JUNE 2012

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Nazzano stretches

Italy widens the bore while live traffic flows beneath

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The only thing we have to fear...

Some 60m under Zhanjiang Bay in southern China, and about a kilometer from the tunnel entrance, this editor breaks for water with the project manager and the chief engineer.

Together we are walking the four per cent slope down to the TBM cutting the water transfer tunnel. The tunnel is pristine. It is lined with smooth concrete segments, gasketed and sealed with a coating of mortar to hold back the six bar of water pressure bearing down on the tunnel.

The ventilation system hums as it battles to keep the tunnel cool. With outside air temperatures creeping above 30°C the tunnel can quickly become stiflingly hot.

As we continue to march down the tunnel, the journey is cut short by the sound of rushing water and a thunderous slapping of the severed ventilation line. Elevated on a walkway above the tunnel invert mud quickly begins to flow beneath our feet.

Instinctively, the video camera is set rolling and homes in on the source of the inflow of liquid mud half a kilometer upstream. As many of you will have just done, this editor leapt to the conclusion that he was witnessing the result of poor design and construction of a Chinese tunnel. Perhaps expecting it to be the last thing he witnesses. In fact, the flow of mud, the ruptured ventilation line and the panic was the result of a failed coupling on the exiting slurry line. We were never in any real danger.

This not-so-near-death experience highlights a major challenge for the industry as a whole in tackling the perception of tunnelling and its dangers.

It is evident – not least by two stories in the news this month, a blast killing 20 in a tunnel in China and an explosion killing four in a tunnel in Japan – that tunnelling is a dangerous business. But with an estimated 500 TBMs currently in operation in China and a presently immeasurable number of tunnelling projects, it is clearly unfair to judge an industry on one-off or rare occurrences.

The Zhanjiang project is being carried out to an international standard; we will be giving a full report in the near future. It was preconceptions of China's tunnelling that spurred the fear in the tunnel. Everything about the project looked to be carried out with utmost integrity.

On page 6 of this issue we report on a scare mongering video released by the Parent Teachers Association in objection to the construction of a metro line under a school in Beverly Hills, USA. The film grossly exaggerates the real dangers of tunnelling and invents a series of new ones in an attempt to halt the project. In our sister publication T&T North America, managing editor Nicole Robinson gets her teeth into the issue, it is well worth a read.

As members of the tunnelling fraternity it is our role to present the industry positively and accurately to the general public, and the first step is understanding the actual ability of our colleagues, near or far, and not the perceived ability.

Safe digging!

Jon Young

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On the cover:
Widening of the Nazzano tunnel was carried out above live traffic flow. The mutli-functional machine cut and supported the new bore

SEATTLE: TOP PERFORMANCE TWICE OVER AT CAPITOL HILL.

For the extension of the underground city train in Seattle, Washington – the so-called University Link – the construction site teams from "Traylor Bros./Frontier-Kemper JV" celebrated a double success with two Herrenknecht EPB Shields. With "Togo" and "Balto" (Ø 6,560mm) the team crossed the target line at Capitol Hill in March and April 2012 respectively, three months earlier than scheduled.

On the route from University of Washington, the TBMs excavated twin tunnels of 3.5 kilometers each beneath the busy Highway 520, under the Montlake Ship Canal and below Seattle's densely populated city center with its historic buildings in some parts. The EPB Shields equipped with Herrenknecht technology mastered this challenge rapidly and safely. Now, the city of Seattle is looking forward to having a quicker link between the university and downtown, less traffic on the streets and better air.

SEATTLE | USA

PROJECT DATA	CONTRACTOR
S-560, S-561 **2x EPB Shields** Diameter: 2x 6,560mm Installed power: 608kW Tunnel length: 2x 3,478m Geology: Clay, silt and sand	Traylor Bros. Inc., Frontier-Kemper Constructors Inc.

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Tunnelling Systems

World's largest TBM on hold as Orlovsky tunnel cancelled

RUSSIA

The City of St Petersburg has cancelled the Orlovsky Tunnel project. The plan to create a new full-time route beneath the River Neva was shelved according to local reports. The project had called for the world's largest TBM, a 19.25m-diameter Mixshield machine from Herrenknecht.

Deputy governor of St Petersburg Sergei Vyazalov, who is in charge of finance, announced the cancellation at the end of April. It followed suspension of city funding for the PPP project announced in September last year. Since then there has been industry doubt about the future of the Russian project.

Sources close to the project have indicated to T&TI that they are hopeful that the project will resume soon. The fact that a large proportion of the project is privately financed is believed to be the source of the optimism.

The St Petersburg Times reported that Vyazalov said a project evaluation had shown that it would entail significant expenses to the city's budget without improving the transport situation. He suggested that the allocated funds could be used to double the number of the city's trams.

The Herrenknecht machine was intended to create a 1km passage through soft ground to link the city centre with the Smolny and major embankment highways. The order by project concessionaire Nevskaya Concession Company (NCC) was announced July 2011.

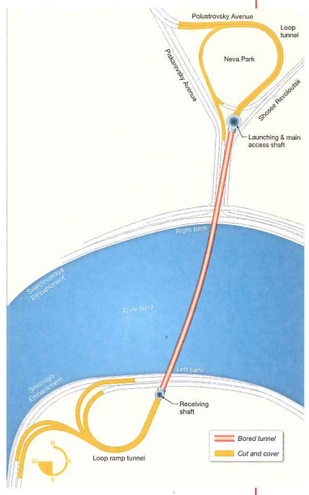
The project would have involved substantial cut-and-cover work or surface and elevated motorway-standard highways linking junctions at both ends of the tunnel. Site preparatory and design work was already under way.

City governor Georgy Poltavchenko effectively called a halt to the project in September and suspended two other major infrastructure projects during a re-evaluation of projects started under the previous governor Valentina Matviyenko.

He said the city "needed to establish how rational and urgent the projects are today". Orlovsky had been valued at a total of RUB 70bn (USD 2.2bn), including interchange construction, but estimates have increased substantially. NCC had won the right by tender to construct and manage the tunnel and to charge a toll over 30 years. And was reported to have been paid for work done so far.

The project was to be jointly and equally financed by the City of St Petersburg, the Russian Federal Investment Fund and NCC.

A major 'Roads, Bridges, Tunnels' exhibition is scheduled for 19-21 September this year at the Winter Stadium, St Petersburg.



Above: The passage under the River Neva called for the world's largest TBM at 19.25m. The machine would have beaten the current record by 3.7m

Crossrail starts digging

GREAT BRITAIN

The first Crossrail TBM to break ground, Phyllis, began tunnelling one bore of the project's twin western tunnels from the Royal Oak portal work site to Farringdon Station.

A Crossrail spokesman said, "Phyllis is now beginning to slowly disappear below ground and will steadily ramp up to the planned average tunnelling rate of around 100m a week."

Following the official unveiling of 1,000t Phyllis, Crossrail's first TBM travelled 400m to Royal Oak Portal including under Hampden Street footbridge, which was jacked up to allow the 7.1m diameter machine to pass beneath.

The arrival of the TBM at the portal in mid-March allowed for remaining major works to get underway to support tunnelling.

A major piece of work has been the construction of the launch structure, which allows the TBM to propel itself forward.

A steel seal has been fitted around the portal entrance to support the ground during the early stages of the drive.

Work has also been underway to install the major conveyor system behind the TBM to remove more than one million tonnes of excavated material from the cutter head to the portal entrance. A total of 24km of conveyer belt will be used to construct the western tunnels. Rail sidings have been constructed to allow freight trains to access Westbourne Park to transport the excavated material to Northfleet from where it will be shipped to Wallasea Island to create a nature reserve.

A narrow gauge railway has been laid to provide for small locomotives to transport materials and supplies into and out of the tunnel. Work has also been continuing at the Old Oak Common concrete segment plant. Over 8,000 segments have now been produced and stockpiled for the western tunnels.

A second TBM, Ada, had yet to be launched from Royal Oak as *T&TI* went to press. Once the first machine has progressed sufficiently, Ada will be brought down to the portal headwall.

When the second TBM has reached Paddington, both machines will progress forward through the Paddington station box to Bond Street and onwards to Farringdon. The tunnels between Royal Oak and Farringdon should be completed late in 2013.

Eight TBMs will be used to construct 21km of Crossrail's twin bore tunnels running between Royal Oak in west London and Pudding Mill Lane and Plumstead in east London.

The Crossrail route will pass through 37 stations and run 118km from Maidenhead and Heathrow in the west, through new twin-bore 21km tunnels to Shenfield and Abbey Wood in the east.

When Crossrail opens it will increase London's rail-based transport network capacity by 10 per cent, supporting regeneration across the capital. Crossrail services are due to commence through central London in 2018.

World at a glance

Project developments, milestones and challenges

LOS ANGELES, USA

The Los Angeles County Metropolitan Transportation Authority (Metro) board of directors approved the Final Environmental Impact Statement/Report for the Westside Subway Extension Project on April 26.

This first step toward certifying the USD 5.66bn project concerns only a 3.9-mile (6.3km) first phase with three new stations along Wilshire Boulevard. It does not include approval for the remaining project to Westwood, which was pending a hearing requested by the City of Beverly Hills as *T&TI* went to press.

Concerns over the proposed location for Century Station and tunnelling beneath Beverly Hills High School will be addressed in the hearing. The alignment has been a point of contention for the city and school district for more than a year when Metro approved the draft environmental impact report on 28 October 2010.

It is reported that the school district has spent more than USD 2M on the issue.

More recently the Beverly Hills Parent Teacher council released a dramatic and highly-charged video depicting catastrophes at the high school, in opposition to the line. "Those tunnels aren't going to be running under the buildings. They're so shallow they're going to be running through the buildings," said Tim Buresh, the school district's lead engineer, between scenes of explosions.

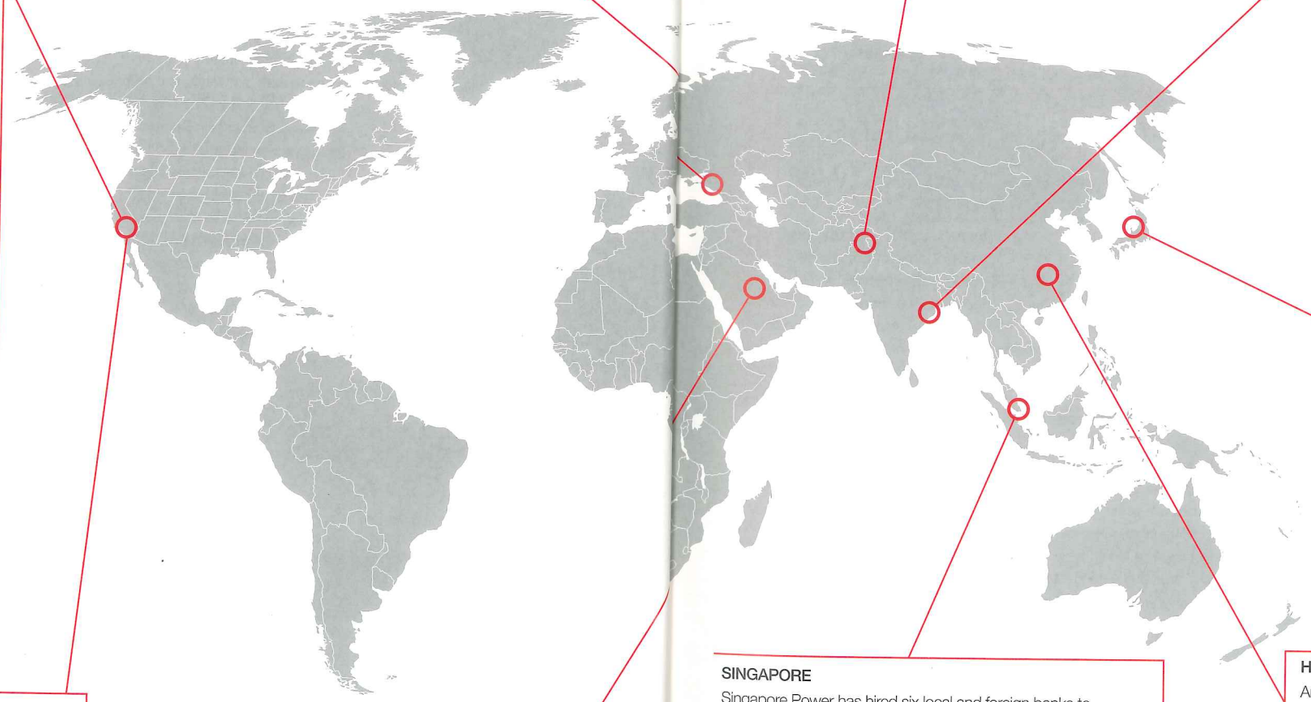
Following the hearing, Metro will still need to approve the full project and obtain federal environmental clearance before moving forward with various pre-construction activities, including awarding a construction contract. Construction could begin in 2013.

SOCHI, RUSSIA

Dismantling and removal of the of the 13.2m diameter TBM for Sochi Olympics motorway tunnels began in late April.

Before the tunnelling operations completed, Russia-based contractor SK Most prepared the ground for the removal of the huge 1,600t Herrenknect machine. For the smooth removal of the TBM a concrete bed was needed at the northern tunnel portal. However, the northern portal was congested by the ongoing construction of a cable-stayed bridge within the narrow valley of the Mzymta River, leaving no room to place the concrete. The bridge forms the next northerly section of the motorway.

The TBM was used to cut the northern section of motorway Tunnel System Number Three , part of the combined road rail route carrying traffic from Adler in Sochi, Russia to the nearby mountain resort of Alpika-Service. The machine took two years to excavate the 3,117m long tunnel, breaking through in March.



LOS ANGELES, USA

Environmental impact reports were certified in April for the Regional Connector Transit Corridor Project.

Estimated to cost USD 1.37bn, the project will connect light rail lines through downtown Los Angeles. The Los Angeles County Metropolitan Transportation Authority's (Metro) 'locally preferred alternative', the 1.9-mile (3.05km) fully underground light rail line, will be excavated by TBM. Three new stations will be required.

The Metro board will seek a record of decision for the project by the Federal Transit Administration before awarding a construction contract. Construction is expected to begin in 2013.

