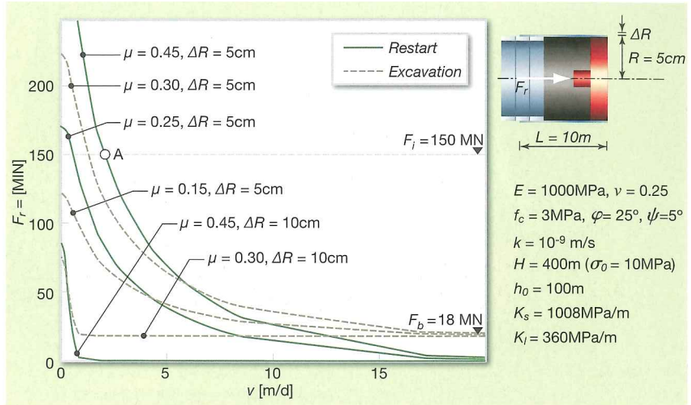
Shield

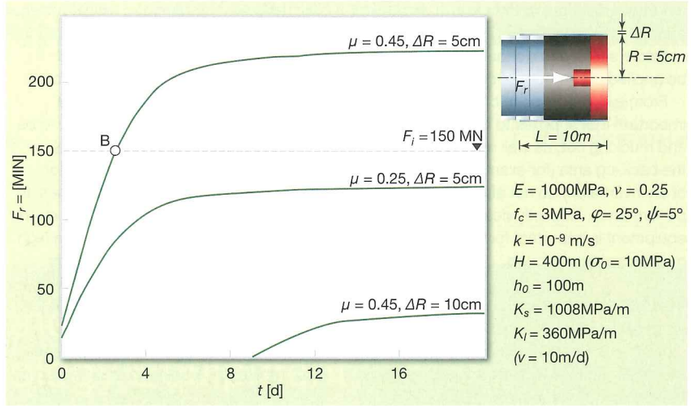
The length of the shield of gripper TBMs is generally short (about half a boring diameter). Improvements in TBM technology have allowed shield length to be reduced significantly (to about one–two boring diameters) for both single and double shielded TBMs. The shield can also be slightly 'conical'. The conicity of single shields amounts to 3–6cm in diameter and is realised stepwise. Depending on their design, double shields may have a slightly larger conicity of up to 10cm in diameter. The ground pressure acting upon the shield can be reduced if the shield is shrinkable. As of today, a solution such as this seems to be possible only for gripper TBMs. Lubrication of the shield extrados (e.g. with bentonite) reduces friction between the shield skin and the ground by up to 50 per cent (Gehring, 1996).

Back-up

Jamming of the back-up equipment is particularly critical, as it always leads to a halt of the TBM drive. The back-up trailers should therefore be small enough relative to the boring diameter to gain some space in case of unexpectedly high ground deformations in the back-up area, such as if the support measures installed do not suffice to prevent ground deformations.

Right: Figure 6, required thrust force Fr during regular TBM operation as a function of the gross advance rate v (after Ramoni and Anagnostou, 2011b).
Right, below: Figure 7, required thrust force Fr as a function of the standstill time t (Ramoni and Anagnostou, 2011b)





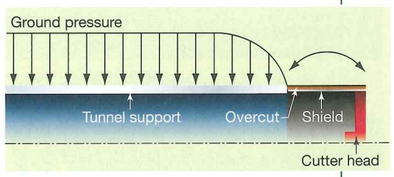
Theoretical investigations (Ramoni and Anagnostou, 2011b) have confirmed the latter statement. The example shown in the following refers to the hypothetical case of a 400m deep tunnel driven in weak ground at a depth of 100m beneath the water table. The tunnel is excavated by a 10m long single shielded TBM with a boring diameter of 10m. The segmental lining applied is 30cm thick and it is supposed to be rigid as well as perfectly backfilled.

Figure 6 (above right) shows the required thrust force Fr as a function of the gross advance rate v in a low-permeability ground ($k = 10^{-9}$m/s) during regular TBM operation. The curves of Figure 6 have been computed for two values of the radial gap size of ΔR = 5cm (normal overcutting) or 10cm (overboring). The dashed lines apply to ongoing excavation (the thrust force required for the boring process has been taken to be Fb = 18MN in this example), while the solid lines apply to a restart. The skin friction coefficient μ was taken to be 0.30 and 0.45 for sliding and static friction, respectively, according to Gehring (1996). Assuming that the installed thrust force Fi amounts to 150MN and that the radial gap size ΔR is equal to 5cm, the TBM would be trapped if v < 2–3m/d (point A in Figure 6). The required thrust force can be reduced to less than 100MN by overboring. This comes with the cost of possible steering difficulties, however, and reduced production rates. Besides the positive effect of overboring, Figure 6 allows to appreciate the reduction of the required thrust force when the shield extrados is lubricated (compare curves for μ = 0.15 or 0.25 with curves for μ = 0.30 or 0.45). The effect of lubrication is smaller than that of overboring in this example. However, as overboring may not be sufficiently reliable, a combination of these two measures would be required in order to mitigate the risk of shield jamming.

Operational measures

Tunnelling practice shows that maintaining a high advance rate and reducing standstill times may have a positive effect. In fact, several cases have been recorded of a TBM not becoming jammed until there was a slowdown or standstill in the TBM drive (Ramoni and Anagnostou, 2011a).

The positive effect of a high advance rate and short standstills is beyond doubt. However, it has to be kept in mind that, (i) high advance rates may be difficult to achieve (especially in poor quality ground), (ii) ground deformations may develop very rapidly and very close to the working face (Ramoni and Anagnostou, 2011a) and, (iii) standstills cannot be completely avoided. However, the frequency and the duration of standstills can be kept to a minimum through appropriate operational measures and construction site organisation, as well as by employing skilled workers.



Right: Figure 8, arch action in longitudinal direction around the shield in the presence of a rigid lining (Ramoni and Anagnostou, 2010b)

If a known critical zone has to be crossed, thorough maintenance work should be carried out in advance in order to reduce the risk of mechanical breakdowns and the necessary logistical precautions should be taken to allow operations within the critical zone to be as continuous as possible. Holiday periods (and, depending on local conditions, even perhaps the possibility and frequency of strikes) should also be taken into account. In the case of an unexpected critical zone, reducing the amount of maintenance work may speed up the TBM advance and temporarily help to avoid TBM trapping, but it will increase

Heavy support was frequently needed on the southern Gotthard sections, Bodio and Faido, where squeezing ground was a major challenge

the risk of mechanical breakdown and thus the risk of an even longer standstill. A measure such as this should therefore not be applied as a matter of course.

From a logistical point of view, it is very important that supplies to the machine area and mucking out, as well as all activities in the back-up area (for example the casting of an invert arch) do not affect TBM performance. Robustly designed back-up equipment is important for reducing mechanical breakdowns.

Tunnel support

According to Ramoni and Anagnostou (2010b, 2011c) and Ramoni et al. (2011), practically rigid segmental linings appear to be appropriate for shielded TBMs driving through squeezing ground. Precast segments are standard and exhibit a high resistance, therefore making it possible to accommodate relatively high ground pressures and thrust forces. On the other hand, the systematic installation of a deformable segmental lining has yet to be tested in practice. Deformable tunnel supports seem to be more suitable for gripper TBMs than for shield machines. In fact, the support measures installed during a gripper TBM drive do not provide a high resistance, while for yielding supports solutions similar to those for conventional tunnelling can be applied.

The installation of a stiff support immediately behind the shield improves load transfer by arching in the longitudinal direction (Figure 8, page 19). Therefore, the tunnel support – besides ensuring stability and limiting deformations of the tunnel – may also reduce shield loading (Ramoni and Anagnostou, 2010b, 2011c; Ramoni et al., 2011). This effect is more pronounced for short shields and stiff linings. On the other hand, the load developing upon a stiff lining installed immediately behind the shield is bound to be higher than the load developing upon a more deformable tunnel support.

Closing remarks

In the tunnelling community, there is a certain degree of controversy concerning the most appropriate machine type for coping with squeezing ground. Gripper TBMs are proposed on the grounds of their shorter length as well as their greater flexibility with respect to tunnel support. Single or double shielded TBMs are recommended because of their higher thrust force and torque as well as their high degree of industrialisation, which leads to higher advance rates.

There are no universally valid recommendations. Depending on the geological conditions, the advantages of one TBM type may or may not counteract the disadvantages of other types. A systematic approach is indispensable.

Acknowledgments

This paper is based upon the research project 'Design aids for the planning of TBM drives in squeezing ground' (Ramoni and Anagnostou, 2011a), which was carried out at the ETH Zurich, supported by the Swiss Tunnelling Society (STS) and funded by the Swiss Federal Roads Office (FEDRO).

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SCHAUENBURG MAB

When it all goes south

Tropical cyclones, government priority shifts and that nasty financial crisis sweeping the globe have all hit the tunnelling industry down under. Alex Conacher speaks with Ian Hosking of Aecom and Andrew Day of Thiess

In January 2011 Queensland was already reeling from two months of flooding when Cyclone Yasi slammed into it from the north. Financial advice company AMP estimated the losses to the economy due to flooding at AUD 30bn (USD 32.4bn), while the storm caused a further AUD 3.5bn (USD 3.8bn) in damages alone.

The obvious need to reallocate funds to disaster relief, coupled with a stimulus spending focus following the global financial crisis, means that public money is increasingly scarce.

The industry hits the ground running. Ian Hosking, industry director of infrastructure services for Aecom's Australasian operation points to the growth from 50 to 150 engineers in its core ground and tunnelling divisions over the last four years.

Andrew Day, chair of the Queensland Group of the Australasian Tunnelling Society and executive manager of engineering and estimating for Thiess points to the increasing value of projects. "We eventually reached the AUD 4bn (USD 4.28bn) Brisbane Airport Link project. It is currently our only tunnelling project in the field, and it is a massive single contract even for two of the country's largest tunnel contractors: Thiess and John Holland."

Hosking adds that there is still quite a good pipeline of work visible.

Focus shift

Day tells *T&TI* that roadheader popularity in Australia, where they possibly enjoy more widespread use than anywhere else, is largely due to Sydney. He says, "For the last 25 years, a large proportion of infrastructure tunnelling has been focused on Sydney. The rock there is pretty homogenous Sydney Sandstone with strength of around 30 to 50MPa.

"For this no lining is needed and you can cut economically in a arch shape. Roadheaders are well understood, and with improved cutterhead technology, and the new 300kW machines it is far more economical than other methods, and you can get started in just three months. It is very unlikely that someone would construct a tunnel in Sydney with a TBM."

Day adds, "Recently there has been a shift of focus to Brisbane with projects like Clem7 and the Airport Link, and most recently Legacy Way. Brisbane geology includes rock strengths upwards of 100MPa, which makes other methods worth considering. On the Airport Link however, the three-lane sections meant a 15.5m TBM would have been required, so it was still more economical to use roadheaders. In the two-lane sections where variable ground was anticipated, they used TBMs.

Hosking adds, "And now the North West Rail Link will be the next major project in the country, so the focus will switch back to Sydney." (See feature, page 34).

Political

Funding for civil infrastructure has dried up according to Day. "The 'warchest' of money has been diverted to stimulus following the global financial crisis and most of the state governments have limited resources. The Green Party also has control of the Senate, and is unlikely to support Federal contribution towards major road projects."

Despite this, Day argues that Sydney is in desperate need of investment in its underground road network. The M4 East extension was shelved in 2005 by a broke NSW government. It is a missing link in the network and the National Roads and Motorists Association recommended a tunnel option in 2011.

Although rail may be supported with Federal funding, Day points out Sydney rail is in dire need of upgrade and repair, with clear choke points identifiable. In addition, Australian cities are also well spaced, with large distances to cover to get from one side to another. The need for a car is clear.

Day adds, "While projects like Cross River Rail have been deferred due to the disasters, there's a Queensland election next month. Everything could change."

Rail support

"Our clients are most interested in underground rail," says Hosking. "So we are assembling teams to meet this demand. We can change the focus pretty quickly and focus elsewhere, but this is where we are currently. We've had to bring in foreign support, and also transfer experience from Cross River Rail in Brisbane over to the Sydney North West Rail Link. This link is one of the largest civil engineering projects in this part of the world.

"The industry is creating a lot of rail work, there's also the CBD rail project in Auckland, New Zealand, which is in the concept design phase and the completed Clem7 tunnel in Brisbane, which was a great bit of engineering but failed to generate the required traffic so the operator has gone bust."

Follow the money

LNG boom and Wheatstone

The liquefied natural gas (LNG) industry is seeing staggering growth according to Day. Further tunnelling is required to fuel the growth and the Wheatstone project is testament to this.

Tunnelling for the Wheatstone project will form the shore crossing, and at a diameter of 2.5m the 1215m-long drive is the longest pipe jack of its size in the southern hemisphere.

A Herrenknecht AVND2000AB machine was chosen because; according to a Thiess spokesman it is the best complete pipe jacking system currently available. It will be equipped with an SLS-RV guidance system. A double push jacking station will be used to allow three pipes to be installed and pushed in each jacking cycle rather than one. Eleven interjack stations will be employed.

At the end of the drive, the tunnel will transition into a pre-lay trunkline trench. The TBM exit pit marine works have been contracted to Independent Offshore Solutions. The TBM is equipped with a subsea recovery module. A Thiess spokesman said, "The module will be located in front of a custom-designed sacrificial pipe section [the first jacked pipe]

Lining for water ingress in Sydney Sandstone

Although Sydney sandstone needs no structural support, water ingress was going to be a problem in some areas. Hosking says, "Over the past several years, one of our clients, [electricity provider] Ausgrid was facing water ingress on its Sydney cable tunnel projects. In response to this, we brought in concrete segment technology from the UK, purely to keep water out."

Thiess has been awarded a contract to build the City East Cable Tunnel following its completion of the West Cable Tunnel in 2010. A spokesman adds, "The AUD 141M (USD 150.8M) contract covers construction of a 3.2km-long, 3.5m segmentally lined tunnel. Project completion is set for May 2015 when the tunnel completes the 'ring main' for Sydney's CBD, linking the South and West tunnels."

Left: Northern Sewerage Project success, photo courtesy of John Holland

and will be connected to the last TBM can. The sacrificial pipe section will be followed by the first jacking pipe with the attached steel bulk-wall, bolted at the front end. The module consists of slurry and air pipes entry/exit ports, airtight entry/exit lock and four hydraulic push cylinders/jacks, which are built in steel sleeves and can be activated from the recovery ports located outside the machine can.

The spokesman added, "The method of recovery will be by maintaining air in the tunnel. No flooding of the tunnel is envisaged. The last four jacking pipes will be manufactured with thick internal steel lining as well, and will be welded together in order to add extra weight and stiffness for counteracting the buoyancy."

To prevent seawater entering the TBM, pressure within the machine will be maintained at approximately 25 to 30 per cent above the surrounding marine pressure. The design construct contract value is AUD 60M (USD 64.3M).

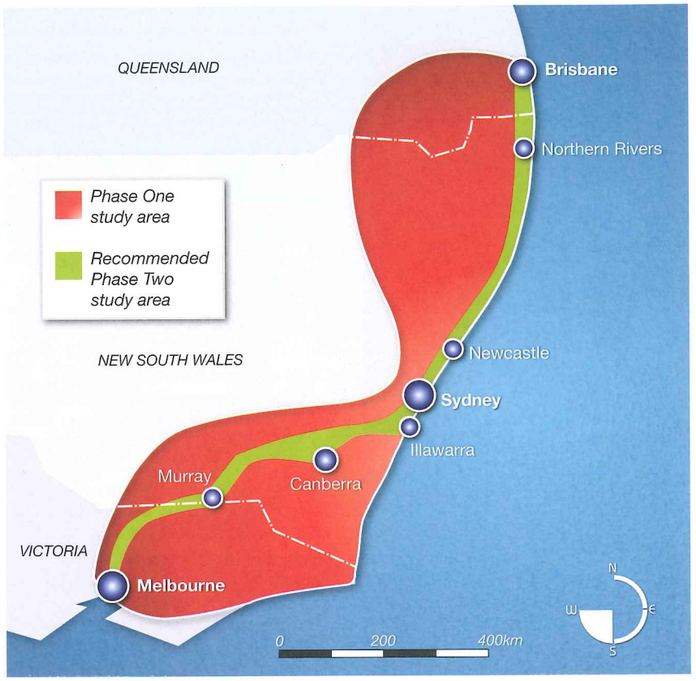
High-speed rail

"Aecom is working on a high-speed rail (HSR) feasibility study for the Federal Government and we are currently in the second phase [see Figure 1, above right]," says Hosking. "Identifying land that needs to be preserved for the future. HSR is new to this part of the world so it brings new considerations, including alignment requirements. We have drawn on the experience of the UK, Spain and China."

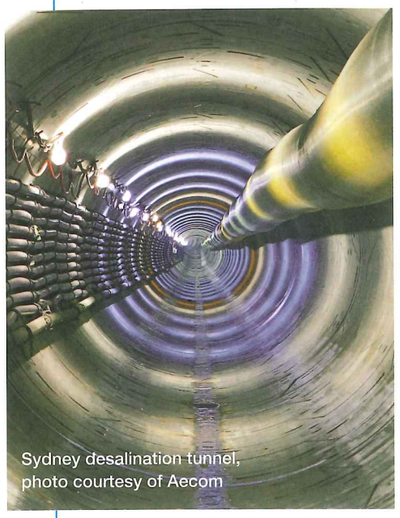
The interim report was released in 2011. A spokesman for the Minister for Infrastructure and Transport called HSR a game-changer in easing congestion and 'integrating communities'.

The project cost will run between AUD 61bn (USD 65.9bn) and AUD 108bn (USD 116.72bn) for the 1,600km route linking Brisbane to Melbourne via Canberra, Sydney and other regional centres. The study envisions 54 million passengers by 2036.

The Aecom-led team carrying out phase two of the study also includes: KPMG, SKM, ACIL, Tasman, Booz & Co, Hyder and Grimshaw Architects. The interim report can be downloaded from:. www.infrastructure.gov.au/rail/trains/.



Above: Figure 1, HSR study areas



Sydney desalination tunnel, photo courtesy of Aecom

Health and safety

The strong health and safety emphasis in Australia is well known. Sandvik global environment health and safety director Stuart Evans tells *T&TI* that the stringency has risen from a mining industry in Australia that could have performed better in the past, though he adds that real progress has been made and the situation is improving.

Day says, "We find that the industry is coming under ever increasing safety scrutiny. The Brisbane projects are currently subject to increased attention due to a recent fatality, with our Code of Practice having just been tightened up in a few areas. Something our authorities grapple with is: 'is tunnelling the same as underground mining?' We say: 'no, it isn't'."

Hosking adds that the cultural demand exists for strong regulations and that it is a government focus. "The incredible thing in Australia is the extent of the consultative process that goes on, with fire brigades and so on – you need to make sure absolutely all the stakeholders are on board."

Into the future

Day is concerned that Australia may see a lull in tunnelling over the next three to five years, with some resources shifting north to Asia. He adds, "It's important to have continuous work. Having developed the skills in the industry, governments should go out of their way to ensure they are maintained, or it may be lost overseas. You must maintain the critical mass."

Hosking says, "Growth is not as strong as it was prior to the global financial crisis and there were more projects mooted at that time. Funds have been diverted, but we are actually gaining momentum in terms of planning studies going ahead.

"It will be a major concern if the fall in the global economy has an impact on our mining industry, which will reduce tax income. But I'm positive about the future for tunnelling in general."

John Holland

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Historic Melbourne sewer replacement

Replacement of the Melbourne Main Sewer required tunnelling through the challenging Yarra Delta. Nick Lewis, John Holland project manager, and Adam Gorny, John Holland tunnel manager, report

The Melbourne Main Sewer Replacement (MMSR) was featured in *T&TI* in 2008 when the project commenced (*T&TI* September, page 17), again at the midpoint in 2010 (*T&TI*, June, page 27) and now in 2012. This third instalment completes the story of this remarkable project, which is set for commissioning and completion in the first quarter of 2012, ahead of schedule and within budget.

In 2005, client Melbourne Water together with the project partners: contractor John Holland, designers GHD and project manager Aurecon, took on the challenge of replacing a section of Melbourne's century-old main sewer. Replacing 2.3km of the main sewer required robust risk management procedures, lateral thinking and innovative solutions to overcome the multitude of challenges presented.

MMSR ventured into the notorious Yarra Delta geology for the first time since the late 1800s. In addition to providing valuable insights into the geology and hydrogeology for future of tunnelling projects in Melbourne, the MMSR has delivered an on-grade wet cofferdam crossing of the Yarra River, excavated 35 shafts using a variety of methods, and utilised five different boring machines to construct a total of 4.2km of new sewers.

John Holland's project manager, Nick Lewis shares his insights on some of the key lessons learnt as he reflects on four years of construction on the MMSR. "It hasn't been plain sailing on the MMSR," says Lewis. "Despite best intentions to plan and mitigate for every eventuality, our situation often called for innovative solutions to solve difficult problems, but I'm proud to say we rose to the challenge each and every time."

Hydrogeology – to drain or not to drain

One of the first lessons on the MMSR was learning to manage the potential risk of settlement due to depressurisation at the project's first shaft site at Fennell Reserve, Port Melbourne. Temporary works incorporated a secant pile wall design through soft geological units into highly weathered basalt. This first shaft was designed as drained, with a maximum water ingress set at two litres per second, and any flows greater than this requiring further review.

In December 2008, secant piling and shaft excavation was going according to plan, and ingress measurements remained below the set rate. Upon reaching the basalt formation at the base of the shaft, water ingress increased and monitoring data from the surrounding area showed evidence of settlement. Though not above pre-set alerts for settlement, this event was worthy of further examination, especially considering monitoring points showed it was above a deep channel of Coode Island Silt.

Taking a determined step, the team opted to flood the shaft over the Christmas shut-down period. What followed was an intense period of investigation and review, whereby the team identified the need to understand and establish the hydraulic connectivity of the shaft's localised geology. "We needed to consider our groundwater monitoring systems for depressurisation, and devise a plan for how we were going to complete the shaft," says Lewis.

Information from inflow rates and existing groundwater monitoring systems was used to develop two- and three-dimensional hydrogeological models. These models were used to conduct settlement assessment on a number of recovery solutions for the shaft. To determine the strata interfaces, 14 strategically positioned boreholes were drilled local to the shaft to house vibrating wire piezometers. Data

Right: Figure 1, Melbourne in Australia
Below: Figure 2, alignment map showing existing main sewer and new sewer

Above: Works included delivery of an on-grade wet cofferdam crossing

obtained from the piezometers was used to calibrate the models and checked against actual settlement figures recorded from around the shaft. Additionally, a full recharge system was designed and built around the perimeter of the shaft as a contingency measure.

The recovery of the Fennell Reserve shaft was successful and shaft construction was completed in April 2009. The experience highlighted the sensitivity of the ground to depressurisation and all of the further temporary works design accommodated this risk. The information gathered through this process provided a clear hydraulic picture for the local area, which will undoubtedly prove useful in the planning, design and option selection for future construction projects in the Yarra Delta.

Yarra Delta tunnelling

The soft geology of the Yarra Delta has been notoriously problematic to the construction industry in Melbourne. Historic data collated by Melbourne Water shows difficulties with ground support, water ingress, tunnel alignment and settlement were all encountered during the construction of the original Melbourne Main Sewer in the 1890s.

To overcome these foreseen challenges, Melbourne Water sought early contractor involvement (ECI) to ensure a buildable solution was developed during the design phase. The design of the main tunnel alignment was painstakingly mapped-out to avoid a myriad of obstacles, including structures, third party assets, building piles and bridges. This resulted in an alignment that snakes its way under Melbourne's city fringe and includes a number of relatively tight 250m curves.

During the excavation of the 1.2km southern tunnel drive, steering the tunnel boring machine (TBM) through Coode Island Silt proved as difficult as predicted. Due to the concentration of weight at the front the 103m, 164t TBM corrections to grade were tough to generate, while line corrections on the alignment's curves proved erratic.

In steering the TBM on the southern drive, the thrust offset required to make a line correction only needed to overcome ground friction and shear strength of the material. In Coode Island Silt this was challenging – only a very small change in thrust offset could change turning rates due to extremely low coefficient of friction and low shear strength of the material.

To effectively excavate positive grade on the 875m northern drive, the MMSR team worked with TBM manufacturer, Caterpillar, to modify the TBM's steering response. A reduction in the size of the cutting wheel slowed the extremely high advance rates and maximised the vertical thrust offset to generate an increase in positive pitch. These changes resulted in a greater control for level corrections as net-positive pitch was generated quickly and consistently.

The final design of the main tunnel utilised two forms of lining as a means of correcting the final sewer grade within the tunnel if steering difficulties were encountered with the TBM. The primary lining consisted of steel fibre reinforced (SFR) concrete segments installed by the TBM, and the secondary lining consisted of glass fibre reinforced plastic (GRP) pipes were independently installed and grouted at the completion of the tunnel excavation.

In total, 580 sections of 1.8m diameter pipes were installed in 3m and 6m lengths to line the new 2.3km sewer tunnel. Around 6,000 cubic metres of grout was used to fill the space between the GRP pipes and the 2.4m diameter concrete lined tunnel.

During the course of the tunnel excavation several other major engineering challenges were successfully overcome by the tunnel construction team through detailed planning, engineering, and risk management. These included the development of:

- An active bentonite support system for the TBM shield to prevent closure of the overcut gap and to minimise settlement.
- An automated plenum bentonite injection system designed to monitor and maintain face pressures during tunnel excavation and day-work only stoppages. This included real time monitoring, email and SMS alarm notification service.
- An airline breathing system designed to provide all TBM personnel working with breathable air at all times. As higher than expected concentrations of Hydrogen Sulphide gas were encountered, the forced tunnel ventilation system could not dilute quickly enough.

Pipe jacking methods

Along with the 2.3km of main tunnel, the MMSR also includes the construction 1.9km of smaller diameter branch and reticulation sewers. The risks and challenges associated with these works were the same as constructing the main tunnel, and the team had to put in as much effort, if not more, to manage the different parameters of each drive.

Lewis says, "We didn't always get our machine selection right the first time, particularly when passing between differing geological units, but we learnt quickly and developed a thorough understanding of machine interaction in all types of strata."

Crossing Yarra River

The original concept planning, which involved tunnelling under the Yarra River, proved unfeasible due to the extremely soft silts and low cover. Working together the MMSR project team planned a three-stage wet cofferdam construction sequence.

With a tight time frame, close collaboration between design teams and the involvement of specialist personnel lead to the development of a simple and cost effective solution.

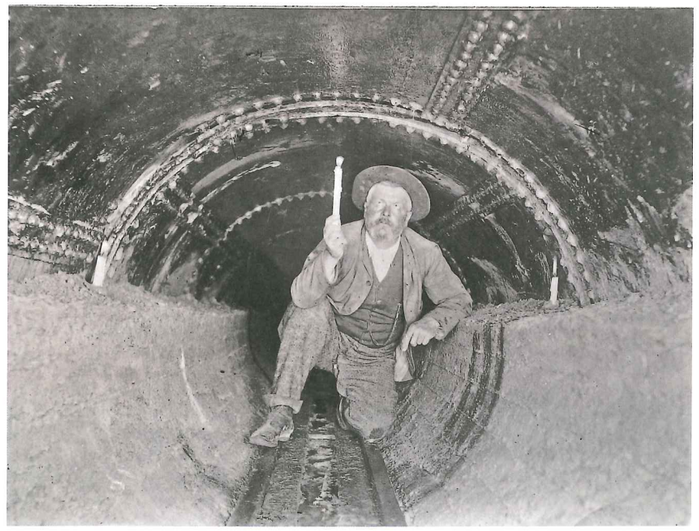
Digital and real life prototypes ensured that the process was fully understood and clear communication maximised the safety of personnel involved. The team followed robust risk management procedures throughout the river crossing.

The 140m, on-grade crossing of Melbourne's iconic Yarra River was completed in February 2011, following the installation of the final section of 2.4-metre diameter pipeline.

During construction, two-thirds of the Yarra River remained open to river users, while specialist divers worked in zero visibility conditions to install sections of pipe within the wet cofferdam.

The journey which commenced in mid-2009 culminated in a walk-through of a dry, gun barrel straight conductor pipe was a highlight for the MMSR team. Lewis adds, "The river crossing design and construction success is attributable to the great collaborative team approach and stands as a best-practice example of wet cofferdam construction technique, both for Melbourne and internationally."

Below: Working on the original sewer tunnel in the 1800s



Bypass pumping – contingency upon contingency

The bypass pumping set-ups used at both the northern and southern connection points of the existing sewer were a first for John Holland and the Australian industry. As the sole outlet for Melbourne's sewage, contingency for bypassing the existing main sewer needed to be iron-clad to avoid the potential risk of flooding Melbourne's CBD and public transport hub, Flinders Street Station.Bypassing the entire city's sewerage was a big job and required systems which could handle peak wet weather flows of 1000 litres per second. The systems utilised were in fact designed so that the peak flow stipulated included 100 per cent redundancy in pumps, with automated switch and rapid retrieval, and 200 per cent redundancy in power supply.

Additionally, works included full-time telemetry and full-time on-site personnel to monitor the systems. Plus, if all else failed, works were sequenced in a manner that allowed the shaft to be evacuated and flows to pass through the incomplete works, with no safety or environmental impacts.

Since August 2011, the pumps have bypassed over 3.5bn litres of the city's sewage, Lewis reports. Throughout construction, the MMSR has attracted a great deal of attention from the industry. "We had three papers accepted for the Australasian Tunnelling Society conference in New Zealand last year. These papers demonstrate our commitment to sharing experiences gained on the MMSR for the benefit of the industry".

An overview of pipe jack machinery used on the MMSR

- 1 x 2.1m diameter Herrenknecht pipe jack EPBM – used in Coode Island Silt to overcome steering difficulties experienced during construction of the segmentally lined main tunnel.
- 1 x 300-500mm diameter Akkerman pilot tube ground boring machine (GBM) with powered cutting head (PCH) – used to achieve alignment confidence, fast production rates and no muck treatment costs.
- 1 x 300 and 1 x 500mm diameter Herrenknecht microtunnelling machine with slurry removal (AVN) – Bentonite slurry used to control sand inflows, making these machines perfect for dealing with Port Melbourne Sands.

Auckland's big dig

With a 14.1m diameter TBM, New Zealand is looking to join the tunnelling big league with Auckland's Waterview Connection highway project. Rhian Owen reports on the project that aims to ease congestion in the growing city

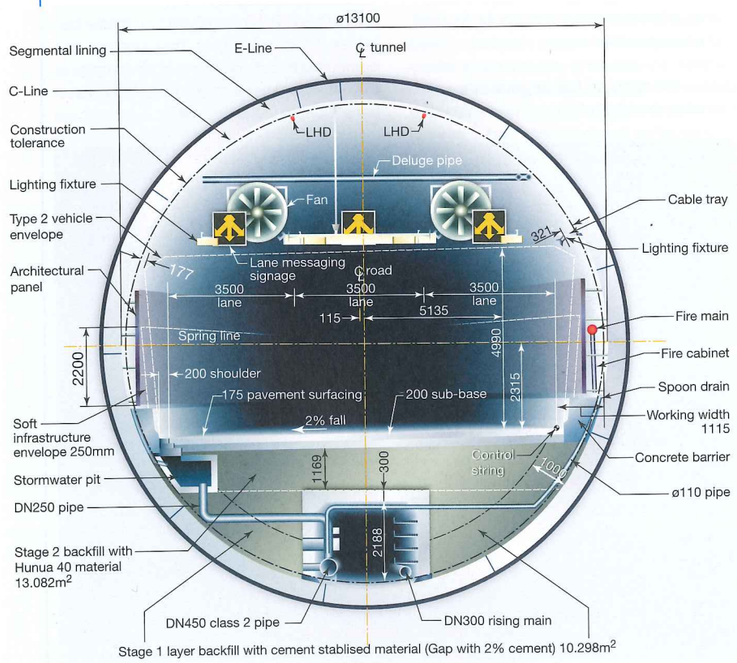
On Wednesday 1 February 2012 Ramonah Patience Toomalatai was born at Middlemore Hospital, the largest hospital in the Auckland region, and was anointed as the city's 1.5 millionth resident by the council and hospital staff. There are now predictions that the city's population will hit the two million mark in less than 20 years.

Auckland is growing at almost twice the rate of the rest of New Zealand and one of the greatest concerns is the city's traffic problem. Time-wasting traffic jams and hour-long commutes are only expected to worsen – Auckland Council has recently stated that motorist travel is forecast to increase from around four million trips per day in 2006 to around 5.5 million trips per day in 2041.

In 2002 the New Zealand government began an investment programme for Auckland's transport infrastructure. The country's biggest and most complex road project - Auckland's Waterview Connection – is due to be completed by 2017. The project is expected to reduce congestion by about 14 per cent by 2021.

The Waterview Connection will provide the final link in Auckland's Western Ring Route (WRR). It will connect the Southwestern Motorway (SH20) at Mt Roskill to the Northwestern Motorway (SH16), providing a 48km motorway. In early 2009, the government announced it as one of the seven 'Roads of National Significance', because it will improve transport links and contribute to the country's economic wellbeing.

Below: Figure 1, the project comprises 2.5km of 14.1m-diameter twin bore tunnels



engineering companies with the world-class tunnelling expertise of its international partners. This arrangement allowed the alliance to produce a competitively- priced bid that promises delivery of a world-class project with a distinctly Kiwi accent."

Together with the NZTA, Well-Connected will be responsible for constructing nearly 5kms of new motorway that includes the tunnels and interchanges that will connect the Southwestern and Northwestern motorways. Half of the new motorway will be underground; traffic will drive through two three-lane tunnels, which will be a first for New Zealand.

It is also one of the country's most challenging tunnels to-date – 2.5km of 14.1m diameter twin bores. The tunnels will be 13m apart and have a 13.1m internal diameter. The tunnel has a maximum gradient of five percent. Tunnelling on the Waterview Connection is expected to commence in early 2014.

Parker says, "The twin tunnels pass underneath the predominantly residential West Auckland suburbs of Mt Albert and Waterview along an alignment that also includes a major supermarket and a service station."

Going under

The WRR has been a highly contentious issue since it was first mooted with various community, environmental and business-oriented groups demanding a variety of forms. "The most vocal of the groups was the "Tunnel or Nothing" residents' group, however the project's final form - half tunnel, half over ground – reflects a balance between economic, environmental and community imperatives," says Parker.

The option to tunnel rather than provide an over ground motorway link reflects local public preference and demonstrates a balance between contributing to Auckland's economic development and meeting the needs of the surrounding communities; the final route is the result

Below: Figure 2, eastern end of the Waterview Connection project

Above: **Figure 3, south portal concept**

of sifting through more than 100 original options to create a practicable solution. In addition, the project's environmental management plan will not only cover the mitigation of the tunnel operation but will address how the team can shrink its own carbon footprint through the construction process.

"To ensure that community concerns were appropriately considered, consent was sought through the country's Environmental Protection Authority (EPA)," notes Parker. "The EPA referred the application to a board of inquiry, which heard an extensive array of public submissions before approving a framework for the project to proceed. This framework incorporates a significant amount of community-focused elements such as walking paths, cycle paths, parks and restoration of derelict heritage areas. The multi-level interchange that connects the new stretch of motorway into State Highway 16 traverses a heritage area, therefore the design has to leave a minimal footprint and facilitate interpretive regeneration of this area."