RIYADH, SAUDI ARABIA

Saudi Arabian authorities have launched a tender process to develop a new USD 3bn metro transit system in the capital, Riyadh. The 25-mile (40km) system should be complete within the next four years.

Arriyadh Development Authority (ADA), which is overseeing the Riyadh Public Transport Project, issued a notice calling for international consortia with metro tunnelling experience to notify their interest by 20 June 2012.

MUZAFFARABAD, PAKISTAN

Pakistan's Water and Power Development Authority (WAPDA) agreed to pay for two Herrenknecht TBMs for the Neelum Jhelum hydropower project near Muzaffarabad, Pakistan.

Contractor consortium China Gezhouba Group and the China Machinery Export Corporation, suggested the use of TBMs, though they were not included in the original contract.

A spokesman said, "very high pumping capacity is required, otherwise all is lost. If the TBM has ideal conditions it can advance 20m a day in good rock conditions but Neelum Jhelum's soil will not even permit 10m a day."

The machines will add to the overall cost by PKR 16bn (USD 300.5M). The project has risen from USD 1.4bn in 2008 to USD 3.6bn. Both TBMs arrived on site early this year.

KOLKATA, INDIA

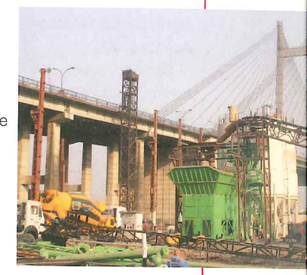
The East-West corridor of the Kolkata Metro Railway, which had a delayed deadline of 2016, could be ready for a trial run by 2013. The first phase of the INR 48.74bn (USD 993.5M) metro project is slated to be in operation by October next year.

"We are hopeful that we can start a trial run for the first phase of the project by October 2013," said GC Mitra, chief executive engineer of the East Metro Railway project. "The work for the project is going on at a good pace."

The tunnel had an initial deadline of February 2011 but construction work on the tunnel did not start until February this year. Land acquisition problems and ownership issues shifted the completion date to 2016. Paul Verall, project manager with Afcons, said he could not confirm that the tunnel will be operational in 2013.

The first phase of the 14.67km Metro line, which will run 8.9km underground, will be built and maintained by Kolkata Metro Rail Corporation (KMRC), with the Indian Railways holding the majority stake.

The stations Salt Lake Stadium, Phool Bagan and Sealdah will all be underground. Two 6.35m Herrenknect TBMs will excavate the tunnels.



MINAMI UONUMA, JAPAN

Four Japanese construction workers were confirmed dead last month after being recovered from inside a tunnel where they had been trapped for three days.

A blast occurred early on Thursday 24 May, roughly 1.2km into the 2.8km-long Hakkatoge tunnel, being built in Minami Uonuma, about 180km northwest of Tokyo. Rescuers were unable to enter the tunnel until Sunday 27 May due to high gas levels. Sensors detected oxygen, hydrogen sulphide, an unidentified combustible gas, and carbon monoxide.

On the same day, police searched the office of contractor Sato Kogyo's Hokuriku branch in the city of Toyama and two other places for evidence of professional negligence resulting in injury. The tunnel is scheduled for completion in December.

SINGAPORE

Singapore Power has hired six local and foreign banks to provide a SGD 1.5bn (USD 1.2bn) finance loan for its power cable tunnels project.

Bloomberg reported the banks were: the Bank of Tokyo-Mitsubishi UFJ, DBS Bank, Mizuho Corporate Bank, Oversea-Chinese Banking Corporation, Sumitomo Mitsui Banking Corporation and United Overseas Bank.

Both tunnels will transfer electricity beneath the city-state and will have a 100-year design life. Mott MacDonald won a contract to design the 18.5km-long North-South cable tunnel. A consortium of Worley Parsons and Aecom was awarded the 16.5km-long East-West tunnels contract.

HUNAN PROVINCE, CHINA

An explosion killed 20 people last month on an under-construction Bamianshan expressway tunnel in Hunan Province, central China. Rescuers said that only one body had been retrieved.

When the blast occurred, a total of 24 people were working in the tunnel, which forms part of the Yanling-Rucheng expressway. Four workers were pulled out, with one in critical condition and another slightly injured.

Rescuers have conducted life detections six times at the site with no success. The blast occurred at about 8:30am on Saturday 19 May when a vehicle carrying explosives was unloading in the tunnel. The explosives were contained in 12 cases, each weighing 24 kilograms. An investigation into the cause of the explosion was under way, and rescue and clear-up work continuing as *T&TI* went to press.

Leaks keep Gautrain link closed

SOUTH AFRICA

The Rosebank to Johannesburg Park Station section of the South Africa's 15km Gautrain tunnel is destined to remain closed pending a full solution to its water leakage problem. The leaks have been a major point of dispute between the project concessionaire Bombela, and the provincial government led client, Gautrain Management Agency (GMA).

Barbara Jensen, Gautrain communications and marketing manager, said that the problem of leaks through the tunnel walls had not been solved. Bombela is responsible for construction, operation and maintenance of the route through its 14-year concession while the provincial government owns the system through the GMA, its agent.

According to the GMA, the water inflow is still four times that agreed with the contractor as acceptable. Concern has been expressed about the possibility of resulting damage to the train system and removing groundwater from vegetation at the surface.

Bombela invited the media on a train test run through the line section in dispute, claiming that the trains were ready and that all was required was permission to start operations, and that the water problems had been addressed. Bombela spokesperson Errol Braithwaite said that the tunnel invert had been grouted to prevent water leaks, and that water coming through the walls was 'minimal and normal'.

A statement issued by Jack van der Merwe, CEO of GMA said, "Last year Bombela was directed by the Dispute Resolution Board to remedy the situation so as to meet the specification for tunnel water inflow as set out in the contract between the province and Bombela. To date this has not been achieved.

"What this means is that, while Bombela may be able to manage the excessive quantity of water flowing into the tunnel and provide the train services in the short term, up to the present time it has not provided any credible assurances to the province that the water will not cause irreparable harm to the tunnel itself and the environment around it on the long term."

French contractor Bouygues leads Bombela. Atkins designed the tunnel. Other sections of the 77km Gautrain system were opened last August.

World's first underground park

USA

Multi-disciplinary teams are designing the world's first underground leisure park.

The proposed Delancey Underground in New York is the brainchild of social entrepreneur Dan Barasch and architect James Ramsey of Raad Studio.

The space was the subject of a display at the Mark Miller Gallery in New York's Lower East Side in April and May; the exhibit featured photographs of the existing site and life-size renderings of the architects' plans.

The development will include measures to bring in sunlight through special equipment, vegetation and fresh air to an abandoned subterranean trolley (streetcar) terminal.

The teams from designer Arup were working on feasibility studies, testing of the site, and working on proposed designs from the aspects of project safety and constructability as *T&TI* went to press.

Staff involved on the project have included structural, mechanical, electrical, plumbing and geotechnical engineers, consultants in fire life safety, coding and acoustics, plus lighting and tunnel designers.

Arup is also working on another project exhibit in September in an abandoned section of the Essex Street Market to feature the proposed lighting technology.

Below: Artist conception of the finished underground park

Road tunnel inspections called for after fire kills two

CHINA

China's Democratic Progressive Party (DPP) has called for a nationwide inspection of road tunnels following a vehicle pile up that killed two and left more than 30 injured.

The deaths have triggered inspections of 12 other tunnels in the Taiwan capital of Taipei, according to local media reports.

The accident occurred in the 12.9km Hsuehshan tunnel when a small truck with a blown tyre caused a large bus behind it to brake heavily. A small passenger vehicle following the truck also slammed on its brakes, swerved and was rear-ended by a second bus. The car caught fire, killing both occupants.

China's National Freeway Bureau has slashed the speed limit on the southbound lanes of Taiwan's longest tunnel to 80kph following the crash. The speed limit inside the tunnel was 90kph, but drivers were not fined at speeds below 100kph.

The speed limit was increased in 2010 following complaints of congestion, as vehicles are not allowed to change lane in the tunnel. As *T&TI* went to press it was not clear if the increased speed limit was in accordance with the tunnel's design.

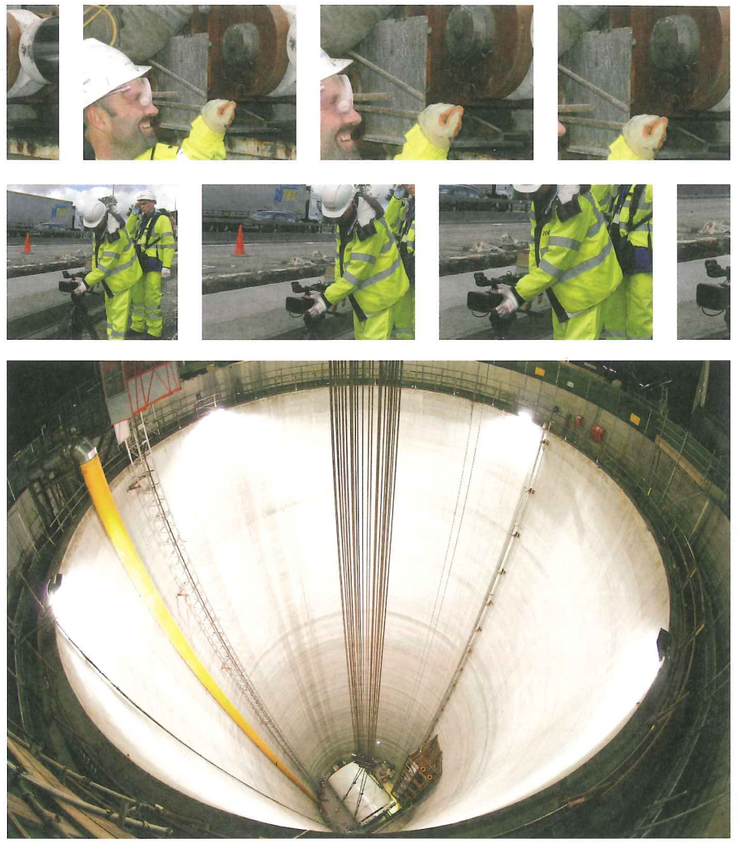
The DPP also called for fire drills to be conducted every month. They are currently conducted every three months. According to local media, the DPP questioned the decision to award a three-year contract for fire safety controls to a gardening company called Shang Hung Gardening.

The company is a supplier of fire fighting equipment.

News in brief

Caterpillar LPT TBM reaches first milestone

The 3m Caterpillar dual mode TBM from Canada, which is digging 19km of the 32km London Power Tunnel project, has achieved breakthrough into an intermediate shaft. The machine, now below National Grid's Channel Gate Road, began its journey from Willesden Substation earlier this year.



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Diamond mine collapse kills 10 in South Africa

SOUTH AFRICA

The bodies of 10 illegal diamond miners were pulled from a disused tunnel in South Africa's Northern Cape province, De Beers announced on 26 May.

Diamond giant De Beers and caretaker Namaqualand Mines have been at the site in Kleinzee since Tuesday 22 May after it collapsed. De Beers said the illegal miners were working in a tunnel that has been left by the producer two years ago, adding that they had ignored warnings not to enter the disused shafts.

"The operation will progress until all illegally excavated tunnels are found," De Beers said in a statement. "People are knowingly entering mine property, destroying fences, ignoring signage, evading arrest, transporting mining equipment and undertaking the dangerous excavation of tunnels that have proven to be unsafe and have in fact cost the lives of illegal diggers in the past."

The tunnels were not part of a previously worked underground mine but were excavated illegally at the site.

It was previously reported by local media that 11 workers managed to escape the collapsed tunnels and one person was rescued and taken to hospital.

In 2011, De Beers announced it was exiting the region where it has mined for 90 years. However, the company announced that it has plans in place to create 5,000 non-mining jobs in Namaqualand over the next five years.

Above: Damian McGirr takes over from Bob Ibell

New chair for BTS

GREAT BRITAIN

The chief tunnel engineer at Donaldson Associates has been appointed chairman of the British Tunnelling Society (BTS) at the association's annual general meeting held last month.

Damian McGirr, who was prevously on *T&TI*'s editorial advisory board, succeeds Bob Ibell who was chairman two years.

McGirr wants to build on this opportunity to promote tunnelling in the UK as a safe, cost effective and sustainable method of developing infrastructure. He told *T&TI* (April, page 24) that "the UK tunnelling industry and the BTS need to ensure that tunnelling has a continued and increasing role in the development of major projects [in the UK]."

McGirr wants to continue developing ways in which to attract more young people into tunnelling. "We need to ensure that we have the engineers that we will need for the future support and development of our industry."

News in brief

Jacobs Associates to provide CM support for Seattle tunnel

Jacobs Associates has been chosen to provide construction management support for the USD 1.35bn SR 99 tunnel project in Seattle, Washington, the company revealed late last month. The 2.7km tunnel will be built by the world's largest diameter TBM, which is slated to be deployed in mid-2013. The project is part of a programme to replace the Alaskan Way Viaduct, which had been weakened following an earthquake in 2001.

Two arrested for tunnelling into pawnshop

Two suspected gang members were arrested after they were caught tunnelling into a pawnshop in Galas, Quezon City in late April. An acetylene tank, two saws, two chisels, a hand drill, a boltcutter, two crowbars, two headlamps, a screwdriver and P100,000 (USD 2,297) they allegedly stole were seized from them. Investigators said the suspects had been renting an apartment 50m away from the shop for a month. They said the suspects dug a tunnel from their apartment to the floor of the pawnshop.

Jacobs wins Hong Kong materials testing contract

HONG KONG

US-based Jacobs Engineering late last month announced it was awarded an outsourcing contract from the Civil Engineering and Development Department of the Hong Kong Special Administrative Region to provide management and operating services for the new Public Works Regional Laboratory, Siu Ho Wan. The estimated USD 11M contract starts in June and will chiefly focus on materials compliance testing for the Hong Kong-Zhuhai-Machau Bridge, which includes a 6km tunnel.

Jacobs' scope of work for the project includes operating the Siu Ho Wan facility and managing its 51 laboratory-based staff.

Federal funds dedicated to Sydney freeway tunnel

AUSTRALIA

The Australian federal government has budgeted AUD 200M (USD 197.32M) for New South Wales to help plan major road infrastructure projects, including a freeway tunnel.