Another challenge the team faced is that in New Zealand the land is owned to the centre of the earth. The tunnel runs 85 per cent under existing open space and roads with the remaining 15 per cent impacting about 160 private properties. "Where the tunnel passes beneath private residences or businesses, sub-strata property agreements have had to be struck with the owners," says Parker.

Parker also explains the difficulty the team faces in terms of the geology: "One of the most significant challenges is that the region's volcanic heritage means that the custom-built EPBM will have to reach a depth of [at least] 40m to pass beneath the layers of basalt."

Indeed, the tunnels run through difficult terrain and must stay within the East Coast Bays Formation, a soft rock that includes sandstone and limestone, below the layers of basalt. At the northern end, the tunnels pass through saturated silts of the Tauranga Group.

When it became clear that the Tauranga Group deposits at the north end were unsuitable for open-face excavation. The team proposed using closed-face TBM technology as well as extending the original length of the tunnels to stay in bored tunnel through the materials and underneath a major arterial road. EPBM excavation with appropriate conditioning agents to ensure the soil remains workable, will be applied to the full 2.5km length of the tunnel.

Parker adds that NZTA and Well-Connected are keen to reduce the affect on Aucklanders when excavating. "To manage the impact on the local community, and in particular on local roads, all spoil from the tunnel excavation will be removed via a haul route through the site that connects to the current end of the motorway."

Size matters

In addition, the size of the EPBM puts New Zealand in the tunnelling 'big league', as it will be the 11th largest machine created to-date globally; it will have a 14.1m diameter and weigh approximately 3000t. Parker explains the decision to opt for EPBM: "Initially it had been envisaged that the final part of the tunnel would have to be built via cut and cover, which would have resulted in three years of disruption on one of the region's busiest commuter roads," he says. "The use of EPBM, however, allows the tunnel to be bored underneath the road, significantly reducing the impact of the project on local traffic during construction."

In operation

The ventilation shafts were an extremely hot topic throughout the planning stage. Longitudinal ventilation systems will be used; the exhaust gases of the vehicles that use the tunnels will vent upwards through a ventilation shaft.

"The northern tunnel portal is in close proximity to a primary school and kindergarten, therefore the local community is extremely sensitive to the management and mitigation of environmental and visual effects associated with the tunnel ventilation system," says Parker.

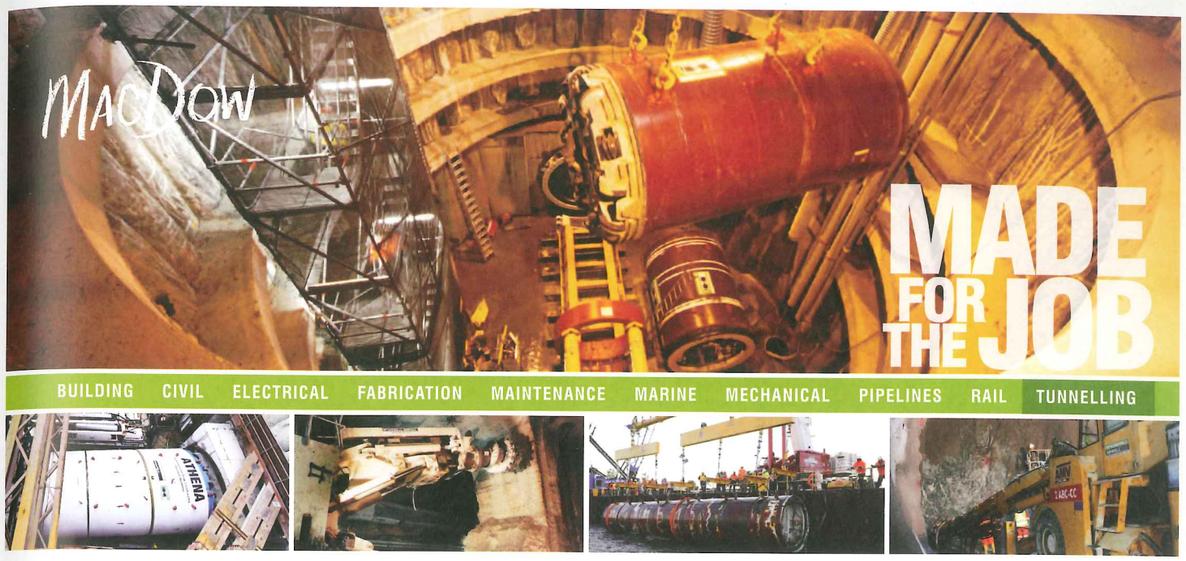
The northern tunnel exhaust tower will be built on the east side of Great North Road, further away from the primary school than planned, at an extra cost of NZD 29M (USD 24M). The southern tunnel exhaust will be built in Owairaka, 70 to 80m south-east of the NZTA's preferred site, away from a narrow chokepoint in Alan Wood Reserve, at an extra cost of NZD 21M (USD 17M).

The tunnels will also have a high-pressure water deluge fire response system, and vehicles carrying hazardous goods will be banned from the tunnel and directed to alternative surface routes. Other safety measures put in place for the tunnel include cross passages at 150m centres to move people from one tunnel to the other if there is an emergency, sensors to monitor light and smoke and CCTV cameras.

Within the project budget, tunnelling accounts for over two-thirds of the Waterview Connection's NZD 1.4bn (USD 1.2bn) total, and is by far the largest and most costly project the NZTA has undertaken. It is also the country's largest and perhaps toughest tunnel to date.

"To put it into context," concludes Parker, "the last two new stretches of State Highway to be tunnelled in New Zealand were respectively 330m long Johnstones Hill tunnels on the Northern Gateway Toll Road – a section of State Highway One north of Auckland – and the 450m-long Victoria Park tunnel on State Highway One in central Auckland."

The tunnel is expected to be operational before the end of 2017.



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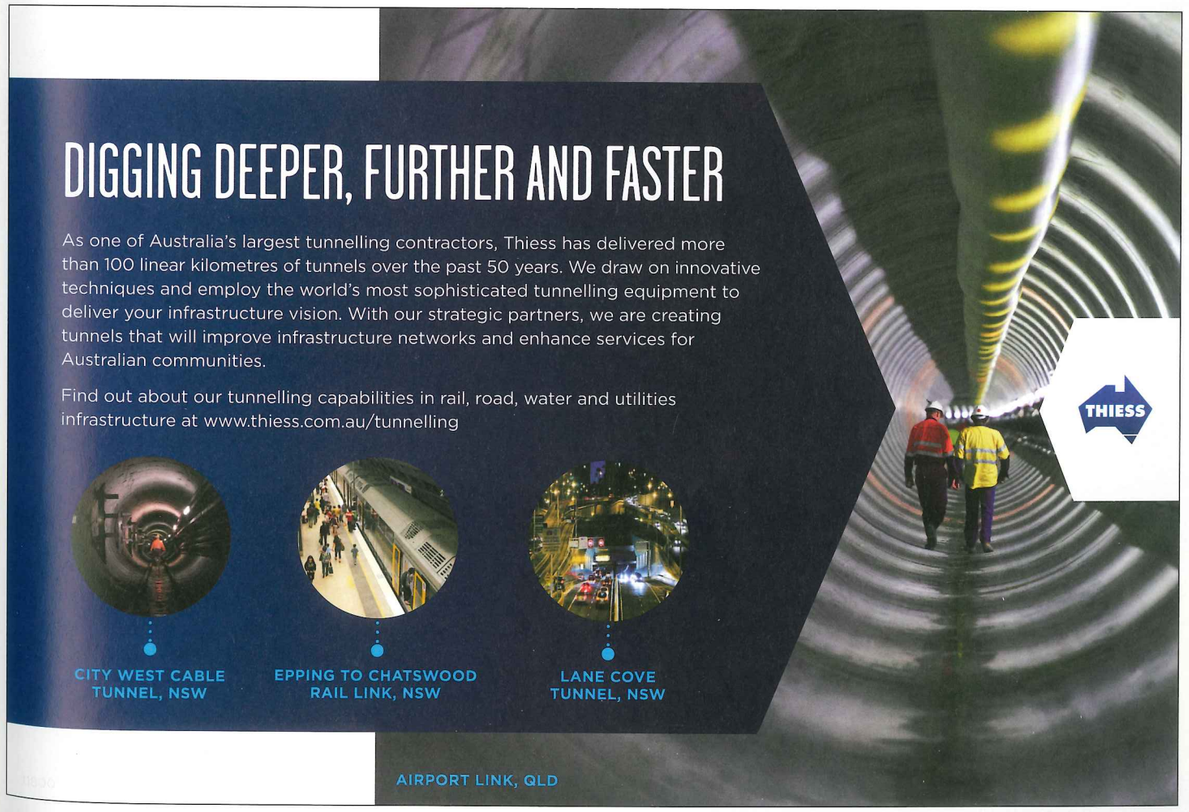


Breaking ground

on tunnel pledge

A new government in New South Wales setting out to prove its commitment to transport infrastructure is pressing ahead at full speed with what will be Sydney's longest ever rail tunnel, Kevin Walsh reports

During the state government elections for New South Wales, Australia in March 2011, the incumbent Australian Labor Party suffered a landslide defeat, ousted by a Liberal and National party coalition.

Led by Barry O'Farrell, the new coalition government came to power with a number of popular campaign promises involving the improvement of transport infrastructure and services across the state.

Prior to the last Federal elections in 2010, the Australian Labor government announced that it had allocated AUD 2.1bn (USD 2.2bn) in funding for a rail link between the suburbs of Parramatta and Epping in New South Wales.

However, as this plan had originally been proposed by the Australian Labour Party back in 2003—by former New South Wales premier Bob Carr—before being scrapped, many were sceptical the scheme was simply a Labor re-election tool rather than a concrete plan.

Capitalising on the Labor Party's indecisiveness on transport infrastructure planning, the coalition government of New South Wales pledged to prioritise a new rail link, between Epping and Rouse Hill, that it says will go ahead regardless of whether Federal funding is switched from the now deferred Paramatta–Epping Rail Link (PERL) to this project, the North West Rail Link (NWRL).

The state government estimates say the project is likely to cost anywhere between AUD 7.5bn (USD 8.1bn) and AUD 8.5bn (USD 9.1bn), and has allocated AUD 314M (USD 338M) of funding for this fiscal year, with another AUD 2.5bn (USD 2.7bn) provisionally earmarked for the project over the next four years.

Along with financial services firm Ernst and Young, who has taken on an advisory position on the project producing a long-term financing strategy and developing cash flow and revenue models, consultant Turner and Townsend has been selected to manage the project purse and ensure the best use is made of taxpayers' money.

The project is expected to support 16,200 jobs during construction and result in a AUD 25bn (USD 27bn) injection into NSW economy, according to the state government.

This 23km-long North West Rail Link will serve a regional population of around 360,000, but the state government is attempting to future-proof the plans to accommodate population growth in the region, which is expected to increase roughly 35 per cent to 485,000 by 2021 and to more than 600,000 within 40 years.

Australian Architect Hassell has taken on the task of producing the masterplan for the project while Aurecon Australia will be in charge of integrating the North West Rail Link with New South Wales' existing transport infrastructure.

To help achieve this the transport department for New South Wales has already applied for planning permission to change the originally proposed alignment, which featured Rouse Hill, Kellyville, Norwest, Hills Centre, Castle Hill and Cherrybrook as the six stations along the route.

Now, in addition to two extra stations, one at Cudgegong Road in Rouse Hill and another at Bella Vista, a 4km-long Skytrain is being proposed for the section of the rail link running between Rouse Hill and Bella Vista. The transport department has also specified that the NWRL must feed into Sydney's existing CityRail transport links to Sydney's central business district.

In the ground

As the topography of the land between Cudgegong Road and Bella Vista is fairly flat, planners fear that the addition of a rail link will not only bisect the local community but also have a significant impact on the existing road traffic network and pedestrian

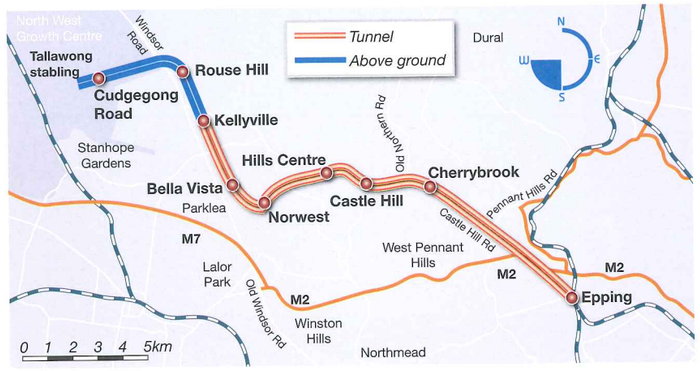
footpaths. It is hoped that the Skytrain will provide a more cost-effective solution while minimising the impact of works on the local environment.

For the 15km section between Kellyville and Epping, the steep topography means that tunnelling below the hills of the region is the most cost-effective way of providing the rail link. The resulting tunnel will be the longest rail tunnel ever constructed in Sydney's history.

In July 2011 a consortium, headed by Aecom Australia and including Parsons Brinckerhoff, Cox Architects and Grimshaw Architects, was appointed to provide engineering, rail systems and architectural services for the scheme.

Investigation of the ground conditions started two months later, in September last year, and are still underway, with consultant Coffey International's subsidiary Coffey Geotechnics performing test drilling operations along the route.

Ground conditions along the proposed route are largely expected to consist of sandstone, for approximately 60 per cent of the route, with shale making up the remaining 40 per cent.



Above: Figure 1, the 23km-long NWRL will serve a current regional population of approximately 360,000 people

Coffey Geotechnics senior geologist, Max Foweraker, has been overseeing drilling of the 150 boreholes needed to assess ground conditions along the route, with core samples of rock taken from each drilling site for further laboratory testing and analysis.

As *T&TI* goes to print, Foweraker says that testing is still ongoing, despite the initial expectation that investigations would be completed by the end of 2011, and seems convinced that testing will continue for some time yet.

However, with tunnelling work on the project not scheduled to begin until 2014, there will be ample time for further consideration of the route if changes are dictated by the ground conditions.

Highlighting the importance of the ongoing geotechnical analysis in determining the final alignment of the 15km between Kellyville and Epping, New South Wales minister for transport Gladys Berejiklian, says, "More detail of the underground conditions is required for the planning and design work which is now underway. Detail about rock type, geological fault areas and other underground characteristics will be particularly important to help finalise the civil design for the 15km of tunnel between Epping and Kellyville, and also for the remainder of the route.

"The North West Rail Link project team will work closely with local communities while the test drilling work is underway. Wherever possible, the site investigation work will be carried out on public property and during normal construction work hours. The geotechnical work will assess all underground conditions to confirm rock and other subsurface conditions deep beneath the region's streets and its suitability for tunnelling.

"This work helps produce a very detailed picture of what the tunnelling contractors will encounter as they build Sydney's longest rail tunnels.

Speaking at a briefing on the rail link for representatives of private sector firms interested in the project, Berejiklian comments on some of the few details supposedly set in stone:

"The NSW Government has confirmed three key parameters for the North West Rail Link—it will be a heavy rail line between Rouse Hill and Epping, tunnelling work will start in 2014 and services will be able to run to the Sydney CBD."

Top left: The NWRL will boast the longest ever rail tunnel in Sydney
Centre left: The NSW Government has applied for permission for eight stations
Below left: Heavy rail services will run into the Sydney CBD

Project team

Design services:
- Aecom Australia
- Parsons Brinckerhoff Australia
- Cox Architects
- Grimshaw Architects

Financial oversight:
- Ernst & Young

Cost planning services:
- Turner & Townsend

Master planning and urban design
- Hassells

Integrated transport & land use:
- Aurecon Australia

Scheduling and programming:
- Tenix Australia

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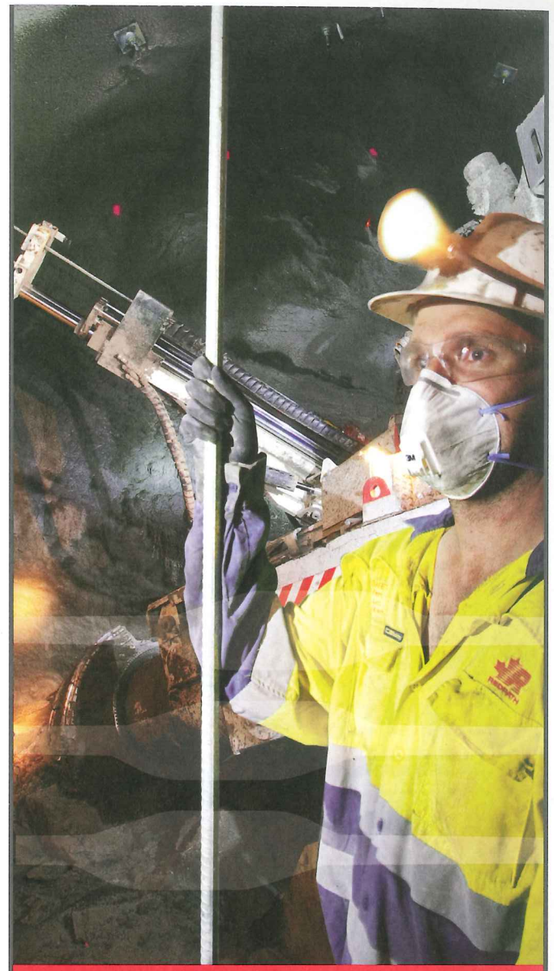

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Victory at Victoria

The Victoria Park cut and cover tunnel in Auckland, New Zealand is the city's first urban road tube and this month will be fully opened, early, to remove a traffic bottleneck, reports Patrick Reynolds

This month will see completion of Victoria Park road tunnel scheme in Auckland, New Zealand, three months earlier than had been envisaged. The state-funded scheme has also finished more than a year sooner than the client – NZ Transport Agency (NZTA) – thought might be possible before procurement got underway. This is thanks to an alliancing approach tied to more funding coming sooner from the state.