The proposed tunnel would link the F3 (Sydney-Newcastle Freeway) with the M2 motorway in northwestern Sydney.

Local media reported that another AUD 25M (USD 24.67M) could be made available, with matching funds from the state, to start an investment company. The financial investment would be controlled by the state government, to attract private financing for major infrastructure projects in the region.

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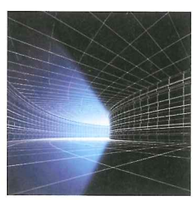

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Brisbane's Airport Link tunnel delay to cost USD 60M

AUSTRALIA

Electrical fit-out problems have pushed back the opening of the USD 4.8bn Brisbane Airport Link tunnel to August 2012. The two-month delay to Australia's largest infrastructure project will cost contractor Thiess John Holland (TJH) USD 60M.

The 6.7km tunnel was expected to open by 30 June. TJH now faces rolling penalties of USD 1.2M a day until the project is completed. TJH parent company Leighton Holdings has named 20 August as the likely opening date.

The firm announced that while construction of the project would be completed by June, the electrical fit-out would still require testing. "Construction elements of the project will be completed in line with our expectations with final commissioning and safety testing programmed to be completed through July," said Hamish Tyrwhitt, CEO of Leighton Holdings.

"More than half of the tunnel is now in the commissioning stage with the testing of services including lights, fans, surveillance, fire deluge and ventilation systems, and tolling systems underway."

Tyrwhitt added, "The commissioning involves around 12,000 individual tests and TJH has completed some 7,000 of these so far. While remaining commissioning activities are complex, we are anticipating that the final tests will be completed in July allowing the road to then be opened to traffic in August."

The delay is further bad news for the project; in April 2012 Leighton Holdings identified 'deterioration in the financial performance' of the Airport Link tunnel, resulting in a forecast profit reduction of USD 263.6M before tax reflected in the current financial year to 31 December 2012.

However, Leighton Holdings has stated that the revised opening date will not impact on its profit guidance for 2012 as the company had made adequate commercial allowances to cover all the schedule changes.

When completed in August, the Airport Link tunnel will run from Bowen Hills, where it connects to the existing Clem7 tunnel, and to near Brisbane Airport through a network of 15km of tunnels and busway tunnels.

EU politicians meet on Fehmarnbelt

DENMARK

EU politicians landed in Femern last month to discuss the proposed tunnel between Denmark and Germany. A delegation from the European Parliament's Transport and Tourism Committee and members of the Directorate-General for Mobility and Transport met with the Danish transport minister Henrik Dam Kristensen and representatives of Femernbelt Fixed Link promoter Femern to discuss the project.

The visitors were welcomed to the island by Secretary of State Tamara Zieschang and mayor Otto-Uwe Schmiedt.

Kristensen showed the visitors from Brussels the future location of the construction site for the tunnel, which will connect Germany and Denmark. An alignment east of the major ferry ports is the preferred option. The exact alignment will only be determined once official approval in Denmark and Germany is in place. In Denmark, this will take the form of a Construction Act passed by Folketinget, the Danish parliament, most likely towards the end of 2014. In Germany, final approval is expected to be in place around the turn of the year 2014/2015. Until then, some modifications could still occur within the 1,200m broad corridor.

A spokesman from Femern said, "[Zieschang] reported on dialogue with residents in the region via the Fehmarnbelt Fixed Link Dialogue Forum, while Leo Larsen, CEO of Femern, gave an overview of the project's current status. Technical director Steen Lykke and project director Claus Dynesen were available to answer any questions."

Ferrovial lands Spain HSR job

SPAIN

Construction of 7.6km of high-speed railway, including one tunnel, on the Madrid to Galicia rail project in Spain has been awarded to Ferrovial Agroman, a construction subsidiary of Spain-based Ferrovial. The EUR 108.8M (USD 143.1M) railway between the Padornelo Tunnel and Lubian will be completed in 2015.

The project includes the construction of the right gallery of the 6.4km Pardonelo Tunnel and galleries connecting with the existing tunnel, to be upgraded as part of a different project. Ferrovial Agroman will also build the 168m-long Leira viaduct and the 295m-long Pedro viaduct, both for the right-hand track.

This section of the 99km route between Puebla de Sanabria, Zamora, and Orense, Galicia is one of the most complex segments of the Madrid-Galicia high-speed railway line due to the area's rugged terrain.

News in brief

Moscow metro excavation set to start

Assembly of a 508t TBM is almost complete, ready for tunnelling 1,800m between the Lermontovsky Prospekt station and Vykhino subway stations in Moscow, Russia. The Herrenknecht TBM will be deployed during June. Installation of reinforced concrete lining will follow tunnelling.

Finnish parliament approves underground facilities contractor

The Finnish Parliament's Office Commission decided in its meeting held last month to launch interior finishing work for the construction of underground facilities, which is part of the Parliament House's renovations. Finnish contractor Lemminkäinen was chosen as the main contractor for the work. The project is valued at around EUR 28M. Construction is expected to begin in June and should be completed by summer 2014.

Shortlisted bidders for Bank Station announced

GREAT BRITAIN

London Underground (LU) announced in late April the four bidding groups who have been shortlisted to go through the new Innovative Contractor Engagement (ICE) procurement process for the Bank Station Capacity Upgrade project.

The Bank and Monument Tube station complex is located in the heart of the City of London financial district and is the fourth busiest interchange station on the Underground network with 96,000 customers during the morning rush hours, which is set to increase.

Bank is a key interchange served by six lines (Northern, Central, Waterloo & City, and at the Monument end of the same station complex, the District & Circle), as well as the Docklands Light Railway (DLR), for which Bank is the main central London terminus.

The upgrade project will, by 2021, deliver increased capacity at Bank station and a step-free route between the Northern line platforms, DLR and street levels.

Following the advertisement in the Official Journal of the European Union in November 2011, LU has completed its evaluation of the prequalification questionnaire (PQQ) responses and aims to award a contract by July 2013. The pre-qualified bidders were: BFK Joint Venture (BAM Nuttall, Ferrovial & Kier); CVC Joint Venture (Costain, Vinci Grand Projets & Vinci Construction); Dragados; MBA Joint Venture (Morgan Sindall, Balfour Beatty & Alpine Tunnelling).

LU capital programmes director David Waboso said, "We are using the new ICE procurement process for the first time with this project. This process should improve our relationship with the contractor market and get the benefits of early contractor involvement while developing major design and build contracts."

The process has been designed to allow bidders to bring their expertise and knowledge to drive innovation that will reduce cost and risk to the project.

This innovation will be commercially confidential to each bidder so they are able to fully derive the value and competitive advantage of their innovation through the procurement process.

Keller releases interim performance analysis

USA

Ground engineering specialist Keller last month issued a statement reviewing its divisional performances in the construction sector. The statement covered the period 1 January to 17 May.

The company announced its performance in Europe, the Middle East and Africa was disappointing and blamed the market conditions. Its response has been to downsize business in the least certain areas including Spain, Portugal and areas of Eastern Europe.

North American business saw growth, and resulted in 'modest' margin improvement. While Keller's Asia activities enjoyed a good start to the year with improvements in Singapore seeing its Resource Piling division trading well. Australia is mixed, with strong performance from resources but weaker trends in construction.

Dassault targets Gemcom

FRANCE

France-based Dassault Systemes announced that it intends to acquire geological modelling and simulation company Gemcom Software International of Vancouver, Canada. Dassault is already a leader in three-dimensional design, mock-ups and product lifecycle management (PLM).

The reported sum was USD 360M. A statement by Bernard Charles, president and CEO of Dassault Systemes, indicated that the company intends to extend its services within and beyond the natural resources industry. Gemcon is the world's largest supplier of mining software.

The completion of the acquisition is expected to take place in July.

Aecom's second quarter results

USA

Aecom released its Q2 2012 financial results last month. Revenue hit USD 2bn with net attributable income at USD 49M and an order book total of USD 16bn as of 31 March.

This meant that revenue growth for the quarter increased by four per cent on the previous quarter. Net income saw a 15 per cent reduction.

Aecom chairman and CEO John Dionisio said, "During the quarter, we saw strength in our professional technical services segment driven by accelerated growth in key end markets and regions, including emerging and natural resources as well as Asia.

"Unfortunately, this strength was overshadowed by challenges in our management support services segment."

News in brief

Hong Kong tenders 5km subsea tunnel

The Hong Kong Highways Department issued a prequalification and tender notice for the northern connection subsea tunnel section of the Tuen Mun – Chek Lap Kok Link late last month. The contract includes a 5km long dual two-lane subsea tunnel that will run between Tuen Mun and the Hong Kong-Zhuhai-Macao Bridge Hong Kong boundary crossing facilities. Works are expected to commence in the second quarter of 2013 for completion in late 2017.

Amsterdam metro milestone achieved

Construction workers on the Amsterdam North-South metro line are lowering the third and final caisson to connect Amsterdam Centraal with station Rokin, the first stop southward, as *T&TI* went to press. The 42m long caisson is descending at 0.5m per day to a 20m depth.

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India faces metro challenge

With a metro project in every major city, save Hyderabad, for now, India's furious investment in infrastructure is just the beginning as its still largely rural population urbanises. However, difficulty securing construction permits is not the only damper on Indian tunnelling. Alex Conacher reports

The second most populous country in the world, India makes most people think of crowded streets full of noise and commerce. Economists see it as a wealthy nation ripe for trade deals. Most tunnellers probably think of the incredible rates of infrastructure construction to meet demand.

India has barely got going. Out of the developing powerhouse 'BRIC' nations (Brazil, Russia, India, China), India has the lowest urbanisation rate at 30 per cent. This is the level the UK was at in the mid 1950s, but with a population some 24 times larger.

This means not just enormous infrastructure demand, but a sustainable one for many years to come. Seen in this context, confidence in a phase five or further of the Delhi Metro and other projects does not seem overly optimistic, but a conservative realism.

The underdeveloped infrastructure is seen as one of the major dampers on growth by the government, which may allow tunnelling to be ring-fenced against slowing GDP growth in the country.

Budgets and bureaucracy

In the 2012/13 budget statement, India's finance minister Pranab Mukherjee said that one of government's strategies was to increase investment in infrastructure through a combination of public investment and PPPs. And in the 12th Five-Year Plan (2012-17) infrastructure spending is planned to rise to the equivalent of nine per cent of GDP, with half of this spending coming from the private sector.

Much still needs to be done to improve the regulatory environment relating to construction projects to facilitate faster growth and development.

According to the World Bank's 'Doing Business' survey, India ranked 181st out of 183 countries in the category of dealing with construction permits. In total there are 34 procedures that take a cumulative 227 days to complete, compared with an average of just 14 procedures and 152 days in Organisation for Economic Cooperation and Development (OECD) countries. It tops only Albania and Eritrea.

The costs involved are also relatively high; on average the equivalent of 1,631 per cent of income per capita compared with an OECD average of 46 per cent.

Drinking money

The Indus River flows from the Tibetan Plateau to the Arabian Sea. Though largely in Pakistan, which depends on the river for water, part of the 'Father of Rivers' runs through the Jammu and Kashmir region of India. This is a boon for energy-hungry India, and hydropower development on this stretch of water is extensive.

Not so for underdeveloped Pakistan. Tibetan glaciers are melting quickly, and while in the short-term this can mean increased water levels and increase the risk of floods, the semi-arid country is highly protective of its liquid lifeline.

Even the lighest research into the many hydro projects in this region highlights the many controversies: Climatologist warnings, arguments and citings of the 1960 Indus Waters Treaty on both sides.

For tunnellers, job security is the issue here. Projects such as the approximately USD 1bn Kishanganga hydropower project, which has already had over half that figure spent on it as *T&TI* goes to press, faces a fight for its survival in front of the International Court of Arbitration. *The Hindustan Times* reports that this dispute is actually over disruption of water supplies to a Pakistani hydro plant further downriver.

Risky business

Mohan Gupta, Mott MacDonald divisional director of metro and civil geotechnical works tells *T&TI* that risk is a key factor in delivering the Delhi Metro at least, on time. "The works are all built in small packages. This minimises the risk and gives a small focus. All types of tunnelling are available in each package, for example cut and cover stations and TBM-driven running tunnels.

"The issue is that in India risk is distributed unusually compared to the rest

Above: **Delhi metro underground work is employed only when cost-appropriate**

of the world. The contractor is commonly asked by the client to carry all of the risk. This has meant that contractors in India have been unable to make large profits and is a risk to the Indian tunnelling business. India is a harder place to do business than many other countries in the world, though of course nowhere is easy enough."

India is listed as a highly competitive environment with many contractors across all sectors of industry as a barrier to entry. Gupta says, "I was here from 2001 until 2004 when I came to the UK to learn about underground construction in detail. Around 90 per cent, or even more of the local tunnellers at one point or other worked for Mott MacDonald. We have a very large local presence and flexible expertise. We try to use locals where we can but international skills have been key to our progress and where we are today.

"[Delhi Metro Rail Corporation MD until December 2011, Elattuvalapil] Sreedharan has been vital in bringing international professionals in where needed."

In this report

In its 2012 India focus, *T&TI* revisits the Pir Panjal railway tunnel far in India's north. The project faces unpredictable ground and difficult accessibility, as well as the associated challenges of building India's longest (11.2km) railway tunnel for contractor HCC and consultant/designer Geoconsult (see feature, page 23).

Finally a summary of the scope of works on the Delhi Metro, which aims to see 400km of line in its network by 2025 and a place among the most extensive metro systems in the world.

The project recently lost its MD to partial retirement. Described by many as visionary, Elattuvalapil Sreedharan was with the project from the beginning and is known as 'Metro Man'. Feature on page 32.