The first two lanes of the three-lane tunnel link went into operation in November last year, shortly after a big gala charity dinner held underground. The last lane has just come into service along with the rest of the improved parts of the northbound motorway to finish the NZD 340M (USD 284M) scheme.

Victoria Park Tunnel was one of the first projects to benefit from the decision to increase road spending and, having already dealt with the investigation and planning phases, was well placed to look at accelerated delivery. The alliance saw NZTA come on board with four partners – contractors Fletcher Construction and Higgins Contractors and consultants Beca Infrastructure and Parsons Brinckerhoff – and together they formed Victoria Park Tunnel Alliance (VPA).

The flexibility borne of alliancing was vital to help compress the timetable for delivery of the key infrastructure, the core of which was the 450m long cut and cover tunnel section.

Placing that three-lane, bypass box structure in the heart of the mature city called for complicated surgery and logistics to take northbound traffic off the heavily-congested, 50-year old viaduct bridge and put it underground in the historic inner city park, which had variable ground, vital main utilities and a heritage structure in the way.

The successfully executed works were characterised by progress being achieved in apparent piecemeal fashion. With a seemingly non-linear approach to building the tunnel there were multiple work faces. The tunnel was in different stages of construction and commissioning in different areas at any one time.

Need and preparation

State Highway One carries 150,000 vehicles per day as it passes over Victoria Park and was a long-standing bottleneck for country's largest city. Removing the blockage is not only critical for the current transport headaches but also because the rate of population growth means that, unaddressed, it was going to get worse with consequent impacts on the community and economy.

NZTA was established in 2008, combines the functions of Land Transport New Zealand and Transit New Zealand to provide an integrated approach to planning, funding and delivery of transport schemes. One such transport challenge was how to resolve the congestion of the motorway system at Victoria Park. Above ground solutions were explored in early planning but adding a tunnel for northbound traffic was seen as the best way to add capacity while preserving green space and increasing amenity for the local area.

Various studies were undertaken over 2001-5, following which statutory approval was sought to build the tunnel – having a covered length of 450m, and a total of 250m of uncovered approaches at the portals – as part of a 2.2km long scheme, which would also reconfigure the four-lane viaduct to solely carry southbound traffic while getting an extra lane. There would also be bus lanes added between Victoria Park to Auckland Harbour bridge. To undertake the works on what would be Auckland's first road tunnel, a Resource Consent was required.

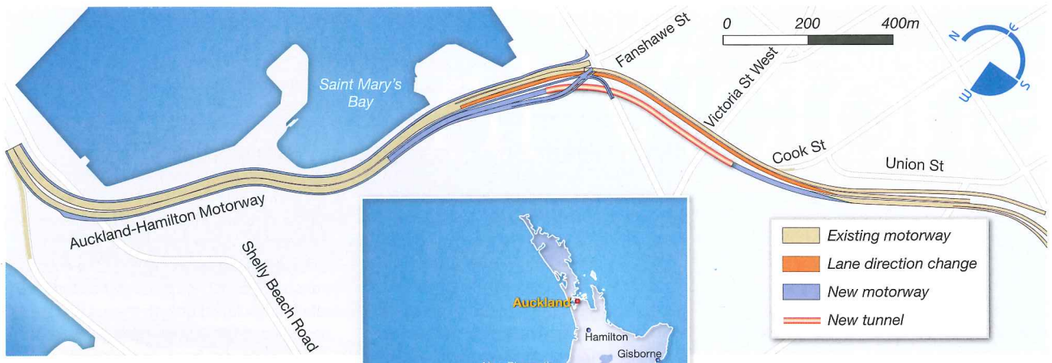
By 2008 preliminary work was underway on the reference design, which helped to firm up the budget and prepare for the procurement phase. The decision was to seek design and construct bids. The reference design, though, was not built as the alliancing approach was ultimately pursued for delivery of the scheme.

Up until then, site investigations were undertaken periodically.

VPA was formed in mid 2009 and took a fresh approach to development of the preliminary design and by January 2010 had agreed the scope and target final cost. By then, work had started on the motorway widening section of the works and tunnel construction began in April, continuing until November 2011.

At the time of gearing up procurement for

Left: Hotel needed to be moved – and returned – for construction of the tunnel



Above: Figure 1, location map and layout of Victoria Park Tunnel, in Auckland

the project, though, in 2009 the Government was looking at ways to respond to the global financial crisis which was weakening the economy. It was decided to have the scheme give extra boost the local economy by increasing the local spend, with: no imported goods; seeking to hire small to medium sized firms; and actively working to increase the capability in the supply chain's suppliers and subcontractors, especially on health, safety and environment (HSE).

In addition, the spend plan was to be brought forward, and therefore VPA set itself an ambitious programme to complete the design, consenting and construction some 12 months ahead of the client's originally conceived programme which proposed completion in mid-2013.

Tunnel – design setting

The motorway corridor generally occupies low-lying reclaimed land as well as naturally in-filled drainage gullies and channels. The tunnel route is within, or bounded to the east, by Victoria Park, and to the west by a mix of commercial and residential areas. In addition, the tunnel is near Waitemata Harbour, within an area reclamation about a century ago.

Generally, the area is relatively flat. Varying depths of alluvium and fills overlay the uneven rockhead, and the water table lies at an average of 2.3m below the surface.

Geology comprises alternating muddy sandstone and mudstone with occasional inter-bedded lenses of Parnell Grit, and together known as the East Coast Bays Formation (ECBF) of the Waitemata Group. The ECBF is broadly divided in two classes – at best very weak or, worse, extremely weak.

The very weak ECBF comprises sandstone inter-bedded with siltstone, has UCS in 1MPa to 5MPa range, SPT-N values of more than 50 and is considered to be rock; the latter, though, is dense silty sand interbedded with stiff to hard silt, having UCS generally less than 1MPa and SPT-N values of 30-50, and is not considered to be rock.

The rockhead varies by approximately 8m in elevation along the alignment of the tunnel, being lowest at the southern portal. There is also lateral variance, across the width of the tunnel corridor, of up to approximately 4m in some stretches.

Overlaying the formation in the reclaimed harbour area are varying depths of Holocene alluvium of the Upper Tauranga Group, which comprises intertidal mud and marine deposits of loose sand-silt and soft cohesive silt-clay. In addition, there is hydraulic fill of alluvium with little plasticity, which was dredged/pumped to the site in the 1950s during the construction of Auckland Harbour Bridge.

Groundwater within the alluvium is a shallow unconfined aquifer system, which can comprise perched water tables. Tidal variations, via Waitemata Harbour, have little effect on groundwater in the hydraulic fill.

There is also Pleistocene alluvium of the Lower Tauranga Group, which comprises mainly clay-silt and interbedded sand-silt. In addition, there is weathered sandstone and siltstone in silt-sand mixes which have higher friction.

At shallow depths there is also general fill and within the top 3m in Victoria Park the ground is contaminated with demolition debris and gasworks waste, including heavy metals and some hydrocarbons (PAH – polycyclic aromatic hydrocarbons).

Other underground risks included the possibility of encountering abandoned and unrecorded utility services, and while possible susceptibility to liquefaction was assessed the conclusion was the risk was low and unlikely.

Tunnel – plan

The box structure of the cut and cover tunnel has a rectangular cross-section of varied width of 14.5m to 16m and broadly sweeps parallel to the viaduct with a horizontal radius of 290m. Inside are 3 x 3.5m wide lanes plus shoulders in the carriageway, and a 2m wide egress/services passage.

The difference in width of the box comes from changes on the left-side, which is affected by a lane merge at the entrance and near the exit where the breadth increases again to help provide greater sight distance at the road bend. The shoulder on the right-side is a constant 0.5m wide.

In planning, the key for the vertical alignment was to take the box below two vital utility services: a 2m diameter sewer (Orakei Mani Sewer) and a 4m x 3m stormwater culvert (Freeman's Bay Stormwater). The resulting height of the box varies between 6m to 11m, the floor is up to 12m below existing ground level, and the maximum depth to the invert is 14m. The gradients at the entrance and exit are 6.2 per cent and four per cent respectively. It was decided, for efficiency, to minimise the

Right: Figure 2, artist impression of Victoria Park with viaduct and tunnel

depth of the tunnel roof below the finished ground level, and the result was overburden of only 0.75m to 1.5m.

The retaining walls of the box have thickness of 800mm or 900mm depending on whether diaphragm or secant pile construction was used. Roof slab panels, formed of prestressed double hollow core beams, were either 750mm or 900mm deep. The base slab was a 800mm thick cast insitu in a continuous, unjointed form over 750m to minimise the potential for leakage. In addition to the weight of the structure, uplift pressures were designed against using bored tension piles, socketed into sandstone.

As required under the Resource Consent restrictions, an 'undrained' – watertight – approach was taken to the design of the structure so as not to significantly alter the groundwater regime and affect building foundations. Groundwater modelling formed the basis of the resource consent application, and placed controls on the effects of the project both during and also after construction.

At quarter points along the tunnel, below ground services rooms, there are two egress stairwells to the surface. The stairwells and service rooms are housed in side alcoves. The service rooms include a low point sump and pumps for collection of deluge, stormwater and groundwater seepage, a piping valve room, switchgear and fan room for air pressurisation of the egress passage.

Construction

Intense and successful juggling of known logistical challenges in the heart of the city was the key to delivering the project in the construction phase. There was also the potential for surprises – though few, it turned out – when working in an area of brownfield and infill land, such as industrial contaminated ground and unrecorded services.

At times some said digging the tunnel was more like being in the trench of an enormous archaeological dig. The total volume of excavation was 160,000m³.

On the surface there was the landmark old building that would need moved, temporarily, and strengthened – the Rob Roy Hotel, a treasured piece of late 19th century heritage. It would be jacked and shifted early and returning it would be one of the last pieces of work on the project.

Carriage way sealing in cut and cover tunnel

Above: Diapraghm wall construction

To construct the box structure of the tunnel, both diaphragm wall and secant pile construction were employed, in roughly equal measure – the former mostly in the southern half of the alignment, the latter in the northern half. The 800mm thick diaphragm walls were excavated by grab-bucket to depths of up to 16m to reach sandstone. The excavations were supported by bentonite and the walls were formed in typically 8m wide panels.

In the northern half of the job, with competent sandstone at a shallower depth, VPA bored 900mm diameter secant piles at 1.35m centres. The piles then had a 200mm thick shotcrete layer sprayed for waterproofing.

Following construction of the cap beams, the roof beams were used to brace them. The 1.15m wide beams were tied in groups of three to form the first roof slabs, slightly more than 3m wide, and had aps of approximately 8m between them to allow access and spoil removal between the walls for the top-down construction.

The base slab, some 4m above the ends of the walls and piles, was used as the lower bracing and to prevent seepage. Tension piles of 750mm diameter at 7m centres were bored along the length of the tunnel as part of the measure against uplift pressures.

With so many other activities needing to be accommodated – utility relocation while keeping prime services live, traffic management at three roads crossing the tunnel, and the relatively brief removal of the hotel building, and its return, the core tunnelling works progressed in 'piecemeal fashion', as intended. A further logistical challenge was utility relocation being needed in the same area as the hotel.

Hydraulic fill was frequently met towards the north end of the tunnel, although the rockhead was higher and depth of overlaying strata generally less than elsewhere on the alignment.

Groundwater behaviour during construction was consistent with the model predictions, and in areas where contaminated it was treated before disposal. Little collection or pumping of groundwater was required to drawdown the water table, which naturally lowered during excavation. It has re-established levels following main construction. Near an apartment building, however, recharge was undertaken during the works.

Grouting was undertaken when abandoned, unrecorded utilities were encountered – such as at old stormwater and sewers lines, or gravel lenses forming backfill tubes around long lost pipes. The concern was about the possibility of damage to, or collapse of, parts of the diaphragm wall and pile walls, but there were no difficulties despite some instance of bentonite loss.

Once the excavation was complete, the gaps between the roof slab bracing beams were filled with further beams before the entire roof was topped with a monolithic, 200mm thick cast insitu slab. A waterproofing membrane was placed over the roof slab before the backfilling.

Within the box, precast panels were used to partition the carriageway from the egress/services passage.

More than two million man-hours went into the development and delivery of the Victoria Park Tunnel scheme, the workforce peaking at 600 and monthly expenditure of up to NZD 16.4M (USD 13.6M). More than 850 invitations to tender were issued for the scheme, 214 contracts worth approximately NZD 75M (USD 61.98M) were awarded – 80 per cent to businesses in the local area, and almost half to small and medium firms.

Victoria Park Tunnel – in context

Addressing the problem of highway congestion in central Auckland was the last in a series of Government transport projects called the Central Motorway Improvements initiative, aimed at improving the efficiency and safety of Auckland's central principal road network.

The initiative's Junction and Grafton Gully projects were previously completed.

The initiative itself is part of the NZD 10bn (USD 8.3bn) National Infrastructure Plan to complete seven essential state highway projects to reduce congestion, improve safety and support economic growth for the country's five largest population centres.

From north to south of New Zealand, the other schemes are:

- Puhoi to Wellsford;
- Auckland's completion of the Western Ring Route, involving twin 2.5km long tunnels each with three lanes;
- Waikato Expressway;
- Tauranga Eastern Link;
- Wellington Northern Corridor (Levin to Wellington)
- Christchurch motorways

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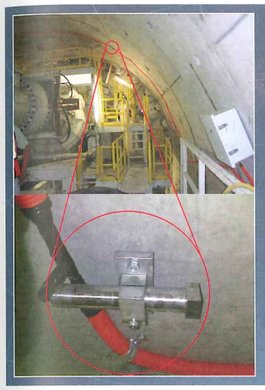

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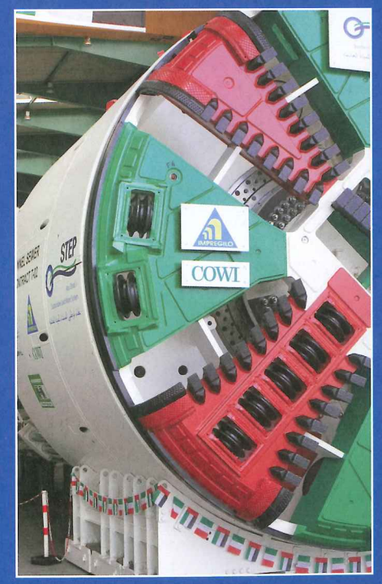

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Earthquake damage in 'mountain tunnels'

This article is based on earthquake damage data and research of tunnels in recent years including Wenchuan earthquake (Ms 8.0); Yushu earthquake (Ms 7.1); Chi-Chi. Taiwan, earthquake (Ms 7.6). It classifies damage patterns and characteristics of mountain tunnels in severe earthquake regions. The authors analyse the damage mechanisms and put forward some proposals for tunnel rehabilitation and new tunnel construction

The paper suggests that in strong earthquake areas, a comprehensive aseismic design should be conducted considering the tunnel portal structures and neighbouring slopes.

When planning future tunnels the alignment should avoid or limit passing through active faults, and avoid placing tunnels too close to slope faces when planning future tunnels. The paper provides a reference for seismic design and construction procedures of tunnel.

The authors' classification of earthquake damage to mountain tunnels are:

- Slope failure near tunnel portal;
- Spalling and collapse of tunnel portal and end wall;
- Lining collapse;
- Longitudinal and transverse cracks of the lining;
- Oblique and transverse fracture of lining;
- Spalled lining in fault areas;
- Steel reinforcement damage of the primary support;
- Pavement or invert cracks.

Mountain tunnels built in areas subject to earthquake activity must withstand both seismic and static loading.

Being situated deep within rock strata, mountain tunnels have generally been assumed to be able to withstand damage from earthquakes. Historically these tunnels have experienced a lower rate of damage than surface structures.

Nevertheless, some tunnels have experienced significant damage in recent large earthquakes, including the 1999 Chi-Chi, Taiwan earthquake and the 2008 Wenchuan, China earthquake.

On 12 May 2008 at 2:28pm local time, a strong earthquake with a magnitude of Ms (see box, right) 8.0 struck Wen-chuan town, in the eastern Sichuan area of west China at a depth of approximately 19km. It was officially named the Wenchuan Earthquake.

According to the statistics of the Government of China as of 16 June 2008, just over a month after the disaster, some 9,016 deaths had been confirmed, 368,565 people had been injured, and many more had lost their homes (CSI, Wenchuan Earthquake).

The paper outlines the findings of an investigation into the earthquake damage to mountain tunnels and geotechnical engineering. It is hoped that the information shared herein can enhance the understanding of seismic behaviour of mountain tunnels and improve seismic design and construction procedures. Previous studies have found earthquake damage in tunnels to be localised at sections with two important characteristics.

Those running through displaced faults, which were damaged by shear forces that developed during the earthquake. And those near surface slopes, which were damaged owing to slope failures.

Research

Several studies have documented earthquake damage to mountain tunnels. The International Tunnel Association (ITA) took interest in the open session 1984, in Caracas, Venezuela with the reports 'Seismic Effects on Underground Works' and originally published in the journal Advances in Tunnelling Technology and Subsurface Use (ITA, 1984).

In 1987 and 2001 the ITA issued two reports, namely 'Aseismic Design of Underground Structures' (St John, CM & Zahra, TF, 1987) and 'Seismic Design and Analysis of Underground Structures' (Hashash et al, 2001).

W L Wang made investigations of mountain tunnels after the Chi-Chi

Left: **Figure 1, Slope failure over a twin tunnel portal with bores blocked by a 'scree' and large boulder**

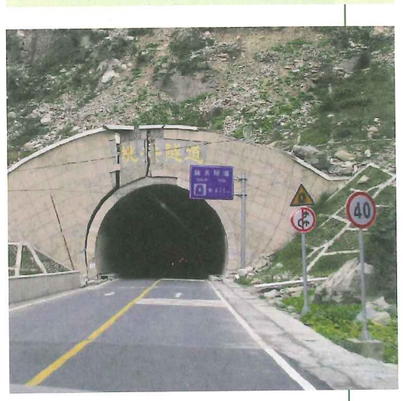
Paper and authors

This article is based on the paper 'Classification and Analysis of Earthquake Damage on Mountain Tunnel' presented at the ITA World Tunnel Congress in Helsinki in May 2011, as published in the WTC 2011 Proceedings, copyright of the Finnish Association of Civil Engineers and the Finnish Tunnelling Association.

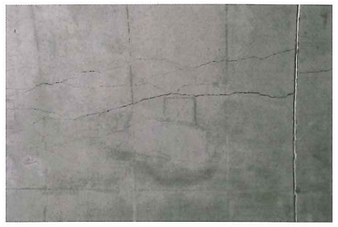
The authors are Hui Hu and Wenge Qiu, both of the Southwest Jiaotong University, China.

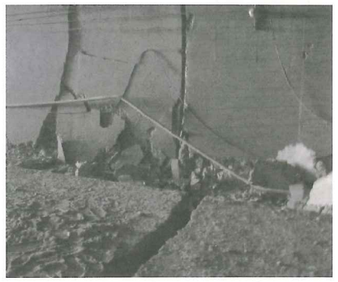
'Mountain tunnel' is a term often used in Asia to differentiate from tunnels in urban areas as well as to describe the usual location of such tunnels. In general they are in hard rock as opposed to the soft ground more common in urban areas.

Ms = Surface wave magnitude on Richter scale



Above: **Figure 2, Spalling and collapse of tunnel portal and end wall;** Below: **Figure 3, Support lining collapse at the crown in a tunnel during construction (top) and in operation (bottom)**





Above: **Figure 4, Longitudinal cracks (top) and transverse cracks (above)**

Earthquake in central Taiwan, revealing that many tunnels suffered significant damage to various extents (Wang et al, 2001).

It was found that among the 57 tunnels investigated 49 of them were damaged.

Damage classification

Damage patterns and characteristics of mountain tunnels in severe earthquake region are classified as follows:

Portal failure: Damage at and near tunnel portals was found in the investigated

Below: **Figure 5, Oblique (inclined) and transverse fracturing of a support lining**

Right: **Figure 6, Lining slab shearing in a displaced fault zone**

tunnels. The damage patterns can be further classified into two major types:

- Slope failure near tunnel portal;
- Spalling and collapse of tunnel portal and end wall (see Figure 1).

Lining collapse: Support lining collapse damage was found mainly in the tunnel crown in some tunnels, which made huge damage to the tunnel.

Figure 3 presents the lining collapse at different tunnels during both construction and operation.

Longitudinal and transverse cracks: Longitudinal cracks observed in some tunnels were developed and extended along the whole tunnel.

This kind of damage pattern was often found at the crown and shoulder of the tunnels. Cracks in the concrete lining were also developed perpendicular (transverse) to the direction.

Inclined and transverse fracturing: Single fracturing inclined at 30 to 60 degrees to the horizontal was observed (see Figure 5).

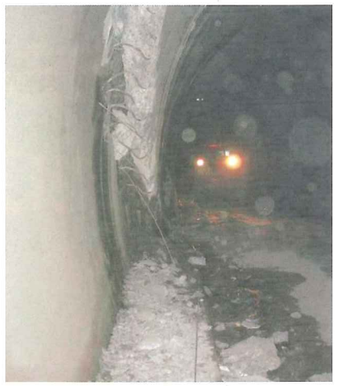
Shear failure of lining in fault zone: Tunnels passing through a displaced fault zone and previously fractured zones suffered heavy damage through the relative shear deformation imposed by surrounding rock (see Figure 6).

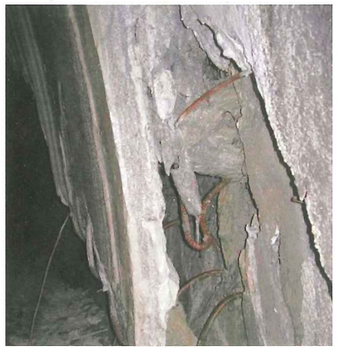
Main support lining damage: Steel reinforcement damage was found in some of the tunnels, with steel bar distortion and plastic deformation.

Conclusions

The three characteristic aspects of earthquake damage to mountain tunnels are listed below.

- Landslides and rock falls engendered damage to the mountain tunnels in the portals, while the inner part of tunnels mainly suffered damages mainly due to fault displacements.
- Various damage types to mountain tunnels were observed, including portal failure, lining collapse, longitudinal cracks and transverse cracks, inclined and transverse fracture of lining, shear failure of the lining in fault zones, and primary support damage.
- It is necessary to study further the seismic behaviour of mountain tunnels, while the seismic design of mountain tunnels is in deep need of development and improvement.





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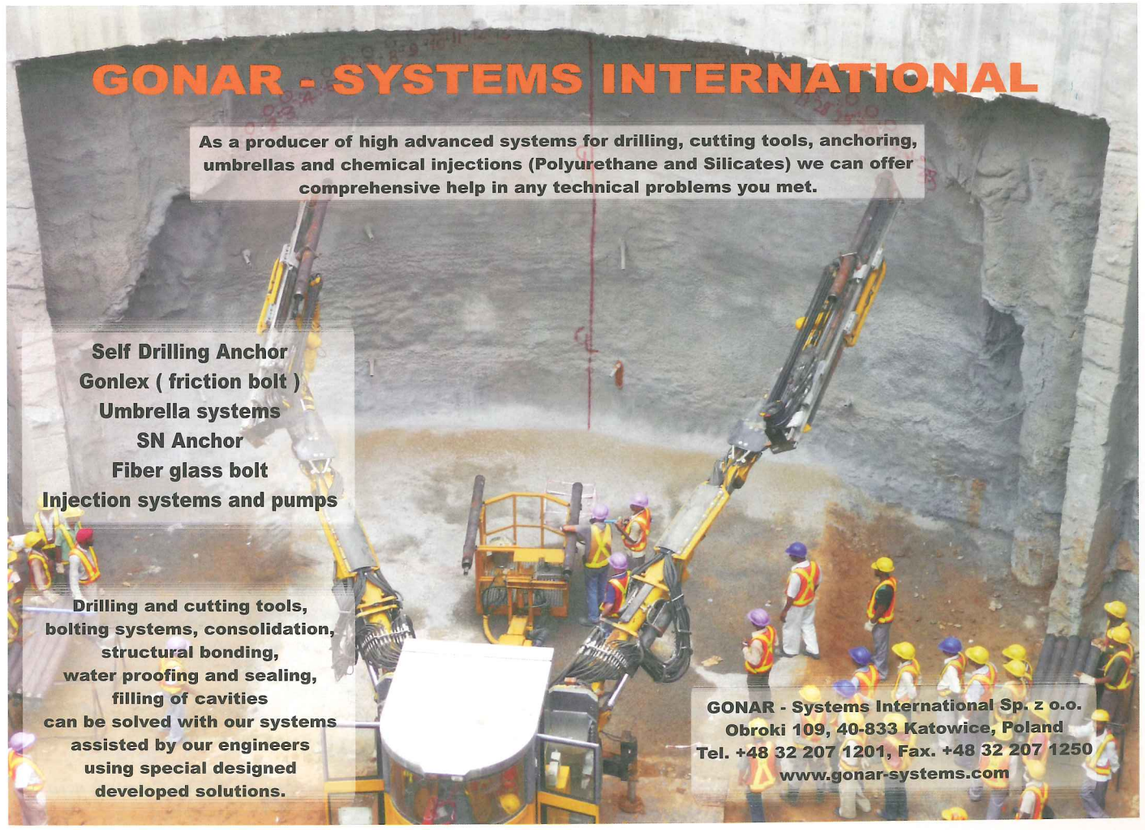

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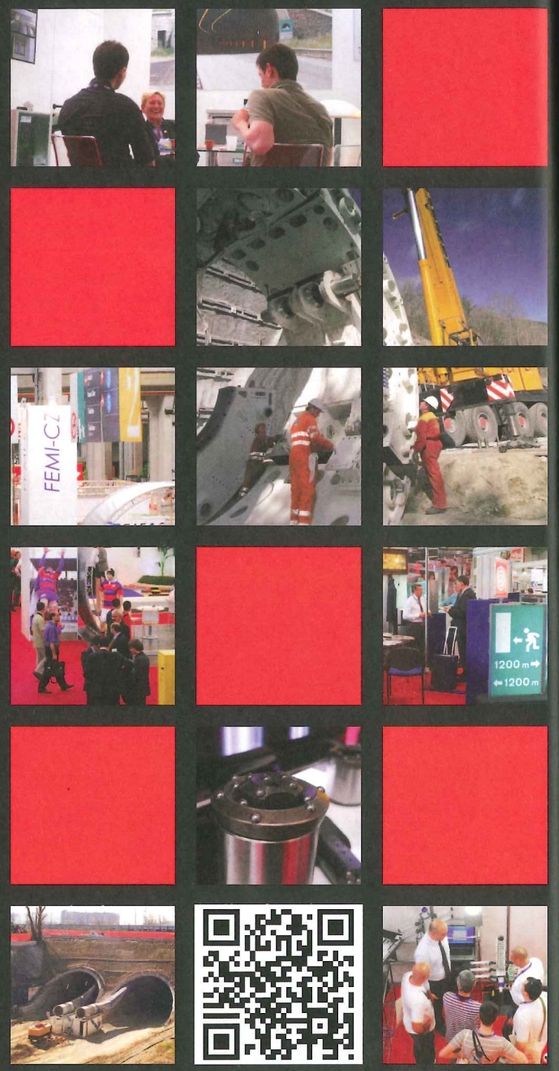

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Sustainability and safety – the role of renewal

The less glamorous and usually less profitable side of underground construction is nevertheless important in maintaining the 'green' credentials of our industry. With widely varying requirements and often small-scale needs, renovation and rehabilitation of underground spaces do not lend themselves readily to the efficiencies of mechanisation and economies of scale. Maurice Jones explores

It is often said that the planning of a tunnelling project starts with the ground. In renovation work, the ground may play a part, but the main consideration is the state of the existing underground structure and whether it can be made to meet changing needs and modern standards.

Depending on circumstances, all types of underground assets, from sewers and pipelines to large-section motorway tunnels may need renovating at some stage in their life due to such factors as:

- Wear and tear including erosion;
- Deterioration of structure due to passage of water and other fluids, chiefly causing corrosion or removal of part of the structure, especially cementitious and ferrous elements;
- Dimensions becoming inadequate for current use such as increased flows and/or larger section vehicles, or due to ground conditions causing closure;
- Emergency damage such as from fires, explosion or flooding;
- Safety and environmental systems (especially in transport tunnels) not being adequate for current traffic flows or accepted modern standards. In Europe all tunnels on the Trans European Network (TEN) must meet the improved standards of the European Parliament Road Tunnel Safety Directive 2004/54/EC by 2014. Many tunnels on other non-TEN routes are also being brought up to similar standards.

In many circumstances it may be tempting to solve such problems by relatively expensive, but readily available, new build. Indeed this may be the only adequate solution, but with experience and innovative thinking, the problems of deteriorating or inadequate tunnels can be resolved more economically.

Apart from decreasing costs, more acceptable renovation solutions may be:

- Readily mechanised if possible;
- Easily applied/installed;
- Greatly increase tunnel useful life through durability;
- Avoid major structural modifications;
- Reduce maintenance requirements;
- Be safe in application and in end use

Above: **Smoke generators make post-renovation exercises as realistic as possible, as here in the Holmesdale Tunnel, M25 London orbital motorway (Photo: David Townend Photography for Highways Agency)**

Broadly speaking, tunnels that may require renovation can be divided into those for: fluid transmission (sewers, water and other pipelines), transport and cables.

The last rarely requires much renovation useless there is a problem with the original structure, providing systems for ventilation are maintained properly and the section remains adequate for the cables required to be installed.

Sewers can be a major renovation need, especially in older urban areas where the asset may well be over a century old and brick-built. In more recently developed sewerage systems, often in tropical or

sub-tropical climates, the high ambient temperatures can increase corrosion rates of a concrete fabric, necessitating lining with a less corrodible materials, such as glass-fibre-reinforced plastic (grp), or replacement. The case of sewers, and old rail tunnels, illustrates the point that the renovation can rarely adopt the original methods, unless subsidised. Modern economies rarely have the relatively cheap, skilled labour that allowed massive brick or stone structures to be built as in the 19th century. Consequently, alterative materials that can be more easily installed are required.

Transport tunnels may have similar structural problems, albeit without much internal corrosion. However the main drivers of renovation are now capacity and safety/environment standards. Some older tunnels were built only with horse-and-carts in mind, and so have been unsuitable for modern requirements without several renovation programmes in some cases. Typical needs are:

- Higher road traffic flows causing:
  a) Excessive levels of environmental contaminants such as exhaust gases and particles;
  b) More rapid incident detection and response times, perhaps automatic;
  c) Desirability of detecting moving hot-spots on vehicles;
  d) A need for staggering traffic flows to safe vehicles spacing with traffic control signalling;
- Alternative and secure means of egress or refuge for emergency use;
- Standardisation of signage to be more easily understood by international travellers, especially for escape routes;
- Bigger and more trucks and trailers increasing carriageway wear and ventilation requirements, and possibly higher level of fire risk;
- Transfer of freight traffic from international trunk roads to rail;
- Trains with increased speeds, and larger-section rolling stock such as double-deck passenger coaches and piggyback freight systems. Larger tunnel sections may be required to accommodate the larger envelope to allow higher speeds and suspension sideways movement, plus the larger rolling-stock;
- Better fire and rescue access and facilities to save life;
- Water leaks causing possible structural damage and safety concerns, especially in sub-zero temperatures when icicles may be formed;
- Greater margins of safety demanded by government and safety organisations e.g. European code EBO10 in rail tunnels requires a minimum line distance between track centres of 4m.

Even when all these improvements have been made they will have to be tested in realistic exercises, as if the tunnel was a new build, to ensure that new systems can be seen to work with the old.

Left: Simulating fire fighting in a post-renovation exercise in the Bell Common Tunnel, M25 London orbital motorway (Photo: David Townend Photography for Highways Agency)
Above: Exercise in Hatfield Tunnel on England's A1(M). Note the room for an elevated walkway, and hence jet fan positioning. (Photo: David Townend Photography for Connect Plus)

Site investigation

The process of site investigation before a renovation project has little in common with that for new build but is of equal if not more importance. If possible, an investigation should start with the original construction drawings, and those of any modifications. Even so, older drawings may not be reliable in structural terms. There have been many instances of a recorded six-course brick lining being actually three courses and fill or rubbish. Also the practice of attacking tunnel excavation from several intermediate construction shafts, with subsequent, sometimes partial, backfilling and sealing over with the final lining may not be adequately recorded. This can lead to some nasty surprises during reconstruction, especially if the old shaft has developed into a groundwater course.

Notice also has to be taken of any adjacent excavations, including basements, whether abandoned or in use, so that any interaction between the excavations can be assessed. This may require probe drilling, perhaps with additional grouting.

Water inflows are obvious indications of leaks although point of emergence may be a considerable distance from the source, and so attempts to treat it locally may not be successful or cause another leak elsewhere, unless more investigations can be carried out.

Where there is any degree of uncertainly modern instrumentation such as ultrasonic or thermal imaging equipment can be used to betray the presence of structural anomalies, cavities and water.

Lining renovation

Although age increases the likelihood of renovation being necessary, it is far from the only factor. Even the comparatively recent Eurotunnel, constructed as probably the safest tunnel in the world with its three bores, has exhibited a need for some upgrading, highlighted by the fires it has suffered. In addition to repairs of fire-damaged lining, other renovation measures have included the installation of improved heat-detection systems for vehicles before entering the tunnel, revised escape procedures and the installation of fire deluge/water spray systems.

Sprayed on

Linings that can be sprayed on meet several of the criteria of an economic, modern renovation system in that it can be easily applied, with good quality control possible, and with minimal interference from the existing structure. Not only can spray systems be used to repair and strengthen support linings, they can also be used to apply linings that improve waterproofing and fire-resistance.

The more traditional dry-mix sprayed concrete systems are usually adequate for limited area repairs, although the wet-mix process has also been used where there is space for the generally larger but more efficient equipment.

Injections

Grouting also has its role to play in renovating linings, particularly in corrective water-proofing and ensuring that any cavities, such as may have been caused by water flow or ground movements, are filled.

This results in a stronger pressure arch around both the tunnel and its lining to improve support and eliminate point loading of the lining.

In renovation work, instrumentation and control of the grout injection process is particularly important as excessive pressure may react on the old, and possibly insecure lining, to cause more instability.

Surface improvements

Whilst tunnel renovation is under way the

Left: Renovation of the Connaught Tunnel for Crossrail was originally intended as a fill and re-excavate operation. It will now be open-cut within coffer dams after investigations found the structure unsafe. (Photo: author)

opportunity may be taken to improve the appearance and functionality of the lining, either by the choice of material, or the installation of a tertiary lining. These are particularly important in highway tunnels and metro stations, not only for improved aesthetics but also better or more economical lighting, easier cleaning and, in stations, income-raising through advertising opportunities. Linings might also be colour-coded to indicate the presence of escape routes or emergency equipment.

Ventilation

One of the highest potential costs in current highway tunnel renovation can be the upgrading of ventilation. However, a redesign of ventilation may be impossible or prohibitively expensive using traditional methods within an existing structure. This is where strategically placed jet-type fans can be invaluable. *T&TI* has carried articles on this subject several times, including the relative merits of the various jet-fan designs and the possible location of units.

Even so the limited space available in the section of many road tunnels means that the position of many service lines (power, signal and telecommunications cables; fire-fighting ranges and drains) may have to be juggled to free space for the most effective position for a jet fan or group of them.