Above: **Rapid expansion could be the result of splitting the gargantuan metro project into small packages, with all of the risk on the contractor**

Reference

Data and analysis by: timetric.com

Ease of Doing Business Rankings: www.doingbusiness.org/rankings

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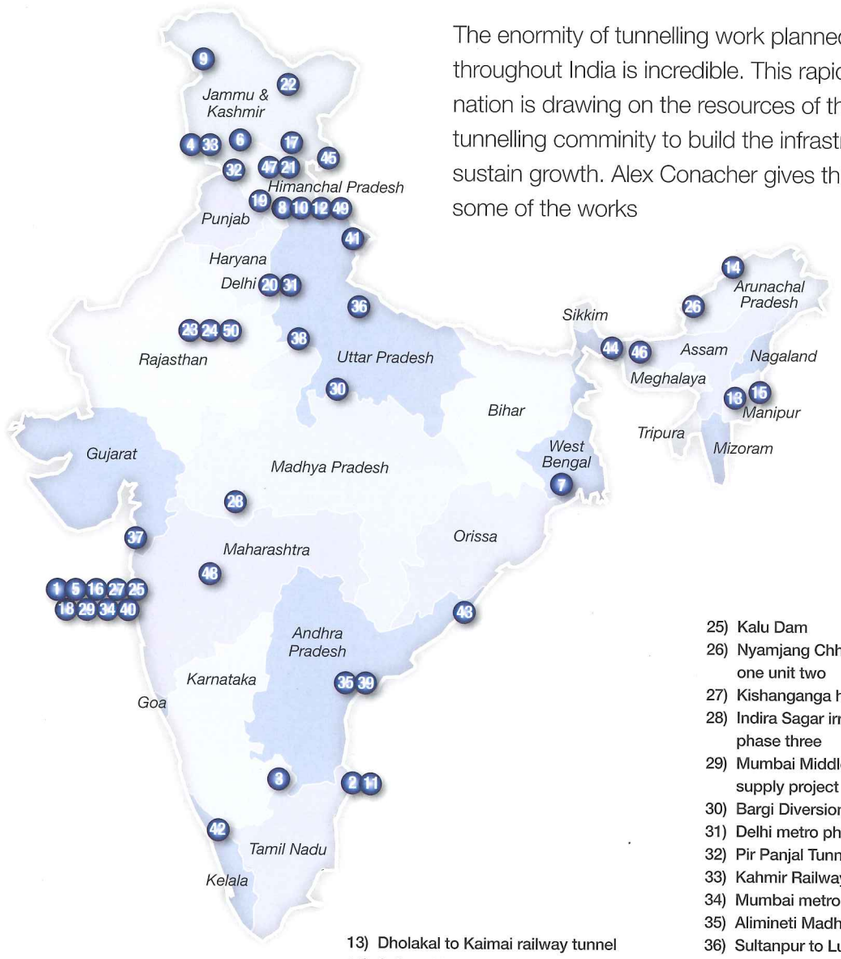
Uncovering India



The enormity of tunnelling work planned and under way throughout India is incredible. This rapidly developing nation is drawing on the resources of the international tunnelling comminity to build the infrastructure needed to sustain growth. Alex Conacher gives this snap shot of just some of the works

1) Anik Panjarpol Link Road Development
2) Chennai Metro Phase One Corridor Two
3) Namma metro tunnel
4) Chenani-Nashri Highway Development
5) Maroshi-Ruparel College Water tunnel
6) Budhil hydropower plant
7) Kolkata metro east-west rail tunnel
8) Rampur hydropower plant
9) Uri-II hydropower project
10) Parbati hydropower plant stage Three tunnel
11) Chennai metro phase one corridor one
12) Parbati hydropower stage two tunnel
13) Dholakal to Kaimai railway tunnel
14) Subansiri lower hydropower plant tunnels
15) Khongsang to Tupul railway tunnel in Imphal
16) Tambe Chowk tunnel
17) Shinkula pass tunnel
18) Nariman point tunnel
19) Holi-Utrala tunnel
20) Prime Minister's House to Delhi Airport tunnel
21) Swarghat-Bilaspur tunnel
22) Rohtang Pass tunnel
23) Jaipur metro north-south corridor
24) Jaipur east-west corridor
25) Kalu Dam
26) Nyamjang Chhu hydropower plant stage one unit two
27) Kishanganga hydropower project
28) Indira Sagar irrigation development phase three
29) Mumbai Middle Vaitarna water supply project
30) Bargi Diversion Scheme
31) Delhi metro phase three
32) Pir Panjal Tunnel
33) Kahmir Railway line
34) Mumbai metro phase one
35) Alimineti Madhava Reddy
36) Sultanpur to Lucknow highway upgrade
37) Tapi Rubber Dam
38) Agra Yamuna River Barrage
39) Pula Subbaiah Veligonda
40) Parsik Hill Highway Development Project
41) Tehri Pumped Storage Project
42) Padur cavern project
43) Vishakhapatnam rock cavern
44) Teesta hydropower project
45) Chutak hydropower project
46) Dagachhu hydropower project
47) Chamera hydropower project
48) Pare hydropower project
49) Sainj hydropower project
50) Ghat Ki Guni tunnel project

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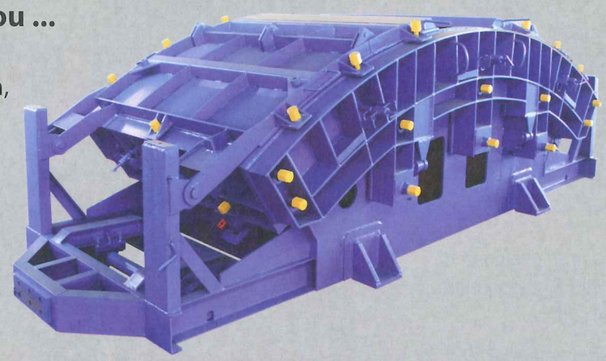

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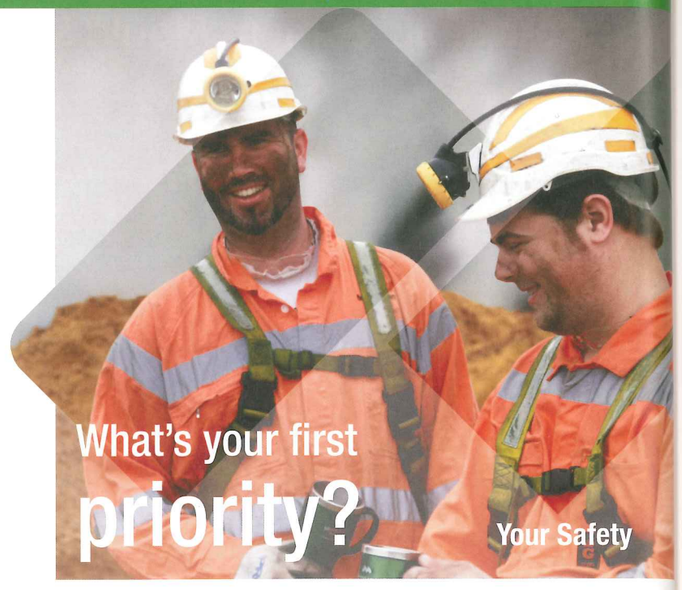

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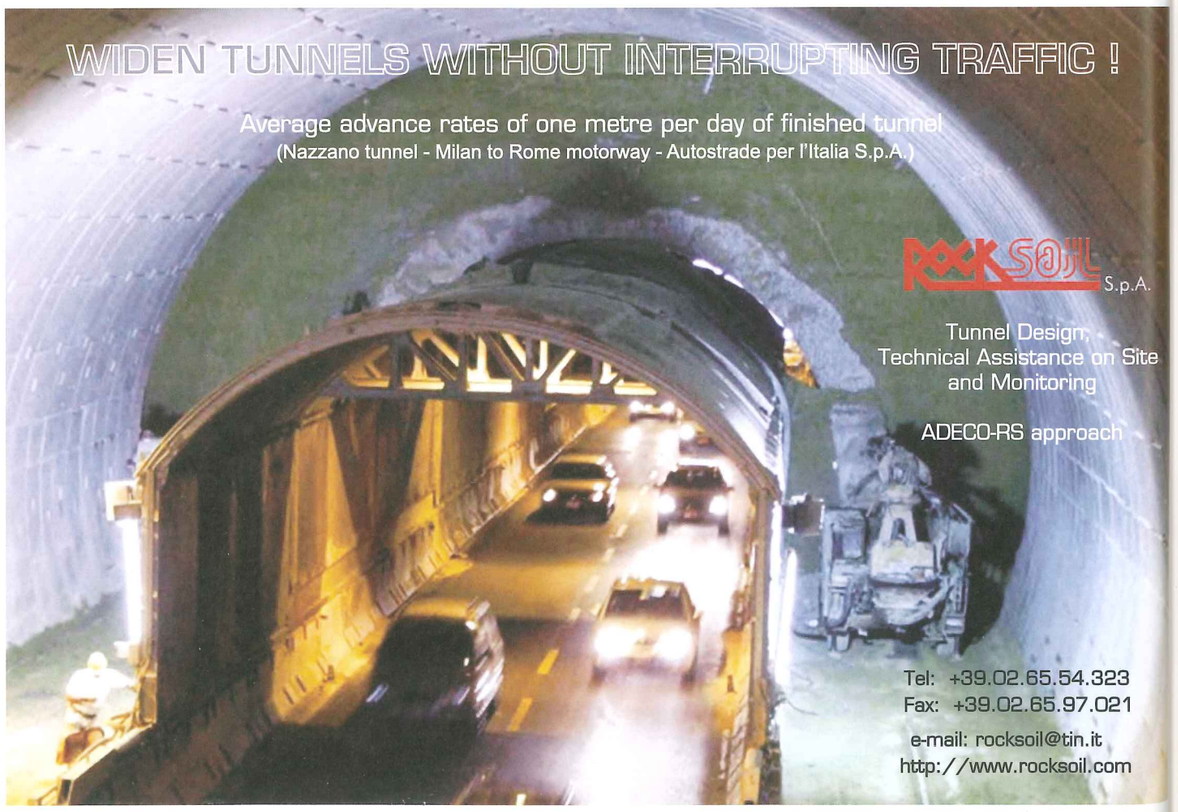
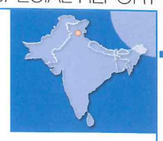
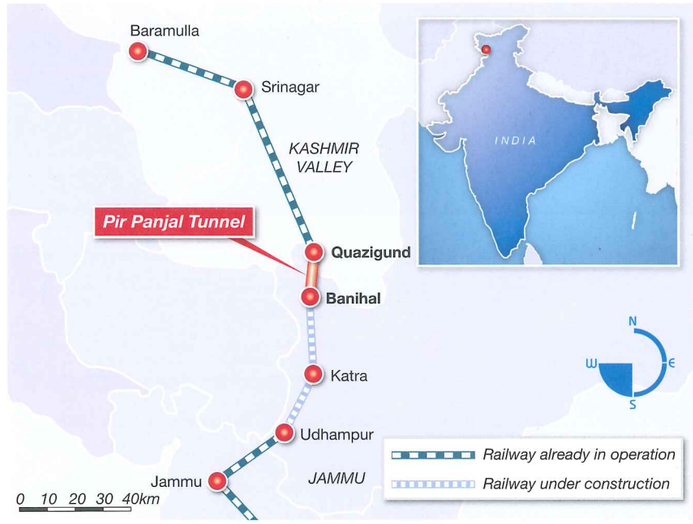




Finishing India's longest

Following tunnel excavation breakthrough last September, and the final blast in April this year, work is continuing on the long and notoriously difficult Panjal railway tunnel in India to complete support lining including some necessary ground reinforcement work. Maurice Jones reports on the latest progress



Above: Figure 1, simplified location map of the Jammu-Udhampur-Srinagar-Baramulla rail route showing thef Pir Panjal Tunnel and other stretches still under construction

The Pir Panjal railway tunnel is a key element of the new Udhampur-Srinagar-Baramulla broad-gauge railway through Jammu & Kashmir. It is not only the longest railway tunnel in India (beating the 6.5km-long Karbude Tunnel of the Konkan Railway) and the second longest in Asia, but is also being constructed under very difficult conditons of both geology and access to the site.

The early stages of the project and geology were the subject of an article by Geoconsult project director Dr Friedrich Prinzl (*T&TI* Feb 2010 p23). This article concentrates on recent work to complete the tunnel, which also has the project designation T-80.

Geology

It should be emphasised that the geology is quite unpredictable, including squeezing ground (see Figure 2, below). This makes the flexibility of the adopted NATM suitable, within which the necessary tunnel support design can be employed according to the ground conditions encountered.

Due to the uncertainty contractor HCC drilled probe holes, 64 or 76mm in diameter and 25-55m long with a 5-10-m overlap, throughout the drive. The number of holes in each session was between one and six depending on the ground encountered.

Contracts

Tunnel construction was split into four contracts, of which HCC was awarded the great majority (see Figure 3, top right). Contract VA also includes slope stabilisation, slope protection and portal construction at the south portal, and an 85m-long connection to the access adit. Similarly contract VB includes construction of the north portal.

Environment

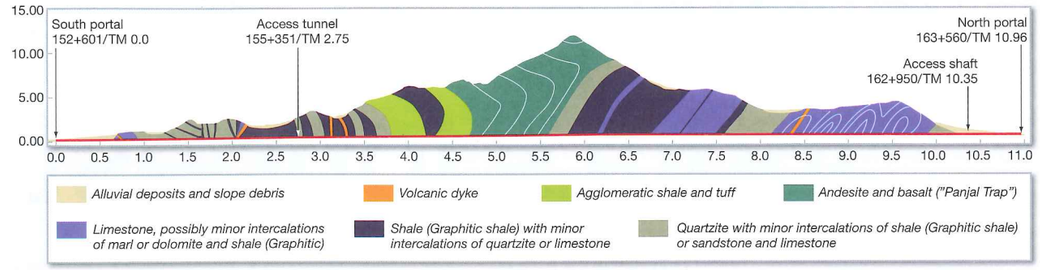
As described by Prinzl, the site logistics were very difficult, particularly in the early stages. The climate includes a winter season with snowfall from November to March. Between December and March temperatures are down to -10°C with frequent snowfalls covering access tracks. Work sometimes had to be halted although the aim is round-the-clock operation.

The environment inside the long tunnel is also important, particularly in ventilation terms. The capacity of the force-fan ventilation systems for all faces took into account requirements for personnel (4.25m³/min each, diesel drive (3.5m³/min for each kW of power) and a general return air velocity requirement of 0.3m/s across the fully excavated section.

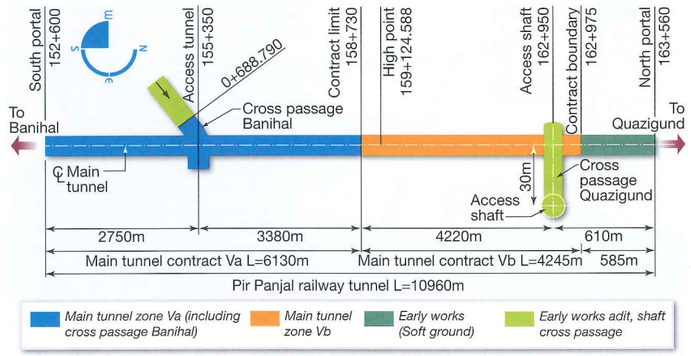
Alignment

The tunnel is aligned approximately north-south on a straight route for its entire length through the Pir Panjal pass that connects the Banihal valley at the south end with the Kashmir valley at the north end. Vertically the base tunnel passes under mountainous terrain with a maximum overburden of 1,100m. It also passes 440m under the existing Jawahar road tunnel.

Railway standards require the maximum deviation, both vertically and horizontally, to be 10mm/km. Maximum offsets of up to



Above: **Figure 2, geological section along the Panjal Tunnel**



Above: **Figure 3, diagrammatic plan of Panjal Tunnel including access adits, cross passages and shaft**

60mm are allowed on excavation breakthrough. HCC says that it is not possible to achieve such accuracy by conventional tunnelling surveying, so net surveys were carried out regularly.

Construction method

Ircon International is in overall charge of the railway construction between Dharam and Baramulla with Geoconsult-RITES and HCC providing the special tunnelling expertise. Ircon has already completed the 199-km Quazigund to Baramulla stretch, which was put into operation in September 2009. Ircon divided the 56.4-km Dharam to Quazigund stretch into six zones to expedite the work, of which zones IV and V comprise the Panjal Tunnel, contracted to HCC, plus 13 other tunnels.

The whole tunnel has been constructed on NATM principles, with the majority of excavation by drill and blast, but with roadheader (an Indian railway first) and hydraulic excavator excavation in softer ground. This has been the first major application of NATM in India. In addition to the tunnel itself, HCC was required to provide an access adit and shaft to facilitate construction and to allow maintenance, provide ventilation and for emergency egress.

Excavation of the main tunnel was launched from three faces:

1) South portal northwards;
2) From the access adit northwards and southwards;
3) North portal southwards.

The 2750-m stretch between the south portal and adit includes 650m of soft ground (rock class VII and VIII), which was excavated by sequential excavation in advances of 1.0-1.5m using a Korean Sambo ST-280 Tunnel Excavator boom on a Doosan crawler-tracked carrier. The rotating boom was very convenient for work in restricted sections, reports HCC.

In this stretch mucking out was by a Liugong side-tipping loader and (Atlas Copco) Wagner 20-t articulated dumptrucks. Ground control was particularly important due to the heavily populated village of Cheril over the tunnel with 2-40m of overburden. The ground was mainly clay but with variable hard strata interlying. Firstly a crown heading was dug and supported, and then the two side headings. With temporary walls and crown support installed the central core was excavated. Breakthrough in this stretch was achieved in July 2009. Boulders were encountered in glacial deposits from 380m into the tunnel. These were dug up and broken up, if necessary, by hydraulic breaker, avoiding blasting.

With the increased ground instability and the overlying village, the excavation sequences was modified into eight smaller portions rather than the more usual four (two top headings, two side headings, a core drive and three drives in the bench.

Another stretch of soft ground, 600m long, was also excavated in the same way from the north portal. Before commencing the soft ground excavation the portal faces were reinforced with 9m-long face bolts, and the surrounding slopes stabilised with two layers of reinforced sprayed concrete. To prepare for initial excavation the portal face was further reinforced with 150x150-mm steel girder forepoling, 76mm-diameter pipe roofing, and self-drilling anchors.

Some 521m into the tunnel the miners met shattered ground with heavy water inflow. This necessitated pipe roofing with

Project summary

Owner: Northern Railway (part of Indian Railways)
Overall project management: Ircon International (autonomous construction agency of Indian railways)
Consulting engineer: Geoconsult-RITES JV
Designer: Geoconsult-RITES JV
Lead contractor: Hindustan Construction Co (HCC)
Tunnel length: 11.215km including extra cut-and-cover sections at portals

76 and 114mm-diameter pipes, each 12m long, the latter requiring the use of a Casagrande forepoling rig. Regular drain holes were drilled to release groundwater, and sometimes in the face to reduce water pressure in advance of excavation. Water flows were up to 180 litres/s compared to the predicted maximum of 70 litres/s.

The adit and shaft allowed difficult ground at the portals to be isolated so that it did not hold up excavation of the main tunnel drives over the remaining 7,600m. The sequence of construction from the two faces in this main stretch was:

- Excavation of full-width top heading, followed by temporary support;
- Excavation of the bench and invert followed by support (invert excavated only for rock classes V and above);
- Casting of concrete invert lining;
- Casting of concrete 'kicker';
- Fixing of waterproof membrane over geotextile;
- Casting of main lining.

A Wirth T3.20 Q roadheader with transverse cutterhead was employed from the north portal and was found by HCC to be effective as long as the UCS of the ground rock was less than 100MPa. However, a number of difficulties were experienced, mainly because the heterogeneous geology expected through the length of contract VB (length 3.12km out of 4.22km) was much more mixed. Optimum cutterhead speed could not be achieved says HCC. With supplier assistance, the roadheader was put to work again from 711m into the tunnel.

Above: **Approaches to the existing Jadwahar road tunnel during winter show typical Pir Panjal conditions in the area**

Rock encountered was often very hard. Pick consumption varied between 0.025 to 0.3 per cubic metre excavated depending on the actual rock UCS. Further problems resulted from a shear/fault zone encountered at 677m containing clay and limestone boulders. Mixed ground was encountered in two further zones comprising fine-grained limestone with calcite and clay infilling. There was also a water flow of 35-40 litres/s here, which created mud that was difficult to remove with the roadheader's mucking out system.

Spoil was removed by dumpers loaded by the roadheader's own conveyor.

However, as most rocks encountered in the Pir Panjal Tunnel are above 100MPa UCS, usage of the roadheader was limited to nine per cent of total excavation.

In other (hard rock) stretches, drilling and blasting was carried out with two Atlas Copco Boomer twin-boom drill rigs (L2C and L2D). For blasting HCC used non-electric detonators with long delays and 'power gel' explosive in 40-mm and 32-mm cartridges. HCC says that non-electric detonators were found to be particularly advantageous due to their inherent safety, allowing other activities to be carried out in parallel with charging. Mucking out was as in soft ground excavation.

Table 1: Split of Pir Panjal T-80 tunnelling contracts

Description	Length	Main method	Contractor
Main tunnel Zone VA	6130m	Drill & blast, plus soft ground by hydraulic excavator in SEM	HCC Ltd.
Main tunnel Zone VB	4245m (excavations); 4830m (lining)	Dril & blast	HCC Ltd.
Main tunnel Zone VB (to north portal)	585m	Hydraulic excavator	Gammon India Ltd.
Adit, 12m-diameter shaft, 55m deep, and cross passages	Approx. 863m	Drill & blast	HCC Ltd.

Table 2: Types and lengths of rockbolts used in the Pir Panjal T-80 Tunnel

Type of rockbolt	Diameter (mm)	Lengths (metres)	Min. yield strength (kN)
Self-drilling (SDR)	32	4, 6, 9, 12 & 15	200-230
Soil nail (SN)	25	3, 4, 6 & 9	200
Atlas Copco Swellex expandable		3 and 4	150
Glass-fibre (GRP)		9	

In the stretches where water-bearing structures had been identified, 76mm-diameter probe holes were drilled to 20-30m. Depending on the results, drainage holes of 76 or 114mm diameter were then drilled, 3-25m in length, in successive rounds. This enabled sufficiently dry conditions for successful excavation.

In the young 'mountain building' ground conditions, shear zones were identified in advance along faults and contact areas by probe holes and geotechnical monitoring. Various measures were taken to successfully negotiate these. In drill-and-blast excavation the round lengths were reduced and the number of forepoles increases to 30-40 per round. The length was also increased to 6-9m, plus four to six face rockbolts, 9m in length. Grout was injected through the forepoles. Rockbolting of the periphery was also increased.

Each new face excavation was sealed with sprayed concrete 50-200mm thick, and this was increased on the periphery (walls, crown, etc) to 300mm, including two layers of wire mesh reinforcement. A hydraulic excavator was used if drill-and-blast was not appropriate in sequential excavation, as in the soft ground.

In order to facilitate emergency and maintenance access HCC has laid a 3m-wide concrete road adjacent to the railway alignment. A gravity slope to both portals from a high mid-point facilitates drainage of this base tunnel.

Support

In accordance with NATM, ground instrumentation has been employed not only for routine monitoring of ground movements but also to assess stress redistribution and stabilisation before applying the final lining. The readings are input to a 3D visual monitoring system.

Based on geological investigation the tunnel alignment was classified into eight different conditions for NATM support purposes. Since lining thicknesses therefore varied, the excavated section varied between 67 and 78m², with a final finished sectional area of 48m².

The primary support, according to the design for each of the eight rock classes, consisted of a combination of wire mesh, sprayed concrete, lattice girders, rock bolts and forepoling as necessary.

Firstly a face-sealing layer of sprayed concrete, 50-100mm thick was applied after every round, chiefly for safety. This was followed by installation of Fe500 grade wire mesh sheets of 150 by 150mm and 6mm thick, on the periphery of the fresh concrete to reinforce the primary lining. No wire mesh is required for rock classes I, II and II in hard round, but one layer is used for class IV and two for class V and above.

The main sprayed concrete lining, grade M25, is then applied by wet process to a thickness of 100-300mm depending on the rock class. The mix includes alkali-free accelerator such as BASF Meyco SA-160 or Sika Sigunit L54 AF. The spray equipment used is a robotic Cifa machine.

Another common element of NATM-type support, particularly in poor ground, is lattice girders. They enable triaxial loads to be distributed around the tunnel section with better uniformity. Two sizes are used in the Pir Panjal are type 70 and type 90 with 16 by 25mm bar lattice. The reinforcement bar is 25, 16 or 10mm diameter.

Rock bolting played a major part in stabilising poor ground. In total around 15,000m of rock bolts were installed using the twin-boom Atlas Copco jumbos.

In bad ground, where excavation may cause a roof collapse, forepoling was employed in the crown to introduce pre-excavation support elements, thus shortening the unsupported excavated surface. Three types were used:

- MS pipe of 40mm diameter
- Self-drilling (SDR) bolts of 32mm diameter
- Reinforcement bar (rebar) of 32mm.

In particularly bad areas 76mm-diameter pipe roofing was also employed in the heading and bench drives during sequential excavation. Each element was installed using a Casagrande forepoling rig or the blasthole jumbos.

In addition, in the soft ground excavated sequentially, the temporary invert of the top heading was lined with sprayed concrete and wire mesh to 'close the ring' to NATM principles in order to redistribute the surround ground stresses for equilibrium.

Permanent concrete lining

All concrete used for final lining is of M30 standard. Once excavation and primary support had been completed in a stretch of tunnel lining can be carried out in parallel with other activities further along the tunnel. It is normally carried out in four stages in 12.5m lenghts, known as a 'block', as:

- Casting of invert (if required),
- Casting of 'kicker' portion,
- Fixing of waterproofing membrane,
- Casting of 'overt' i.e. walls and crown.

The invert was for stretches in rock classes V, VII and VIII. Use of a special cantilever 'invert bridge' allowed excavation to carry on further forward at the same time as invert casting beneath the bridge. First the invert was cleaned of loose material and fill laid to enable face access before shifting the 25m-long bridge into position. Excavator, manual and jet cleaning are used. In position, one end of the bridge rests on the already cast invert block and the other on the cleaned invert space. Vehicles can travel over it as reinforcement and concrete is placed. Reinforcement and shuttering can then be installed underneath followed by concreting.

Reinforcement, erected manually, is made of Fe500 grade steel of 10mm diameter. Longitudinal shuttering includes the formation of a drain channel.

Concrete is carried in lining via transit mixers from the batching plant and then pumped to the casting area, with needle vibrators used for compaction. The drain is closed over with flat pre-cast slabs.

Waterproofing

The whole tunnel is being waterproofed with Sika pvc membrane overlying geotextile fleece and beneath the final cast-in-place concrete lining. Installation is a specialist activity. Leaking groundwater is channelled through the geotextile whilst prevented from entering the main tunnel by the membrane. Water is collected by perforated PVC pipes embedded in 'no fines' porous concrete in the corner of the kicker and channelled to the main drain. The procedure is:

- Installation of 200mm-diameter pvc pipes embedded in 'no fines' concrete, with manholes at every 50m,
- Application of smoothing sprayed concrete layer, 20mm thick, to form a suitable surface for the membrane,
- Installation of geotextile and membrane from a gantry to facilitate handling. Roundels and pins fix the geotextile with the membrane at 1.5-m spacing. Each membrane sheet is double-seam welded to the next with a 100-mm overlap. Hot air welding is used at the roundels and

The Wirth roadheader could not be used as much as was anticipated, due to hard and clayey ground, is seen here on the surface

Table 3: Predicted and encountered geological conditions in Pir Panjal Tunnel according to rock class and lengths

Rock class	Anticipated length for tender (m)	Actual total length encountered (m)
I & II	2285	102.4
III	3246	2448.0
IV	2207	5270.8
V	1432	1816.5
VI	500	0
VII & VIII	680	712.3

Left: Using one of the Atlas Copco twin-boom jumbo drillrigs to install drainage holes and pipe-roofing

then for each sheet overlap.

The main concrete lining is of two types: reinforced (RCC) and unreinforced Portland (PCC). RCC is used within stretches of extreme rock support classification VII and VIII, whilst the remainder was lined in PCC, 300-450mm thick. The RCC reinforcement mesh uses bar of 10 and 16mm diameter. The resultant mesh is further reinforced with Pantex lattice girders at one-metre intervals. A separate gantry is used to install the reinforcement and then another Cifa formwork gantry is moved into place.