Les Fielding of London Bridge Associates, a qualified fire officer and member of tunnel safety committees, cites the examples of several highway tunnels on the designated Trans-European Network (TEN) tunnels of the UK including the Holmesdale and Bell Common tunnels on the London M25 orbital motorway and the Hatfield Tunnel on the A1(M). In most cases, increased ventilation capacity could not be installed with modifications to other existing arrangements since available headroom is rarely sufficient for even jet fans. One solution is to provide a bank of jet fans at the tunnel portals, but for efficient movement of air further into the tunnel jet fans have to be sited against the walls.

Positioning of standard jet fans near tunnel surfaces is not the ideal situation for fan efficiency, but designs such as the new Mosen MoJet fan, made by Systemair, seek to minimise the interference from the tunnel surface (*T&TI* January 2012, page 46).

Where other service ducts occupy the ideal fan location, they have to be moved to somewhere within the tunnel section. "In the Bell Common and Holmesdale Tunnels," explains Fielding, "the service ducts could be placed under the service/escape walkway, but the consequent height of the walkway would not allow its use as an escape route by disabled tunnel users. Consequently it was decided to bury the service ducts under the road carriageway so that the walkway could be accessed more easily. With the Hatfield Tunnel the structure allowed sufficient room for fans to be mounted on the outer wall over the walkway, but at the intermediate walls the service ducts had to be lowered to ground level."

Even with large-diameter, more traditional fans, the improved design and control technologies employed in modern units ensure greater efficiency with lower running costs, provided the units can be installed in existing housing.

Safety and control

Coupled with schemes to improve ventilation are upgrades of related and other safety systems. These will not only include control procedures for the fans in both normal and emergency conditions, but the monitoring and processing of data that is used to decide on optimum fan operation, whether under manual or automatic control, from atmospheric condition monitoring instruments, and incident detection and location equipment such as heat detectors, CCTV cameras, and image processing software.

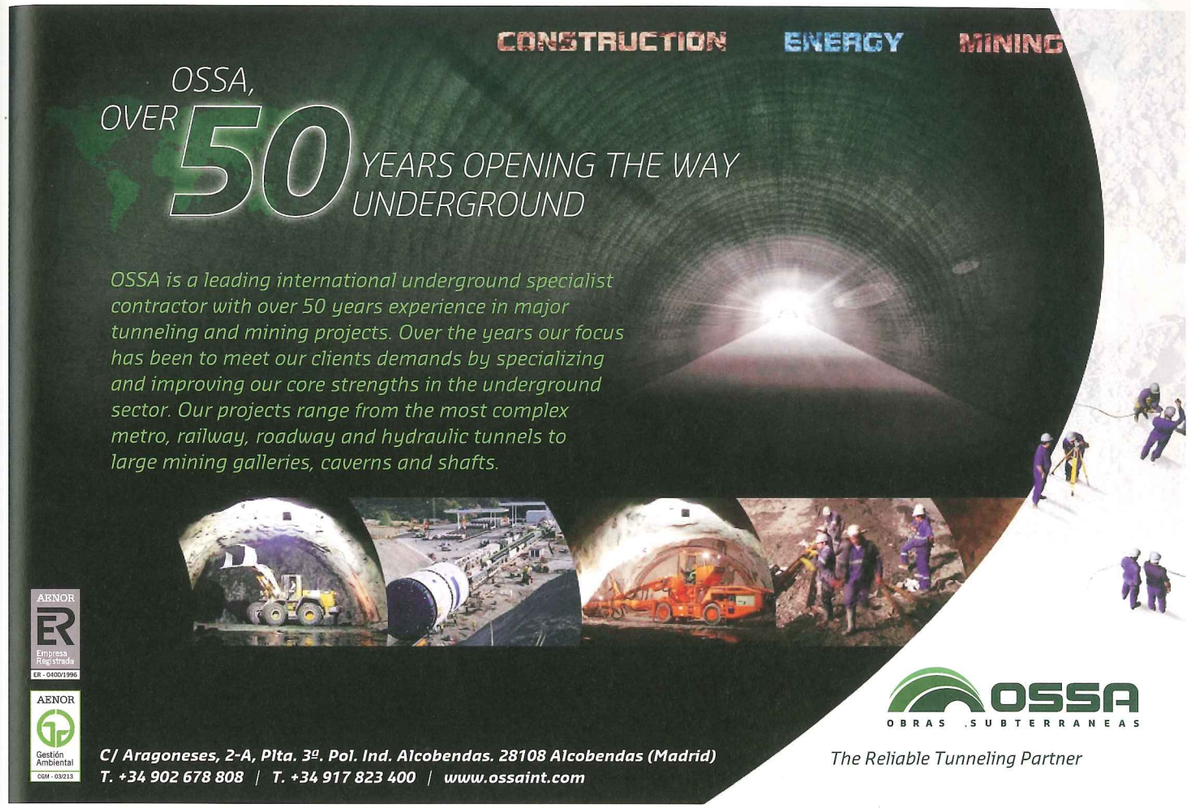
Other likely necessary safety system improvements in transport tunnels include better signage and lighting for traffic control and emergency evacuation, better fire-fighting systems perhaps including automatic mist of deluge equipment, and systems and procedures to prevent the entry of hazardous scenarios from entering the tunnel, whether accidental or malicious.

Even when the best new safety and control systems have planned, it may well be that the physical design and capacity of the tunnel is not adequate for modern requirements. The apparently simple but relatively expensive option is to construct another bore parallel to existing tunnels, thus increasing capacity, eliminating traffic contraflow under normal circumstances, and providing a more secure means of escape for users. This will also provide the opportunity for renovating the original bore without disrupting existing traffic flow, as in the case of the last Tauern Tunnel renovation. Intermediate construction solutions are the excavation of more secure refuges (although of limited use in intense and long-lasting fires), and the construction of escape routes to the surface if the topography allows, as with the Mont Blanc tunnel. If the original tunnel section is large enough, compartmentalising it to form service ducts could also provide an escape route, if nothing else is possible, as well as allowing more ventilation control options.

Exercises

Les Fielding points out the importance of tests, including full-scale exercises, to test all the emergency operations of tunnel systems following any renovation work, before the tunnel is put back into operation. This echoes similar exercises carried out before the handover of new build tunnels. The purposes of such exercises include the physical testing of all systems to ensure that they work as designed, the interactions between the newly installed and existing systems, and to allow third parties, such a fire and rescue brigades and ambulance services to become familiar with the new installations and how they work, including compatibility with their own equipment. Flaws and improvements can often be found in operational procedures, and valid physical improvements may be suggested.

Although not a renovation project, Fielding cites the example of the recently completed Hindhead Tunnel (for which Fielding is tunnel safety officer) on the A3 trunk road in Surrey, England. The area ambulance service suggested the provision of an air-ambulance landing pad in case of an injury-causing incident in the tunnel. Balfour Beatty then provided two.



On-line renewal and enlargement

As well as enlarging its high-speed rail network Germany's national railways operator Deutsche Bahn (DB), has been enlarging its tunnels for regulatory, safety, and capacity reasons. Maurice Jones checks on how they are doing this more efficiently by employing mechanisation to the maximum extent

Enlarging tunnels, or replacing the support lining, is not new. One project involving the use of a shield for excavation and lining segment erection to renew a canal tunnel lining was reported on by *T&TI* (see *T&TI* November 1983, pages 35 to 38) and that was probably not the first. But 'on-line' enlargement or lining replacement remains a particularly difficult and sometimes unpredictable exercise, especially if the transport route, usually a railway, has to be kept operating for all or part of the renewal period. Even if renewal is only allowed within strict possession windows all materials must be cleared back to a safe area before train services can be renewed.

Where electric trains are concerned it would be too dangerous to proceed with construction, unless a diesel alternative motive power can be used. If only electrical power is available then the route has to be taken off schedule within the windows to allow work to proceed.

Recently there have been moves to standardise construction renewal and enlargement procedures as far as possible, akin to the procedures now widely adopted for new tunnel construction with mechanised shields and back-up systems.

Traditionally tunnel enlargement, or even lining replacement, around rail-tracks in use has been carried somewhat piecemeal with an integrated system. Even if some mechanisation has been used it has often been limited to excavation using impact breaker or roadheader, carefully preventing spillage of spoil and debris onto the track unless possession is allowed. This can be prevented by specially constructed shields moved forward as work progresses. Piecemeal operations tend to be less safe so the integration of shield and excavation systems, similar to new tunnels, leads to the integrated systems now available. It has been shown that special work such as junction construction can be carried out safely in adjacent to an operational railway. A recent case has been the Josaphat link, in Brussels where Denys and other contractors constructed such a junction with operational routes whilst using one of the tracks for soil removal to prevent congestions of roads at the surface (see *T&TI* September 2010).

Potential hazards that have to be avoided or eliminated during tunnel enlargement or lining replacement, and better achieved with an integrated system, include the following.

- Spillage of spoil and debris onto rail track, especially if required for operation;
- Hazards to tunnellers from train movements;
- Possible falls of ground, especially when deteriorated behind the old lining;
- Inadequate ventilation behind the shield, especially dead spots.

On the positive side there must be an efficient means of removing and disposal of spoil and debris, integrated with an acceptable rate of progress in excavation and installation of new tunnel support lining, ideally without interruption on any normal train schedules.

The need

In rail tunnels in particular, but also for highway tunnels in some circumstances, the above factors lead to the need for an integrated system of renewal. The tunnels still employed for both long-distance rail travel and urban metros, at least in the older developed parts of the works, were built in the late 19th century. Now, for various reasons, they have often passed their useful working life as they stand. Since the secure 'hole in the ground' is the greatest asset in underground structures, it makes sense to, if possible, renovate the structure to presently required dimensions and durable materials, and renewed or updated safety and operational systems.

In the context of a need for tunnel renovation and enlargement of the sections, distances between track centrelines are generally too small for today's needs in that they cannot accommodate the generally larger envelope of today's faster trains. Without remediation, it may be necessary to run trains at less than their design speed through older tunnels along the route.

Elements

Replacement by microtunnelling, and even pipe bursting, have shown that the principle is sound, although use on live utility lines is hardly possible. With a live sewer, for example, the flow is diverted, usually by pumping over through temporary lines.

The elements that have to brought together into an integrated on-line tunnel replacement or enlargement system include the following.

- Excavation method: typically boom-mounted cutterheads, impact breakers and also backhoe excavators have all been used;
- Shield or shields for temporary support of excavated ground and to prevent debris from falling into a live tunnel;
- Support method including materials supply: typically pre-cast concrete segments and/or sprayed concrete can be used, depending on the project ground conditions.

Herrenknecht

One of Herrenknecht's development programmes is centred on tunnel enlargement equipment for old railway tunnels, termed as the Herrenknecht Tunnel Expansion Equipment. The system aims at the requirements of the EBO (Eisenbahn-Bau- und Betrieb Ordnung) 10 standard with the force of German law.

The solution, says Herrenknecht, is to ream the old tunnel and to reclad it with lining segments in the same operation, whilst allowing single-track operation throughout the construction work. This is possible because a protective 'mantle' separates the working area from the track in use.

The refurbishment increases both the tunnel diameter and the distance between track centrelines to at least the 4m required under EBO 10 to enable train speeds of up to 230km/h.

During refurbishment of a twin-track tunnel, 10 to 12m in diameter, single-track operation can continue at up to 60km/h. Construction progress is said to be up to 10m per 24h-day.

This is achieved through use of trailer-based systems with all equipment optimised to work together on the carrier, in a similar manner to TBM back-up systems.

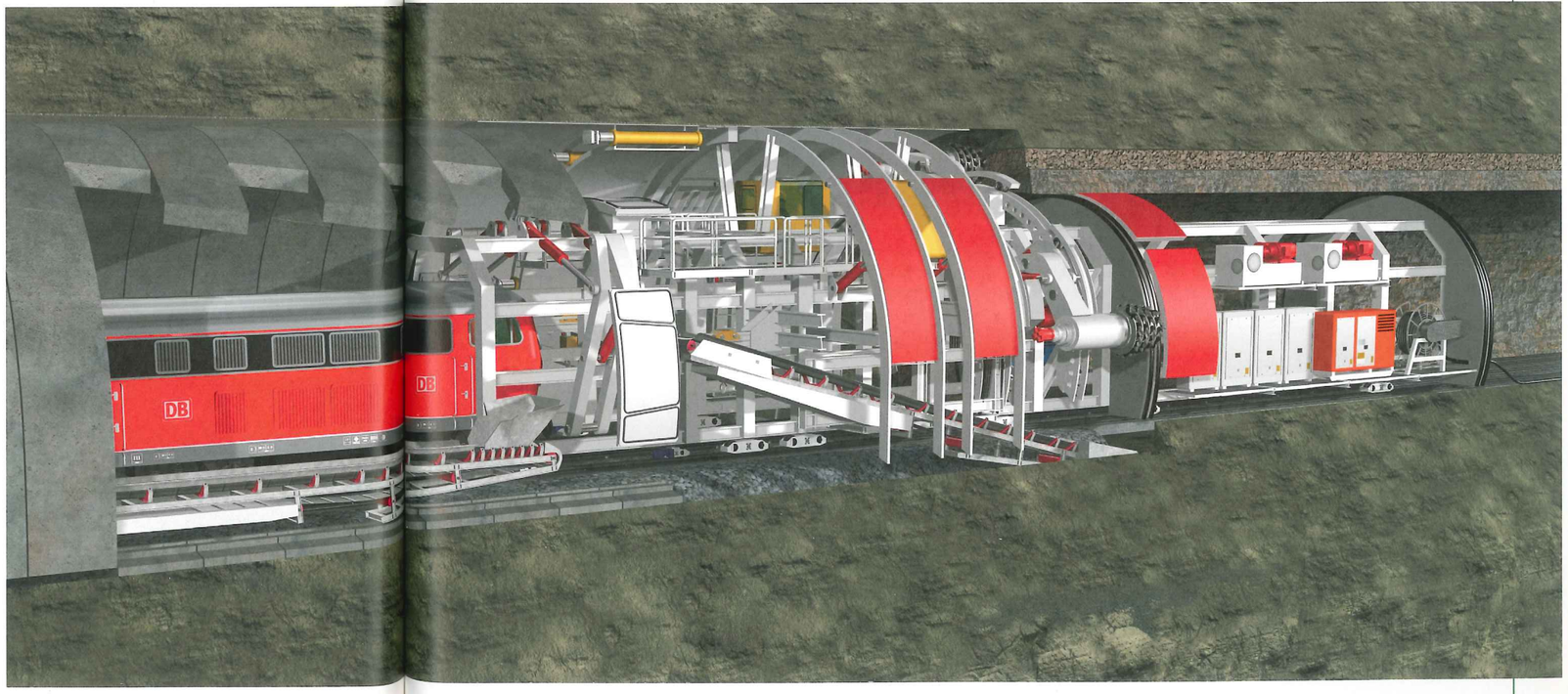
Under the current system, three units are employed. They are:

- Service trailer: Carries switchgear and pumps but also supports the old tunnel with stabilisers, and protects the rail track from any falling rock and debris;
- Enlargement trailer: Carries two roadheader-type cutters on a radial boom to rotate around the periphery, creating sufficient space to comply with the new dimensional requirements;
- Lining trailer: A standalone unit to erect a new precast segmental lining support.

Deutsche Bahn

As with the Herrenknecht system, the 'Tunnel in Tunnel' system developed within Deutsche Bahn (Breidenstein) is intended to be applicable to twin-track tunnels without electrification, but with a requirement for passenger railway operational availability possible on one track.

This is achieved by relaying the track to allow room for tunnel renovation.



Right: **Figure 1, general layout of the Herrenknecht railway tunnel enlargement system being developed**

Above: **Using a Sandvik M-series hard rock roadheader to lower the floor of the Mont Cenis rail tunnel in France in 2008, adjacent to an operating track**

Safe operations are achieved by the use of fixed enclosures at the tunnel portals and a 'sliding housing' to progress with the renovation work through the tunnel and protect the way for train operations.

The system had to be designed so that all major tunnelling activities were possible with efficiency and safety including demolition of the existing masonry lining, back-packing of any annular cavities, and any necessary opening of the ground by excavating with an excavator arm or impact breaker. The enclosure also provides room for loading out the spoil and sprayed concrete lining. The necessary equipment is mounted on holders that can be adjusted radially on guides, and also displaceable longitudinally to ensure that all work positions can be reached.

Primary sprayed concrete lining is applied to the new tunnel profile from inside the enclosure, and anchors installed to secure the casting formwork for new permanent inner lining.

The final construction work is to cast the permanent concrete lining using a separate formwork carriage.

The stated advantages of this process include that only a few items of equipment are ever required in the training running space, mainly for track work, and these can work reliably without delay to train operations. The renovation work is carried out with a single system whilst protecting the train passageway from occurrences such as possible rock falls or improper equipment operation.

Pilot tunnels

The two pilot project tunnels chosen for the 'Tunnel-in-Tunnel' method were the Mausenmuhlen Tunnel and the Jahrodter Tunnel on the twin-track, non-electrified route from Bingen to Saarbrucken. They are 149m and 129m long respectively and lie within a 1,200-m stretch reachable by a road central between the two tunnels. Small construction areas, no bigger than 500m², were required as each portal.

As part of the project the route was operated as a single track over the 1,200m stretch for a period of a year with the existing tracks towards Bingen remaining in place, except in the tunnels themselves where it was moved to the tunnels centreline.

The removal of the second track provided room for the renovation system to run and a construction road between the tunnels to the portals with guardrails. The renovation system was erected at a tunnel portal to run on rails laid in the tunnel renovation space made available by moving the train track.

The renovation system itself consists of a 6m-long shield, held to the old tunnel lining with hydraulic rams to ensure the stability of the old lining. It then works in stages, two metres long, to carry out the renovation and tunnel widening.

The equipment carried can suit the tunnel conditions, such as a hydraulic hammer with chisel head for demolition, and two drill booms for drilling blast or anchor holes as required in all directions.