The formwork is hydraulically operated and controlled from a single console for the collapsible shuttering, with a check on accurate alignment with each block to be concreted. The shuttering has 'windows' in strategic positions, and its own pipework, for easier concreting. Vibrators for concrete compaction are also integral to the gantry. Concrete production and delivery is as for the invert and kickers.

Challenging conclusions

Some of the challenges that have been faced were already described by Prinzl (2010). For its part, HCC list its main challenges as:

- Changes of geological conditions compared to anticipated rock class, plus rock bursting;
- Excavation of soft ground;
- Blasting restriction due to proximity of villages over tunnel alignment;
- Excavation through heavy water inflows;
- Excavation in shear (fault) zones;
- Casting of invert lining;
- Lower performance of roadheader.

According to HCC there is a 'huge variation' between the predicted rock classes and characteristics compared to the geological interpretative report presented to Ircon at the contract tender stage. The differences are shown in Table 1.

Progress

With the completion of excavation, the final heading breakthrough occurring six and a half years after the start of tunnelling. Completion of the permanent lining is now under way, with HCC reporting only 850m of the total 10,960m of the excavated tunnel left to be completed.

However, Dr Prinzl reports that in a few sections of shaley ground with high ground pressures, since the beginning of 2012 the lining has been affected by creep displacements of 5-10mm per month, mainly horizontally. These were observed under an overburden of approximately 800-900m.

"The deformation could be controlled only after installation of extensive bolting with 12m-long rockbolts in the side walls," says Prinzl.

HCC says that the length affected is 638m in shaley ground. In addition to ther invert, the thickness of the rest of the concrete lining has also been increased to 450mm and the shale grouted throughout, in addition to rockbolting.

The concreting of the railway base for ballast-less track is also under way. Track-fixing and M&E were scheduled to start last month (May).

Acknowldgements

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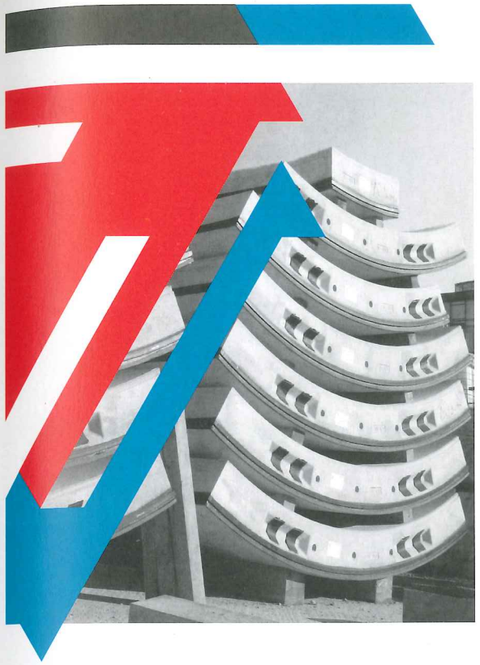

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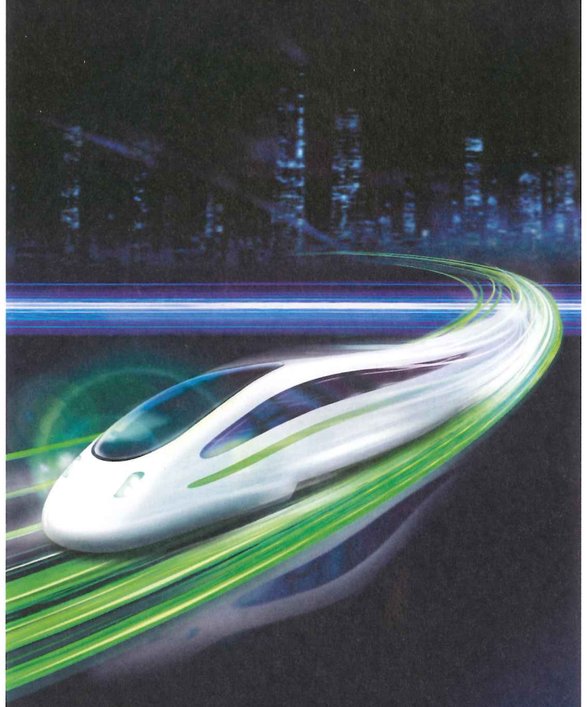

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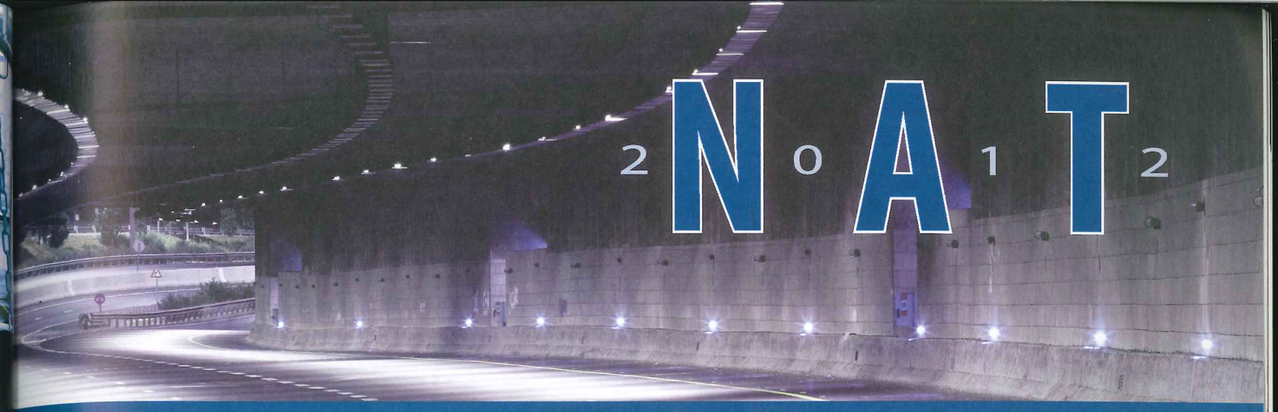

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Delhi digs

With a metropolitan population of over 16 million, a failed foray into privatised bus services and cars choking up one of the densest road networks in India, need for a metro has never been more pronounced. Alex Conacher interviews designer Mohan Gupta and Delhi Metro Rail Corporation spokesman Anuj Dayal to get the jewel of India's infrastructure crown into perspective

The Delhi Metro could equal the present day London Underground network in 13 years. The sprawling city needs it. And the pride of the engineers making it happen is clear.

"Spreading risk. That is how we have been able to build such a project at this rate," says Mohan Gupta, metro and civil geotechnical divisional director for Mott MacDonald. "The Delhi Metro has been split into packages of three to 4km. You can get all elements of tunnelling in these sections: TBM drives, cut and cover stations and so on."

The various phases of the Delhi Metro, while prioritising vital districts of the city, have been planned in a web configuration.

Phases one and two focussed on constructing the radial routes spreading outwards from a centre point.

Phase three will add circles to connect these radial routes and phase four, if it goes ahead, will extend the radials while adding more circle routes.

Table 1: Delhi Metro phase one

Line	Length (Kms)	No. of Stations
Shahdara-Tri Nagar-Rithala	22.06	18
Vishwa Vidyalaya-Central Secretariat	10.84	10
Indraprastha-Barakhamba Road -Dwarka Sub City	32.10	31
Total	**65.00**	**59**

Table 2: Delhi Metro phase two

Line	Length (Kms)	No. of Stations
Shahdara – Dilshad Garden	3.09	3
Indraprastha – Noida Sector 32 City Centre	15.07	11
Yamuna Bank – Anand Vihar ISBT	6.17	5
Vishwavidyalaya – Jahangir Puri	6.36	5
Inderlok – Kirti Nagar -Mundka	18.46	15
Central Secretariat – HUDA City Centre	27.45	19
Dwarka Sector 9 to Dwarka Sector	21 276	2
Airport Express Line	22.70	6
Anand Vihar – KB Vaishali	2.57	2
Central Secretariat – Badarpur	20.04	15
Total	**124.63**	**83**

Phase one

Phase one kicked off in 1998 with the least tunnelling of all the phases. Some 13km of the 65km, three-line central Delhi network were underground.

Project developer the Delhi Metro Rail Corportation [DMRC] estimates the cost of this portion at INR 105.7bn (USD 1.95bn).

Gupta says that the decision to go underground is not the first choice for Delhi, and it is a decision entirely based on cost. The price of an elevated line is roughly 10 per cent that of a tunnelled line, so if the government is in a position to acquire land along the alignment, it prefers to go over it.

Per kilometer, Delhi Metro tunnels cost around INR 2.5bn (USD 46M), while elevated line sets DMRC back some INR 250M (USD 4.6M).

Completed in December 2005 just about three years ahead of schedule and on budget, *Businessweek* reported at the time that the achievement was a miracle in a country previously renowned for inefficient public works. Like many others, its praise for the miracle worker fell on DMRC's former director (see box, overleaf).

Phase two

T&TI reported the start of phase two tunnelling in 2008 with the lowering of two 6.54m-diameter Herrenknecht EPBMs (*T&TI*, March 2008, page 8). Some 14 machines were launched that year, with excavation due to be completed on all drives by or during 2009.

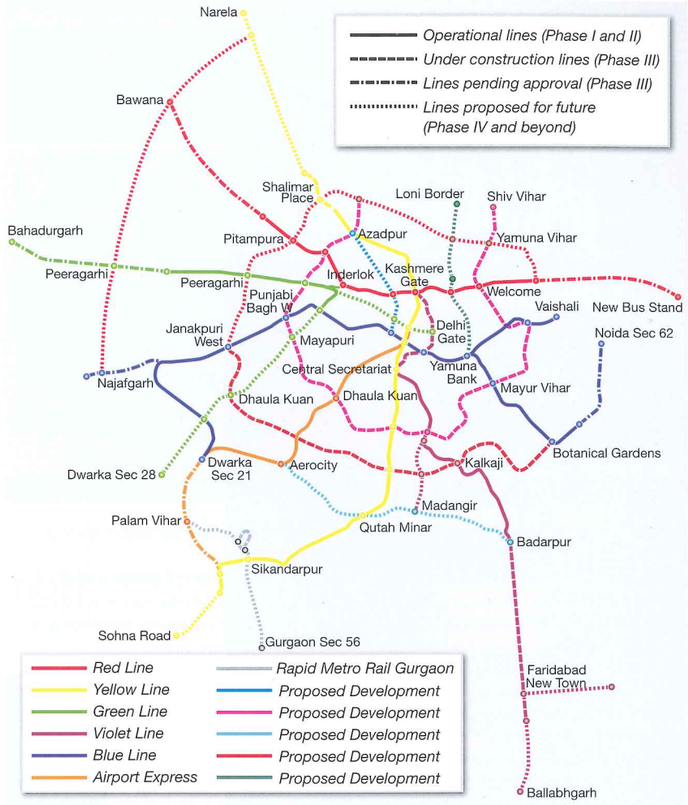
The 30 tunnel drives called for this record-breaking number of TBMs working in a single city. Of the 124km to be added to the metro in this phase, 35km were underground. Driven 16km by TBM and 2.8km by NATM. The 20 underground stations were constructed by cut and cover, twice as many as in phase one.

Gupta recalls the Airport Express Line (orange line on the map, above) as giving him important life lessons. "In most situations, preliminary designs have been carried through to construction. On the Airport Express Line however, the client said alluvium soils reached down to around 30m, and the bid by the contractor was priced at that.

"When digging began, it was found that the rock was higher than expected. Where the station was to be located, rock was 8m below the surface. We wasted two to three months on investigations and changing subcontractors and so on. Finally Airport Express contract C1 was delivered on time by the contracting JV Alpine, Samsung and HCC with Mott MacDonald as designer."

Risk in India

One of the problems with doing business in India is the amount of risk being placed



Geology

Delhi has mostly alluvian geology consisting of clays. The water table is high, sometimes at ground level, and all structures for the project are designed for a water table at this level as a requirement. In some areas at the centre of the city, rock is closer to the surface, as shallow as 10m below in places.

Gupta estimates that around five to seven per cent of the total alignment is through rock, with the rest in alluvium. The general excavation strategy has been to procure EPBMs with rock-cutting capabilities and work with these. Gupta adds, "There is a possibility, and discussions, for NATM and drill and blast in limited applications."

Water ingress is controlled by the gasketed precast segments and grouting that covers most of the metro. Gupta adds that walking through the sections he has never seen water seepage, only dampness.

Table 3: Alignment and station breakdown for Delhi Metro phase three

Corridor	UG (km)	Elevated or at grade (km)	Total	Stations		
				UG	Elevated or at grade	Total
Mukundpur- Rajouri Garden- Dhaula Kuan -Anand Vihar – Shiv Vihar	14.836	44.021	58.389	9	28	37
Janakpuri west – Munirka - Kalka Ji - Kalindikunj	21.65	11.21	32.86	15	10	25
Central sectt. – Mandi House - Kashmiri Gate	9.37	0.000	9.37	7	0	7
Jahangirpuri – Badli	0	4.489	4.489	0	3	3
Badarpur – YMCA Chowk (Faridabad)	0	13.875	13.875	0	9	9
Total	**45.406**	**73.595**	**118.96**	**31**	**50**	**81**

Note: *T&TI* went to press waiting for DMRC to clarify the discrepancy between the total length and the sum of the individual corridors

with the contractor. Gupta says employers generally ask contractors to design all risk into the bid.

He says, "This is an issue as contractors often seem to face difficulties because of this and are not making very big profits in India. The client is not legally allowed to pay more [if circumstances change]. Professional understanding can [sometimes make this] different, but I do not know of any cases to comment on.

"In the case of the Airport Express I was only involved on the technical side and so not overly affected [by the unexpected conditions]. Although with the balance of risk being entirely on the contractor, it is important that risk information is accurate and shared.

"I think the Airport Express was an example of lack of information at concept design and not intentional withholding of information," says Gupta."

T&TI reported in November 2010 that DMRC had ordered USD 2.53M in penalty fares against the developer and contractor for the project Delhi Airport Metro Express, which has a 30 year concession to operate the line once completed. The fine was for a failure to obtain safety clearances from the Commissioner of Metro Rail Safety before the line could be allowed to operate, resulting in delays.

Metro Man

Western cultures can undervalue their civil engineers. The 2012 Harding Memorial Lecture at the Institution of Civil Engineers in London, UK by Arup director Bill Grose touched on this, calling on engineers to raise awareness of the good work done.

In India, no such advertisement is needed. Elattuvalapil Sreedharan, former managing director of DMRC has probably ensured his immortality as a civil engineer.

Gupta credits Sreedharan with much of the Delhi Metro's success. "He has been instrumental in bringing international skills to the project. He is very dynamic and took care of everyone involved, which is good as the heavy risk allocation on the contractor makes it difficult to do business in India.

"Sreedharan is still available for consultation, but we will see an impact."

DMRC was founded with Sreedharan as MD in 1995 on the back of a 40-year career of completing government projects close to budget and schedule. In 2009 he resigned from his position, taking moral responsibility for the collapse of a launching girder and portion of a bridge in an under-construction elevated section of the metro. Six workers were killed.

Chief minister of Delhi Sheila Dikshit instantly rejected the resignation. As of December 2011 he has retired for good, and his replacement formerly DMRC director of works Mangu Singh faces a tough task emulating the first director.

Phase three

For phase three, around 45km of underground lines will be built with 31 underground stations. DMRC spokesman Anuj Dayal says that this will be almost as much as the underground work from the previous two phases combined. For the first time, Delhi Metro lines will have to cross. Some 25 TBMs will be used on the project, the first two of which have already been lowered to work on the north-south Violet Line.

Dayal says the corporation will set up a centralised TBM control room for this phase. The facility will monitor the 'fuctioning' of the TBMs with GPS technology, enabling coordination of progress. Bidding for phase three will be over by the end of the year.

Dreams of the future

Phase four planning is in place, but as funding has not been finalised, no bidding information has been released to the market. Gupta is confident it will go ahead, with completion by 2020.

"Everyone involved in the project has a common goal," says Gupta, "of course we are very proud of what we are doing. We've constructed over 190km of metro in ten years, the highest rate in the world. I remember back in 2001 when I had little experience in underground work. I was worried like some others, we had professional doubts, but we took up the challenge and it has happened.

"By 2025 and with the successful completion of phase five, we will have connected the entirety of Delhi and its satellites with over 400km of metro."

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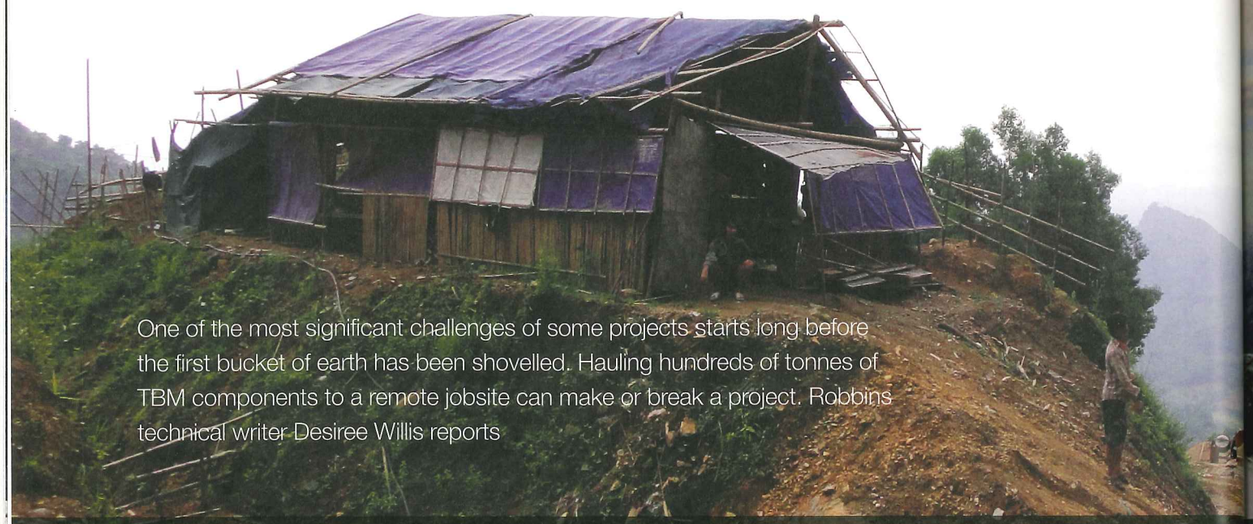

One of the most significant challenges of some projects starts long before the first bucket of earth has been shovelled. Hauling hundreds of tonnes of TBM components to a remote jobsite can make or break a project. Robbins technical writer Desiree Willis reports

From point A to point B

Whether the challenge is TBM assembly in the most populous city in the world, or delivery to a remote site, those managing the transport of these huge masses of steel agree: it is seldom an easy process. "TBMs are different from industrial project cargo, in that they are transported to the job site just to accomplish the boring of the tunnel and need to be removed after that," says Ralf Riemeier, owner of Freight Forwarder Contex Shipping, with 18 years of experience in the field. "Many of those projects are in areas that do not offer the infrastructure needed for smooth and easy transport of such huge and heavy components. It is often a big adventure, which needs a lot of creative people to get the job done."

That adventure is well underway on a number of Robbins projects—from a TBM assembled in the snowy mountains of Georgia to an inaccessible project in Vietnam requiring nearly 100km of newly built road. The process is understandably a long one, beginning before the TBM contract is even signed.

Far ahead of the game

Planning of shipping begins early on, as part of a quote for an upcoming project, and are refined as the manufacturing moves forward. Melea Basom, Robbins logistics coordinator says, "Logistics planning begins with accurate drawings from the engineering department with input from the project manager, which we then insert piece by piece into a spreadsheet showing the dimensions and weights. Once we have nominated the freight forwarder for the job, we are involved with the shipment until it lands at the port or job site, depending on the contract terms."

TBMs are typically assembled via two methods: either in the shop, or at the jobsite using Onsite First Time Assembly (OFTA). Once a machine assembly in the shop is complete, the breakdown process begins, at which point the final part numbers, dimensions and weight for each component are included in a packing list that is attached to each skid/crate or floor item. The process for an OFTA project is quicker, as the various components can be weighed and packed without the assembly and disassembly process. OFTA allows machine components to be initially assembled onsite, often saving four to five months on the delivery schedule.

Regardless of the assembly method, however, detailed planning is absolutely necessary to get components to the jobsite. "The major issue is to plan and organize the entire transport from the production plant to the final destination well ahead of time. It is of vital importance to place firm orders for all sections of the entire transport chain when the machine is about ready to leave the plant," says Riemeier.

Components are most often transported by cargo vessel to ports around the world, and then trucked to jobsites. Air freight is generally reserved for emergency shipments of spare parts, due to its high cost. "Every country has its quirks when it comes to the necessary documentation," says Linda Ricketts, Robbins international shipping coordinator. Ricketts mentioned Turkey and Russia as requiring multiple types of documentation for each shipment, though she said all countries can be challenging in various ways.

The overall goal of the entire shipping process is to enable the successful execution of some complex schemes. "One of my most challenging projects was the transport of a Robbins TBM for refurbishment from Morocco to a storage area in Germany.

"The components were spread out in a large remote desert area in the mountains of Settat, approximately 40 miles (64.4km) south of Casablanca," says Riemeier. The remote location required the crew to bring all equipment such as heavy duty mobile cranes and forklifts to load the various parts onto flatbed trucks. A small bridge en route to Casablanca also had to be reinforced to carry the weight of the trucks. Once the parts reached the port, says Riemeier, the limited capacity of the port-based cranes required them to charter a vessel with heavy duty gear to lift the components onboard for shipping.

Above left: **At Vietnam's remote Thuong Kon Tum project, a Robbins TBM can only be transported to the site after rebuilding 95km of nearly impassable roadway**

Above right: **Georgia's Stephandsminda Hydroelectric Project is located more than 1,700m above sea level, requiring transport of the Robbins TBM components up snowy, one-lane mountain roads**

From the high desert to snowy mountaintops

A similarly complex shipping scheme was needed recently for the Stephandsminda hydropower project in Georgia. The 5.5km headrace tunnel and 68MW power plant construction sites are located 160km from Tbilisi in the mountainous Kazbegi District of northeastern Georgia. Snow often blankets the area, which is more than 1,700m high and dips to sub-zero temperatures during the winter.

A 5.3m diameter refurbished Robbins Main Beam TBM was launched in February 2012 to excavate the headrace tunnel—a successful milestone in what was a long journey that began in the high desert of New Mexico, USA. "We arrived at the storage yard in Farmington, New Mexico in above 100° Fahrenheit (37.8°C) weather on 6 July 2011. The pieces needed to be matched up to manual drawings and the shipment was on a tight schedule, leaving Houston, Texas for the Port of Poti, Georgia by 6 August," says Gene Lockhart, Robbins special projects manager.

Lockhart and his team members located the parts based on machine drawings, all the while simultaneously planning for oversize trucking and permitting of components weighing up to 24t.

"The pieces had been in the storage yard for a while, which is in a dry and hot climate in order to preserve the steel. The steel was in great shape, but of course all the hose lines and anything rubber had to be replaced. We had the main bearing and main drive assemblies shipped to Ohio for cleaning, inspection, and reconditioning," says Lockhart.

After components had been located, the Robbins team hired a local carpenter for bracing and boxes, and then rented a 136t crane and 54t crane to load components onto 25 flat bed and dual axle trucks. "We had to have special permits for some loads to drive through Texas and New Mexico, and we were just an inch or two below the requirements for police escorts," says

Above: **The vast majority of TBM components are shipped via sea on often chartered vessels to various ports worldwide**

Lockhart. Once at the port in Houston 1,450km to the southeast of the storage site, a chartered vessel picked up components for the five week long voyage to Poti.

Once in Georgia, major components were refurbished in the contractor Peri LLC's shop. From there, components were trucked into Kazbegi on narrow roadways that gave way to dirt roads for the last few miles. "The weight is not the most critical issue in situations like this; the major concern is always the width. As the components always need to be carried from the port to the final destination by truck, the narrowest spot to the destination sets the limit," says Riemeier, whose company Contex was involved in the shipping of the TBM.

The TBM components arrived at the site in December, in bone-chilling temperatures that often reached -15°C, and -40°C with the wind chill factor. Assembly was often challenging due to the conditions: "The assembly team could only work an hour and a half to two hours at a time at the site, and then we had to go back into the shelter to warm up. It took about 40 days to complete TBM assembly, and we launched on 19 February," says Lockhart.

The assembly in Kazbegi was a success, and the ensuing TBM drive even visited by the President of Georgia, Mikheil Saakashvili. "We jointly worked with the Robbins field service team from the very beginning. We appreciate their experience and relied on them during the working process, where they trained our staff on operation, refurbishment and assembly," said Nana Gvazava of Peri LLC. As of April 2012 the machine had advanced 300 m in slate, sandstone, limestone, and malms.

Building a road where there was none before

The ultimate in complex shipping schemes, however, may be one currently in progress at Vietnam's Thuong Kon Tum Hydroelectric Project. The 220 MW capacity power station will utilise the country's longest tunnel, at 17.4km, when complete. The scheme, set to go online in five years, will draw water from the Dak Nghe River to supply electricity to the Central Vietnam region.

The tunnel will be bored with the second Robbins machine to operate in the country, a 4.5m diameter Main Beam TBM. Other Robbins supplies include the back-up, cutters, spare parts, and a continuous conveyor system for muck removal. The tunnel work is part of phase two of the hydroelectric project, for the HydroChina Huadong Engineering Corporation / China Railway Construction 18th Bureau Group Co. JV.

Just getting the equipment to the exceedingly remote site is the project's biggest challenge. The jobsite is located in a mountainous region 142km away from Ho Chi Minh Port, 95km of which have either no roadway or rudimentary dirt roads only accessible with four-wheel drive vehicles. The contractor is currently building portions of the roadway to the jobsite while components are being staged at the port site. Several bridges, previously built only for light traffic such as bicycles and carts, must also be rebuilt or reinforced in order to carry the heavy TBM components. In a road condition survey report by logistics firm SDV Vietnam Company, the original bridges were described as 'having no shoulder', while some roads were nearly impassable, described as having 'blind corners and sharp curves'. In part to reduce stresses on bridges, OFTA is being used to allow shipments to arrive at the site in smaller pieces.

"I've seen some of the pictures prior to road construction, and it was absolutely amazing. A donkey and cart were just small enough to fit on the road," says Ricketts. As of April 2012 construction of the new roads and bridges was nearly complete, and transport of components was scheduled to begin in late spring.

Above: **The challenge of TBM shipping begins before a contract is even signed, with logistics planning for component dimensions and weights**

Full circle

While shipping is often complex, the freight forwarders and logistics personnel involved find the task challenging and rewarding.

"We treat every single project like it is the first one. There will be permits, regulations and logistics to map out, but we always manage to complete the task," says Axel Strege, also a freight forwarder with 10 years experience at Contex.

Ricketts echoes the same sentiments: "There are always challenges with time constraints and shipment sizes, but when things work out it is rewarding. It's great for me to hear about TBM launches and breakthroughs, and to know I played a part in that."

Of her next project, Ricketts says it will be equally as challenging as some of her recent ones—getting two 6.3m Robbins EPBMs for San Francisco's new Central Subway project into a densely urban downtown area.

"The site is right in the heart of the city, on a cobblestone street that must be torn up to create shafts for the machines. We have to get large pieces from the port through some narrow streets, and we are working with truckers now to determine how those pieces will fit." In short, it will be an adventure, and one that Ricketts is ready to take on.