The procedure is to clear out the loose ground and backfill from behind the old lining, then to demolish the masonry lining. Next drilling and light blasting with detonating cord is used to remove solid rock to the required new profile. The exposed rock is supported with two layers of sprayed concrete to secure it. Beyond the immediate mining area, and further 10m length of tunnel work area is shielded to protect the operational railway.

Two GHH load-haul-dump vehicles are used for spoil removal, working on approximately 30m³ of excavated material per metre length of tunnel. The material is lifted clear of the railway by crane. The enlarged tunnel is completed with a 350mm-thick lining of cast in situ waterproof concrete standing on concrete foundation beams prepared locally. The beam space was later shared with an integrated services duct.

The second tunnel was then expanded with the same procedure, followed by restoration of the twin track to the whole stretch.

The result of the work was two 'new' tunnels with sectional areas of 52m² above rail level, thus providing an additional 10m². All current tunnel construction codes were achieved, with safety and security, to achieve more space to accommodate development in rail traffic speed and rolling stock. This includes the possibility of space for electrification.

Development of the working site was carried out within three months including relaying the railway as a single track during a 50-hour weekend closure. Manufacture of the renovation system took four months.

The 278m-long tunnel was widened within 150 days and secured with sprayed concrete. Widening advanced at a rate of nearly two metres per day with a concrete spraying rate of four metres per day. Overall the project took 18 months of which only 13 months was actual construction, with procedures influenced by the planning timetable and single-track operation. It is estimated that conventional construction would have taken 24 months for the same work with massive disruption of train services.

Following the success of enlarging these two tunnels, Deutsche Bahn planned for four more tunnels to be renovated the same way on the Lahn and Nahe rail routes. These tunnels total 1,200m in length.

The overall potential for such tunnel renovation is indicated by the fact that Deutsche Bahn (DB) operates 450 tunnels over 60 years old, with a combined total length of 160km.

Other European countries are in a similar situation, especially when higher speed trains, electrification, larger rolling stock and bigger freight containers are considered.

As in the Herrenknecht system, DB envisages that the use of pre-cast segments for the final inner lining will further shorten overall construction times.

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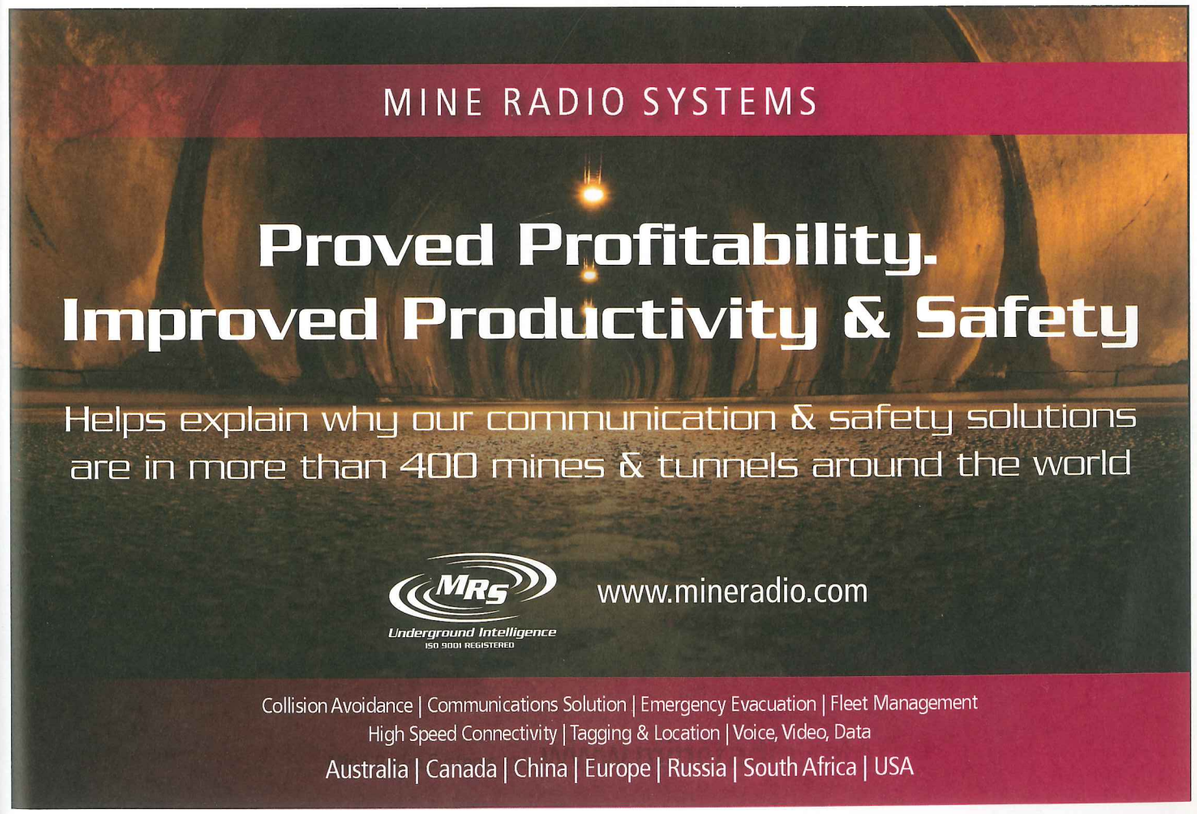


Final piece for Peacehaven

The December 2011 meeting of the British Tunnelling Society saw a presentation on the Cleaner Seas for Sussex project and how it had learnt lessons from a history of difficult tunnelling in Brighton, UK. The presenters were Craig Reade, project manager for Costain, and Ken Spiby of London Bridge Associates (standing in for Ben Green, programme manager for Southern Water, whose wife had just had a baby)

Brighton and Hove lies on the south coast of England almost due south of London. Following the adoption of the Urban Wastewater Directive by the European Union in 1991, Southern Water committed to a new wastewater treatment works to replace the existing screening plant and long sea outfall to the east of Brighton. With many areas of outstanding natural beauty (AONB) and sites of special scientific interest (SSSI) to consider, a substantial number of options were studied, and the scheme was 12 years in planning. It was inevitable that tunnelling would be required as a part of the scheme and, with substantial difficulties having arisen on all previous tunnelling projects in the area, Southern Water were determined to learn the lessons of history.

Brighton

Brighton is situated in a dry valley nestling amongst chalk hills, which to the east form spectacular sea cliffs.

In 1700 Brighton was a largely unknown, small village on the south coast of England, but by 1800 it was Britain's largest and most popular seaside resort. The extremely rapid rise was due to two factors:

- In 1752, Richard Russell published 'Glandular diseases, or a dissertation on the use of seawater in affections of the glands' which rapidly became a best seller. This advocated bathing in, and drinking, seawater as a cure for a wide variety of diseases and complaints and, reflecting the location of his practice, Dr Russell specifically recommended the seawater at Brighton.
- In 1783, the Prince of Wales (later King George IV) visited Brighton. He liked what he saw, bought a house which he later converted into the palatial Brighton Pavilion, and moved his court there for much of each year.

The sewage system in Brighton, however, did not keep pace with the rapid population growth, and in 1800 still consisted of cesspits and a rudimentary system discharging onto the beach, not perhaps the best idea if your town's popularity is based on drinking seawater.

Tunnelling in Brighton

It fell to the eminent Victorian engineer Sir John Hawkshaw, contemporary of Brunel, Bazalgette and Stephenson, to propose in 1869 an interceptor sewer running along the coast and discharging at Portobello, some four miles (6.4km) east of the town boundary at the time. The scheme would involve the construction of around 11.5km of tunnels, varying in diameter from 5ft to 7ft (1.53m to 2.14m), all excavated through chalk.

A construction contract was awarded in 1871, but work progressed for just five months before the contractor withdrew, being unable to cope with the quantity of groundwater inflow. The contract was re-awarded three months later for the increased sum of GBP 104,608 (USD 571,160 at historical rates) and the scheme finally completed in 1874. The contractor reported the loss of GBP 40,000 (USD 216,800 at historical rates) on the project, due to the difficulties of excavation, with groundwater flows reaching levels of 68Ml per day (800l/s). However, the brick lined sewers constructed were of outstanding quality and still serve the population well today. Indeed, tours of sections of the sewers are a very popular tourist outing.

Further tunnelling did not take place until the 1970s when a long sea outfall was constructed to replace the short sea outfall at Portobello. A ground investigation indicated competent chalk, and an open face shield was selected to drive the 1.8km of 2.14m diameter tunnel. Very substantial water inflows caused significant difficulties and required the construction of a temporary bulkhead and pre-grouting ahead of the face on a number of occasions. The difficulties once more resulted in a project that was delivered late and significantly over budget.

The excavation difficulties were concentrated in the first third of the tunnel (where water inflow was substantial and near continuous), and the final third (where water inflow was even greater, but more discrete). We can now recognise this as the differing joint patterns within the various chalk horizons that the tunnel crossed as it descended.

The Victorian interceptor system had a number of overflows which discharge stormwater onto the beach at times of heavy flow. The European Bathing Water Directive of 1976 required that these be removed, and in the 1990s the Brighton and Hove Stormwater tunnel was constructed, a 6m diameter tunnel running some 4.7km beneath the beach. Vortex dropshafts connected the overflows to the new tunnel, which acted as a reservoir, pumping the stormwater back into the interceptor sewer when flows reduced.

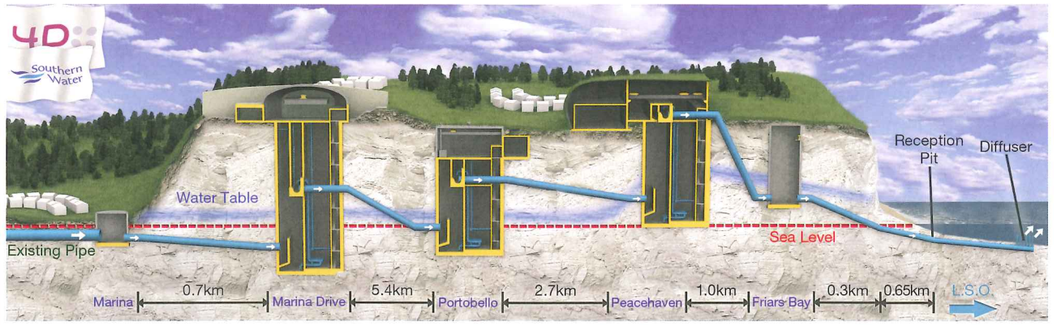
A substantial ground investigation gave confidence that competent chalk would be encountered during the tunnelling, for which a Pressure Balance TBM was selected, this being the old Channel Tunnel land service tunnel TBM which was upsized and modified to take a screw conveyor. However, once again, very substantial groundwater inflows caused enormous difficulties, most significantly in the latter half of the tunnel following a change in chalk horizon. Extensive horizontal sheet flints also caused significant wear to the cutting teeth and cutterhead and, as interventions were regularly impossible due to water inflow, substantial wear to the cutterhead spokes on several occasions. Once again, the project was completed late and substantially over budget.

The project team studied Brighton's tunnelling history in far greater detail than it is possible to describe here and identified a number of lessons to be learnt from the past, as summarised below.

Ground investigation

Study of chalk in the 1990s revealed significant variations between different horizons which would lead to significant variations in tunnelling conditions. Therefore, the ground investigation for the current project included detailed discontinuity logging, lithostratigraphic surveys, geomorphological mapping, chalk subsidence mapping, and solution feature hazard analysis, leading to a high degree of understanding of likely conditions.

Below: Figure 1, Brighton's sewage tunnels through the ages



Above: Figure 2, Cleaner Seas for Sussex Tunnel vertical alignment

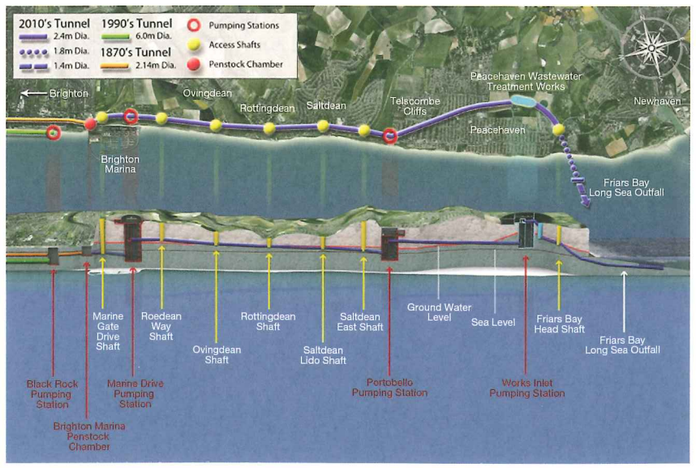
Tunnel alignment

The majority of problems encountered on the earlier tunnels were related to groundwater inflows, and so the project team tried to keep the alignment above the water table as far as was practical. This they achieved by introducing intermediate pumping stations and creating a vertical 'saw tooth' profile (see Figure 2, above).

Bringing Cleaner Seas to Sussex

The Cleaner Seas for Sussex project included the construction of a new wastewater treatment works on farmland to the north of Peacehaven, with much of the plant constructed underground and covered by the largest green roof of its kind in the UK. To take wastewater to the new works and treated water away to a new 2.5km long sea outfall, some 11km of new tunnels were required (see Figure 3, below).

Below: Figure 3, Tunnels on the Cleaner Seas for Sussex project



The new scheme connected onto the existing Victorian sewer at a new penstock chamber constructed in Brighton Marina. Flows were maintained within the existing sewer through a temporary pipe bridge, supported through the works forthe duration of construction.

A 700m, 1.8m diameter pipejack connects the penstock chamber with the first pumping station at Marine Drive. This was constructed in two drives from an intermediate ventilation and access shaft at Marine Gate using a Lovat M86 EPBM from Costain's fleet.

The bulk of the tunnel is 2.44m diameter and was excavated by two refurbished Lovat EPBMs, completing four drives, two each from Ovingdean and Peacehaven shafts. The TBMs were given names by local schoolchildren: Alice at Ovingdean (after Alice in Wonderland, as Lewis Carroll was said to be inspired by visits to Brighton); and Hollyblue at Peacehaven (after a butterfly found on the downs).

Alice was launched first, in July 2010, completing a 1.8km drive west to Marine Gate in open mode before being modified to closed mode for the 3.6km drive to Portobello. Meanwhile, Hollyblue mined 2.7km west to Portobello, and 1km to the Friars Bay head shaft, both in closed mode due to the potential for groundwater at Peacehaven. Progress rates were at times spectacular with Alice peaking at 32 rings (each 1m long) in a 12hr shift, and Hollyblue exceeding this at 37 rings, a figure the project team claim may be a record for bolted and grouted rings.

The final 0.9km of tunnel was constructed as a 1.8m diameter pipe jack by Joseph Gallagher, using a new Iseki slurry TBM. A 288m length descended at a grade of 1 in 10, before negotiating a 600m radius vertical curve and entering a temporary shaft on the promenade at the base of the cliffs. A further 660m was driven out to sea before the TBM reached a dredged trench for an underwater recovery and the connection of the concrete pipes to the 1.4m diameter, heavy duty plastic pipe (that had previously been laid in a dredged trench and backfilled over), running a further 2km to diffuser units placed on the seabed.

Shaft grouting

A number of shafts extended below the groundwater table and the majority of these were treated by stage grouting with microfine cements. These were very successful, far more so than with the difficult cement grouting employed on the 1990s scheme. Two exceptions were Portobello and one of the Peacehaven shafts, where the decision was taken not to grout. Progress during shaft sinking was clearly much reduced, but the costs from this were far outweighed by the savings from not treating.

The base section of each shaft was constructed in SCL, taking full advantage of the easier tunnel eye details afforded.

Additional shafts

Significant programme savings were produced by the construction of additional shafts at the pumping stations, allowing the pumping station construction to continue without a hold for the TBM removal. The short connection tunnels were constructed by open face pipejack, by SCL, or in one case as a timbered heading.

Cutting teeth design and wear

Nodular or tabular flint occurs generally in bands around 1 to 1.5m apart in all the chalk horizons tunnelled through. The impact on large pieces of flint can cause brittle cutting tools to break, and the broken flint forms an extremely effective grinding paste resulting in the rapid wear of unprotected steel. Learning from work carried out on pick design with TBM cutters on the stormwater tunnel of the 1990s, the teeth proposed were fitted with a relatively soft grade of tungsten carbide and very heavily protected against wear. The cutterhead was also fully protected with hardfacing. Very few teeth were damaged during tunnelling, a far cry from the 1990s when teeth required changing as often as every 200m.

Form of contract

Southern Water originally went out to tender under an IChemE Green Book (reimbursable) form of contract, but the industry was not happy with the conditions and no bids were received. Listening to the fears over risk allocation, the client moved to an IChemE Burgundy Book (target cost) form of contract. This ensured collaboration between all parties, and performed well.

Above: Portobello pumping station at the time Alice was recovered from the additional reception shaft

Stakeholder management

The project has always caused strong reactions amongst local residents, and was heavily opposed during the planning process. Therefore, the team left no stone unturned in keeping the local communities informed and involved in the project. It is a testament to the efforts and skill of the whole project team that many opponents were converted to advocates during the construction period.

Questions from the floor

Neville Harrison of Mott MacDonald asked about the segment types and shaft sinking methods. The speakers responded that the 2.44m diameter segmental rings were 1m long and formed of six tapered trapezoidal segments which were (except for a short section beneath a dry valley) reinforced with steel fibres. The upper sections of all shafts were formed in pre-cast rings, and the lower sections generally constructed in SCL and lined with in-situ concrete.

Bob Ibell, BTS chairman, asked whether the use of the IChemE Burgundy Book achieved what it set out to do. Craig Reade replied that the target cost, pain/gain contract had not been 'worked too hard' as the contract had not been beset with the problems previous contracts in Brighton had experienced, but that a successful collaborative ethic was evident. He added that Southern Water had spent a great deal of time planning the works, which resulted in few modifications during the construction phase.

David Percival of Atkins asked about the diversion of existing flows and whether the system will cater for all storm flows. The speakers replied that the 1990s Stormwater tunnel was there to collect and store stormflows, and the new system was fitted with overflows back into the Victorian interceptor sewer at the Marina and into the existing outfall at Portobello.

David Court of BAM Nuttall stated that he had previous experience of working with chalk and asked whether the team had experienced difficulties with disposal of the spoil. Craig Reade responded that some 181,000m³ of chalk was generated from the shafts and tunnels, and ultimately 100 per cent went for beneficial re-use, to a combination of landscaping, capping, to cement works and for soil pH control on farm fields. However, the spoil produced by the TBMs was a very sloppy paste and treatment was regularly required with lime or Dry-Add to ensure transportation could take place without fear of spills onto the roads.

Jean-Marc Barsam of Halcrow described the benefits of the contractor working collaboratively with their designer (Halcrow), and the speakers agreed with this. He also referred to the difficulties experienced in operating within a tunnel so small as to breach the HSE / BTS / PJA guidance for Designers on minimum tunnel diameters and maximum drive lengths. The speakers described the difficulties of maintaining the required minimum escape dimensions and that the back-up gantries on Alice had required modification to achieve this. They also pointed out that the tunnel diameter was not Halcrow's design, but a Southern Water planning requirement.

Philip Wall of Capita Symonds asked why launch adits were used for the Ovingdean TBM and not for the Peacehaven TBM. Craig Reade responded that the groundwater conditions at Peacehaven made the construction of adits here too risky, and that analysis following completion was inconclusive as to whether the benefits from the launch adit construction outweighed their cost.

Beata Bonin of Halcrow mentioned that the shaft construction at the pumping stations are split between pre-cast rings and SCL, this being due to the level of water in the shaft during operation, and hence the need for a secondary in-situ lining. She suggested a further presentation on the pumping stations.

Peter Murphy, consultant, finished the evening by congratulating the team on ensuring that it wasfourth time right for tunnelling in Brighton, and asked whether methods could be put in place to ensure lessons could be learnt more easily. Craig Reade responded that by papers and presentations such as this (and a paper in preparation for the Proceedings of the ICE), he hoped suitable information could be disseminated.

Rapporteur: Ken Spiby

Harriet on Hong Kong

Harriet Rutledge (fourth from right) with female engineers from the Atkins Hong Kong office

"Engineers and their works are more visible in Hong Kong than back home in the UK," says Harriet Rutledge, a principle engineer for Atkins' 50-strong Hong Kong tunnelling operation. "The projects and the speed at which they are completed here are obvious all around you. It's possible that engineering is a lower status profession than in Britain, but you can't ignore it."

Rutledge took a four-year BEng in civil engineering at Edinburgh University followed by an MSc in soil mechanics and environmental geotechnics at Imperial College London. "This is not at all my specialism," Rutledge adds. "I've worked at numerical tunnel design, now with more and more coordination responsibilities and bid work for Atkins."

"I had no idea what I wanted to do and had never even thought about tunnelling. Maybe I had one underground lecture at university. A maths teacher had suggested engineering. I have no idea what I would do for a different career path. There's nothing else I feel passionately drawn to."

Rutledge has worked on upgrade schemes in Dublin, Ireland; Channel Tunnel Rail Link, UK; Crossrail, UK; Gautrain in South Africa and the Express Rail Link in Hong Kong. "Gautrain was my most and least favourite project so far. I spent two and a half years there. It was my first very big project and was a real eye opener to the pressure you can get in tunnelling."

She is currently working on a bid for the Shatin to Central Link contract 1109 – Sung Wong Toi and To Kwa Wan stations and tunnels with contractor Dragages.

"I like the bigger projects best, you get more of an overview of different aspects of the job. I'm happy to stay in Hong Kong if there are large projects available, there's always one around the corner and you often get several chances to work on them.

"You can't approach two projects in the same way keeps work interesting, and tunnelling is a great career for anyone who wants to try a bit of everything: geotechnics, structures and so on. More responsibility is almost a certainty."

An Atkins spokesman points out that Rutledge is part of an increasing percentage of women taking engineering positions in the company's Hong Kong office. Without a study of other companies and locations it would be difficult to tell if this is an emerging trend worldwide. Rutledge suggests that the visibility of engineering in Hong Kong may be a factor, as well as an increased awareness there of what people's friends are doing.

Rutledge says, "There are more women coming in and they are being promoted fairly I think. One of our associate directors is female. There are cases of women not being allowed in tunnels for various reasons. One I've heard is a tradition that the earth is female and somehow jealous if women go below ground.

"I think it's fair to say that there are not many female contractors in Hong Kong, and although the argument can be made that the worksite is too rough, perhaps if women were on site, things would start to be done differently.

"I'm not sure what advice to give to young engineers as I haven't had any disasters yet," says Rutledge. "The expat community in Hong Kong is really good – the usual known drinking areas… but also around 70 per cent [of the SAR] is country parks. There's a big expat watersports community and meet-up groups and so on. I've taken up sailing, and it's a good hub to visit the rest of Asia.

"Graduates are less well paid here, but chartered engineers are very well paid. The tunnelling society here in Hong Kong is informal and has a talk at the meetings – I go, depending on the talk. It's seen as a meeting for expats – the secretary is one.

"I volunteered to come to Hong Kong, and I'll stay here for a few years."

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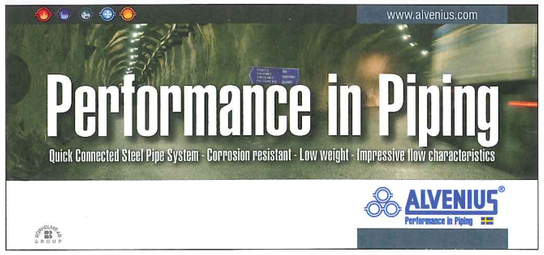

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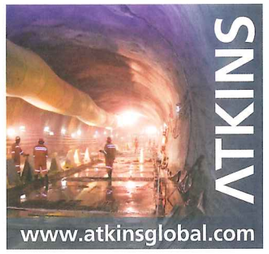

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14-16 MARCH 2012
ISTSS 2012, New York, USA
Forum with the themes of risk and security, human behaviour, passive fire protection and construction, active fire protection & fire fighting, ventilation and fire dynamics. The focus is shifting more and more towards security, with new the terrorist threats and the focus on how to solve these problems increasing. Organised by SP Technical Research Institute of Sweden - Fire Technology. For more information see www.istss.se, email info@sp.se or tel.: +46 10-516 50 00

20-22 MARCH 2012
3rd Brazilian Congress on Tunnels & Underground Structures & Intl Seminar 'South American Tunnelling', Sao Paulo, Brazil
At Centro Fecomercio de Eventos. The event will include 11 topics and be run with an exhibition and technical visits to World Cup sites etc. Now more than 70 subscribers reported. Two days will be reserved for a refresher course and training. Contact Executive Secretariat, Acqua Consultoria on tel.; +55 11 3868 0726, email 3cbt@acquacon.com.br or see www.acquacon.com.br/3cbt.

22-23 MARCH 2012
Intl Sym 'Practices & Trends for Financing & Contracting Tunnels & Underground Works', Royal Olympic Hotel, Athens, Greece
Organised by the Greek Tunnelling Society and ITA endorsed. Contact GTS on tel.: +98-21-88630496, email bakojon@otenet.gr or see www.tunnelcontracts2012.com

27 - 29 MARCH 2012
INTERtunnel 2012, Turin, Italy
The tenth edition will be staged at the Lingotto Exhibition together with Expo Ferroviaria. Italy's only regular exhibition on tunnelling technology but also with great international input. Italy claims the greatest number of tunnels in Europe and also has cross-border projects between Turin and Lyon, France, and also the Brenner Base Tunnel to Austria. Alongside Expo Ferroviaria rail exhibition. For more information email: intertunnel@mackbrooks.com or tel. Arianna Rosini on telephone +44 (0)1727 814 400

12-14 APRIL 2012
UnderCity 2012, Dubrovnik, Croatia
Colloquium at Hotel-Congress Center Valamar Lacroma on using underground space in urban areas in south-east Europe. Organised by ITA Croatia. Contact Tanja Rabar on tel.: +385-51-410-447, email tanja.rabar@hubtig.com or see www.undercity2012.com.

16-21 APRIL 2012
Intermat, Paris-Nord Villepinte, France
International exhibition of equipment, machinery and techniques for the construction and building materials industry. Companies registered so far include Casagrande, Cifa, Herrenknecht, Jean Lutz, Montabert, Peri, Robit and Sandvik. Enquiries to Maryvonne Lanoe or Maud Carcy on maud.carcy@comexposium.com, tel.: + 33 (0)1 76 77 11 93 or see www.intermat.fr

24 - 26 APRIL 2012
3rd Intl Conf on Shaft Design & Construction, London, UK
Organised by the Mining Technology Division of the IMMM and the BTS at 1 Carlton House Terrace. The scope includes all areas of design and construction of both civil engineering project and mine shafts. Contact Paul Harris at IOM Communications by email paul.harris@iom3.org, tel. +44 (0)20 7451 7302 or see www.iom3.org/events/sdc2012.

18 - 23 MAY 2012
World Tunnel Congress WTC 2012 & 38th General Assembly of the ITA, Bangkok, Thailand
Organised by the Thailand Underground & Tunnelling Group (TUTG) of the Engineering Institute of Thailand with the ITA, the theme is 'Tunnelling & Underground Space for a Global Society.' For more information email: secretariat@wtc2012.com or visit www.wtc2012.com

29 MAY - 01 JUNE 2012
SSCS - Numerical Modelling, Strategies for Sustainable Concrete Structures, Aix-en-Provence, France
Organised by the Association Francaise de Genie Civil (AFGC). Contact Nadget Berrahou-Daoud on tel.: +33 1 44 58 24 29, email afgc@enpc.fr or see www.afgc.asso.fr

24 - 27 JUNE 2012
North American Tunneling Conference (NAT), Indianapolis, Indiana, USA
UCA's biannual conference, which has continued to grow each year with more exhibits, technical sessions & attendees. More information regarding housing and registration will be available at http://uca.smenet.org/ in spring 2012

18 - 21 SEPTEMBER 2012
Eastern European Tunnelling Congress, Budapest, Hungary
The Hungarian Tunnelling Association is organizing the 1st Eastern European Tunnelling Congress to share experiences and exchange knowledge of design, construction management, research results and technical developments of tunnels completed by the regional associations and experts. The planned regional sub European conference is open to all other co-organizers and participants as well as to those who having ongoing or completed projects, research works in this area. More information at http://www.eetc2012budapest.com/

8-10 OCTOBER 2012
Intermat Middle East, Abu Dhabi National Exhibition Centre
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7 - 9 NOVEMBER 2012
13th World Conference of ACUUS, Singapore
The Associated research Centers for Urban Underground Space (ACUUS) presents 'Underground Space Development – Opportunities and Challenges' to focus on new opportunities in developing the urban underground space as part of sustainable development, and the issues that planners, developers, and engineers face. More information at http://www.acuus2012.com

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition, which is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site: Editor, 'Tunnels & Tunnelling International', Boundary House, 91-93 Charterhouse Street, London, EC1M 6HR, United Kingdom. Fax: +44 20 7936 6826 Email: editor@tunnelsandtunnelling.com Web: www.tunnelsandtunnelling.com

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ALL BTS MEETINGS ARE AT THE INSTITUTION OF CIVIL ENGINEERS, LONDON, UNLESS OTHERWISE STATED, AT 17:30 FOR 18:00 UNTIL APPROX. 19:30. TRADITIONAL BAR AND SNACKS WILL BE AVAILABLE AFTERWARDS.

15 MARCH 2012
Report from the BTS Compressed Air Working Group
Presentation by Dr Donald Lamont, Hyperbaric & Tunnel Safety and Roy Slocombe, Director of Herrenknecht International to link with the joint BTS/ITA international seminar on high-pressure compressed air work.

19 APRIL 2012
Harding Memorial Lecture Underground Infrastructure in the UK - meeting the future needs of society
The lecture by Arup director Bill Grose will look at the drivers of change in our industry, and some of the success stories of recent times. What is the shape of our industry in the future and how do we need to change in response? What technological advances and directions of research should the UK take?

17 MAY 2012
Annual Dinner
At The Brewery, Chiswell Street, London

14 JUNE 2012 (A WEEK EARLY)
The Thames Water Lee Tunnel – London's deepest and largest
Roger Mitchell, CH2M Hill; Scott McFadzen, Morgan Sindall; Jean-Christophe Galan, Vinci Construction will present the design and construction of the double lined shafts and novel aspects of the main.

contacts

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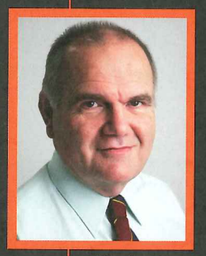

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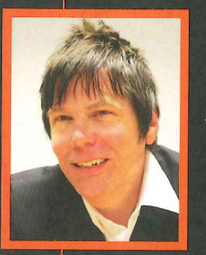

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EDITORIAL

EDITOR
Jon Young
Tel: +44 20 7336 5256
Email: jon.young@tunnelsandtunnelling.com

TECHNICAL EDITOR
Maurice Jones
Tel: +44 1296 397 353
Email: maurice.jones@tunnelsandtunnelling.com

AMERICAS EDITOR
Nicole Robinson
Tel: +1 612 9402 780
Email: nicole.robinson@tunnelsandtunnelling.com

NEWS EDITOR
Alex Conacher
Tel: +44 20 7336 5257
Email: alex.conacher@tunnelsandtunnelling.com

REGULAR CONTRIBUTORS
Adrian Greeman, Bernadette Ballantyne, Patrick Reynolds, John McKenna

PRODUCTION & DESIGN

DESIGNER
Dan Becker

TECHNICAL ILLUSTRATOR
Nick Stenning

PRODUCTION CONTROLLER
Loraine Lee
Tel: +44 20 8269 7799 Fax: +44 20 8269 7840
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John Carpenter House, 7 Carmelite Street,
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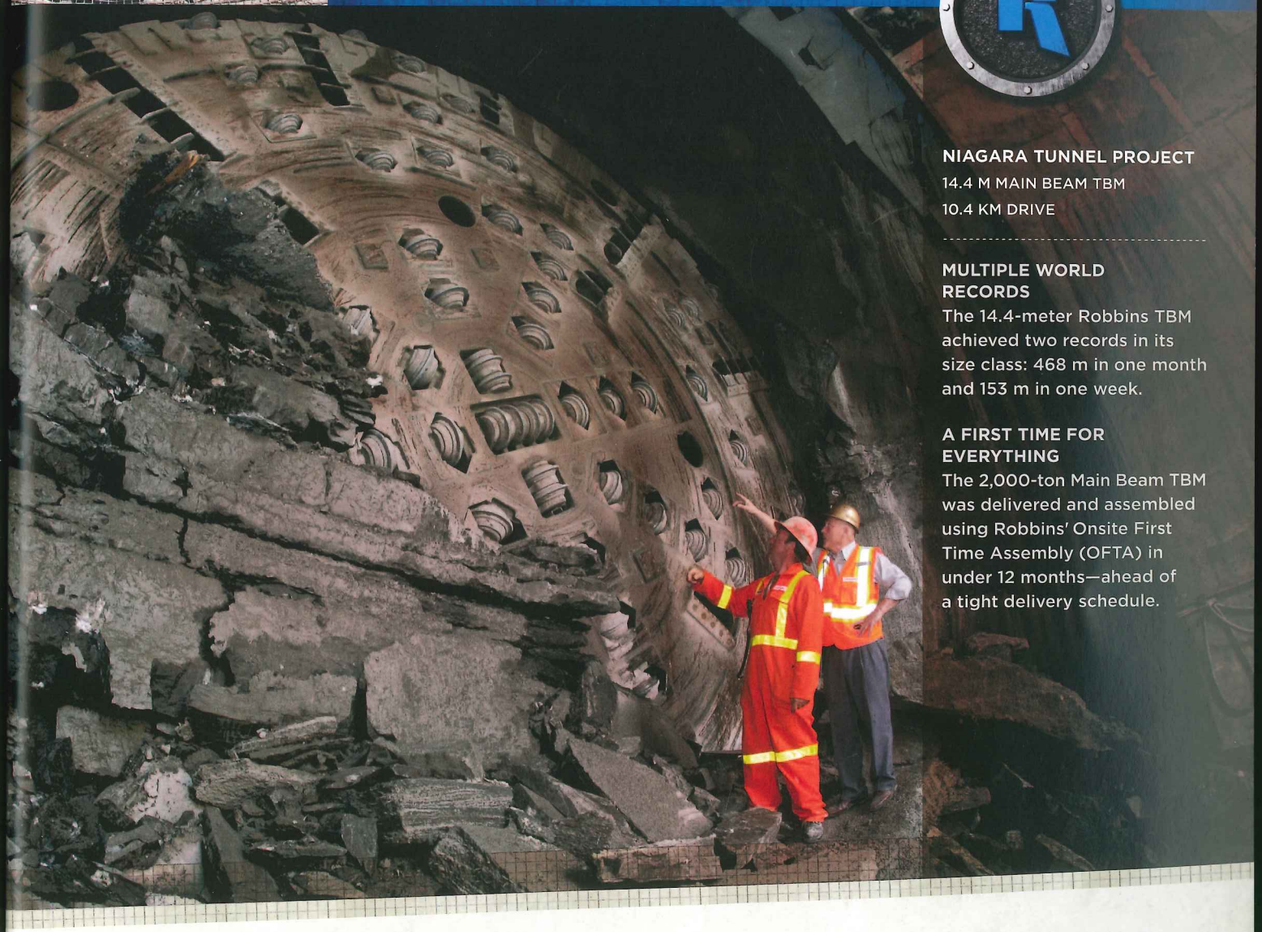

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