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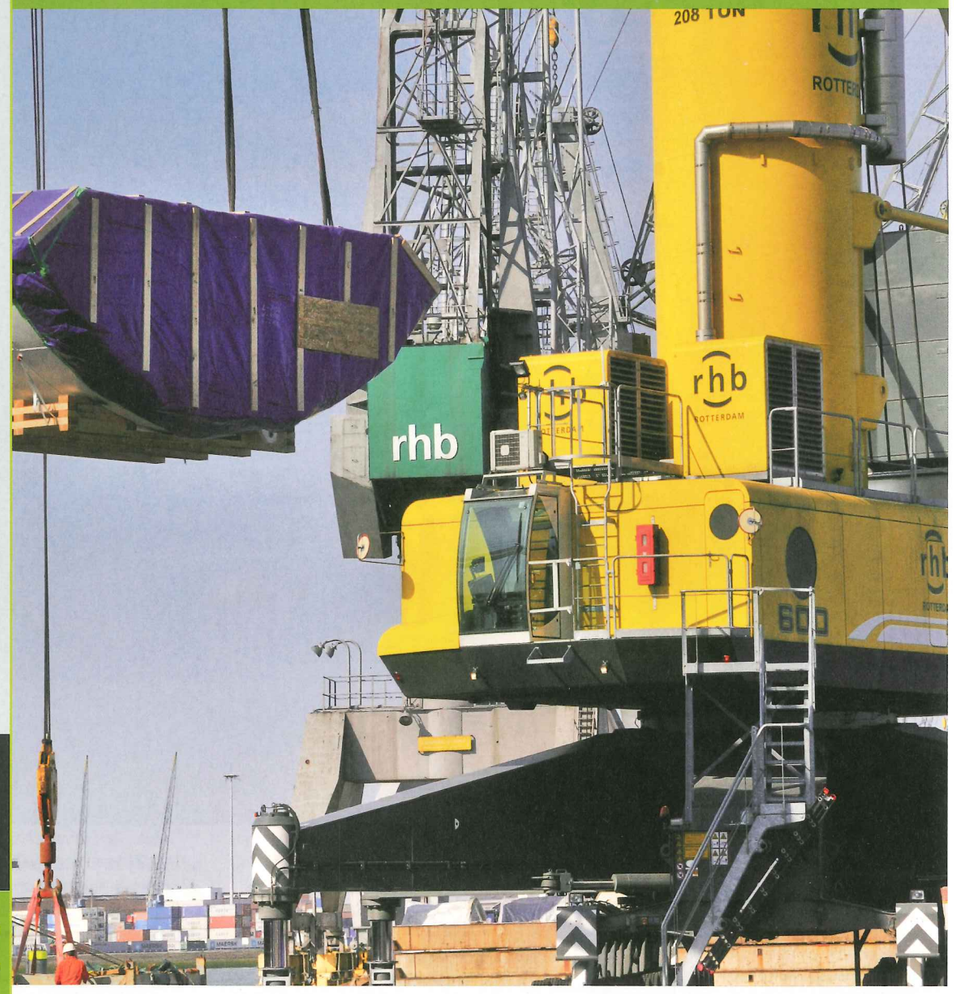

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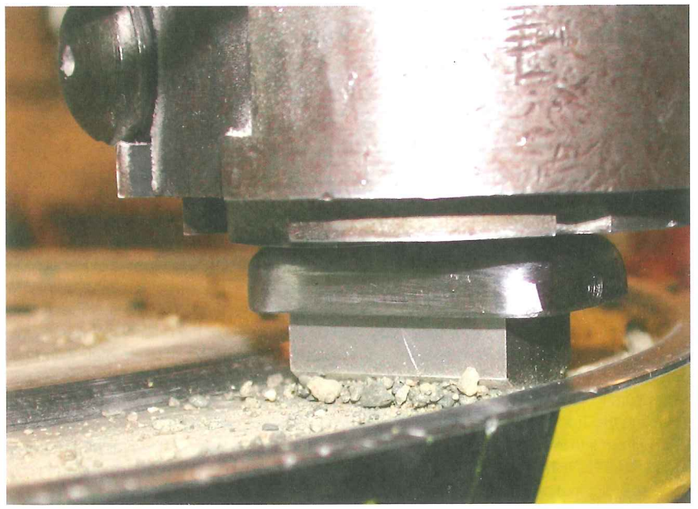
Predicting the abrasivity of in-situ like soils

Jakobsen, Langmaack, Dahl and Breivik report on further work undertaken at the Norwegian University of Science & Technology (NTNU – Trondheim) and SINTEF on better ways to study tool-soil interaction on abrasivity, particularly relevant to soft ground abrasion

Determining the abrasiveness of soil and predicting TBM tool life in shield tunnelling has become a popular research subject in the last few years. Nilsen et al (2006a, 2006b, 2006c and 2007) and Jakobsen and Dahl (2010) converted NTNU/SINTEF´s existing abrasivity measurement technique for hard rock and made it applicable for measuring soil abrasivity. Thuro et al (2007) converted the LCPC abrasivemeter, also intended for hard rock abrasivity testing, to measure soil abrasivity. Gharahbagh and Rostami (2010) and Rostami et al (2012) developed a new soil abrasivity measuring technique that takes into account in situ soil properties. Jakobsen et al (2009) and Langmaack et al (2010) presented results on the influence of anti-abrasion foams on wear by the use of the Ball Mill Test and NTNU/SINTEF abrasivity test. The main conclusions from this work were that the results showed a clear reduction of rock and soil abrasiveness by utilising polymer enriched foams. However, further evaluations are needed due to difficulties in controlling the amount of foam as well as difficulties in comparing abrasiveness results from samples with different grain sizes in the Ball Mill Test. NTNU together with SINTEF and BASF Construction Chemicals are, as a continuation of this initial work, developing a new measuring

Below, left: **Figure 1, steel-soil interaction with the current Soil Abrasion Tester;**
Below, right: **Figure 2, drilling tool for new proposed test**



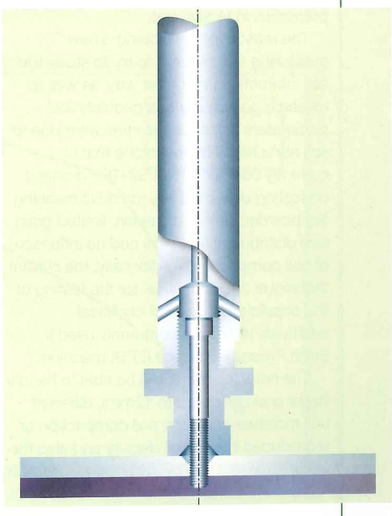


Table 1: Summary of soil properties of the tested soils

	Soil 1 (from the Trondheim area)	Soil 2 (from a tunnelling project in Europe)
Quartz content measured by DTA	44 per cent	34 per cent
Cu = d60 /d10	4.66	15.5
d50	4.8 mm	4.9 mm
d25	1.5 mm	2.5 mm
Soil Abrasion Test (SAT) value	26	23.5

technique which takes several different soil properties in to account.

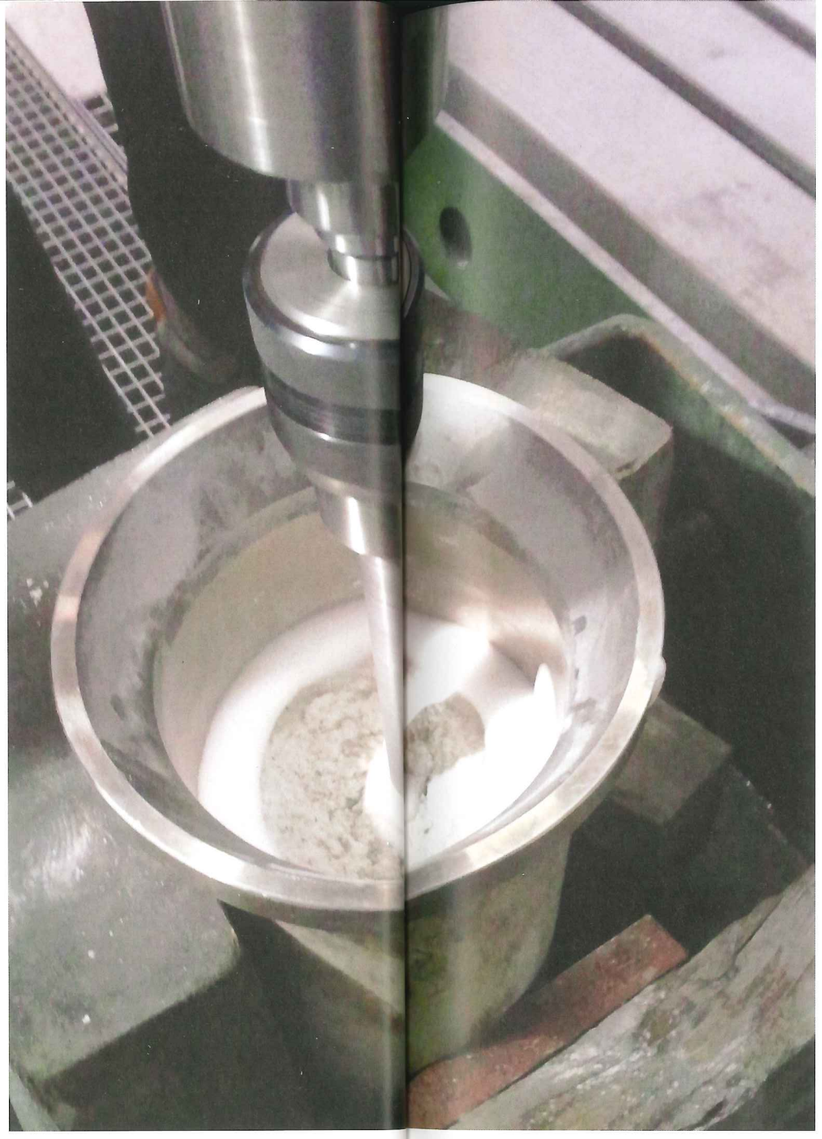
The reason for developing a new measuring technique is to try to study tool – soil interaction in a better way, as well as research on how various geotechnical parameters influence the steel wear due to soil abrasivity. The technique that is currently used at NTNU/SINTEF is based on testing disturbed soil material: meaning dry powder, lack of cohesion, limited grain size distribution (< 4 mm) and no influence of soil compaction. Additionally, the current technique does not allow for the testing of the possible influence of chemical additives, which are commonly used in Earth Pressure Balance (EPB) machine.

The new apparatus will be able to handle larger grain sizes (up to 12mm), different soil moisture contents, soil compaction or reproduced in-situ soil density and also the use of chemical or natural additives such as foams and bentonites.

The test is designed to take into account hyperbaric conditions, as the test chamber can be pressurised up to six bar. Additionally the required torque for drilling in the soil sample at variable rotation and thrust will be monitored, thus indicating different torque requirements in various compacted soil-additive-water matrices.

The interaction between soil and steel will be based on both rotation and penetration of the drilling tool. The drilling tool consists of four steel spokes, which drill into the soil to a depth of 200mm in each test. The steel used in the test piece has a Vickers hardness of 227.

Preliminary atmospheric tests have been performed in order to evaluate the test procedure. The tests were conducted on two natural soils. One (Soil 1) is from a local source in the Trondheim area and the other (Soil 2) from site investigation of a planned European EPB TBM tunnelling project. The grain size distribution of Soil 1 ranges from



Left, top: **Figure 3, hyperbaric test chamber 150 x 300 mm;** Above: **Figure 4, boring in to a compacted soil sample with soil conditioning foam under atmospheric test conditions**

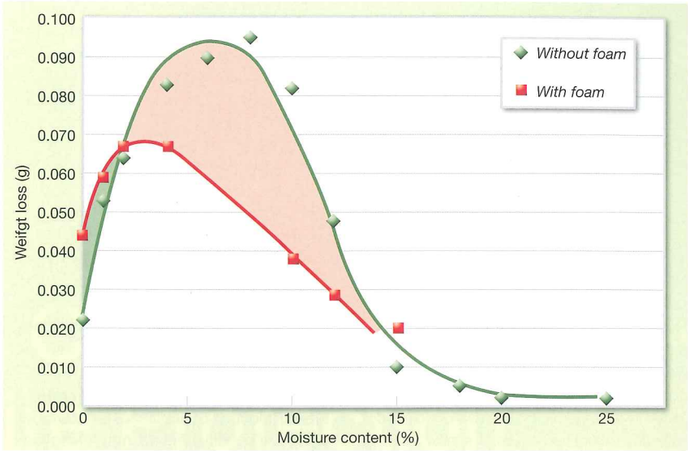
0 to 6.5mm and for Soil 2 from 0 to 30mm. Particles above 12mm were removed from the Soil 2 prior to testing.

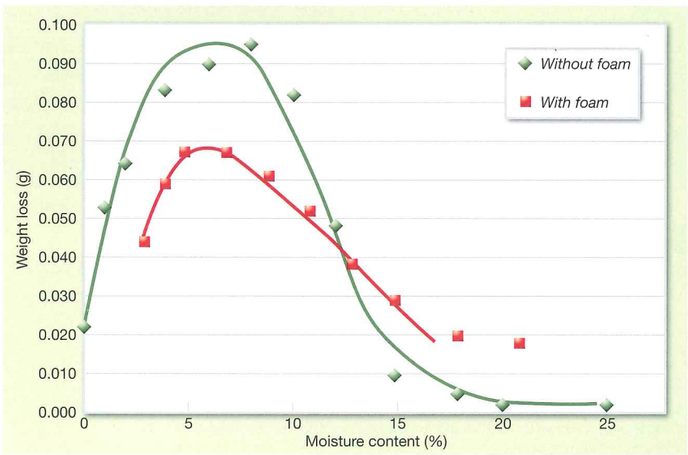
Test procedure

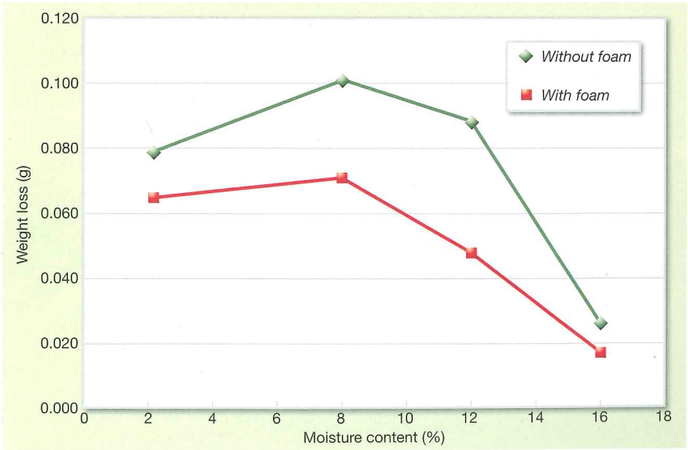
The soil specimens to be tested were assembled in four layers, each compacted by ten strokes of a Proctor Hammer of 50mm diameter and 2.5kg load. The rotation speed of the drilling tool was set at 90 rev/min, and a constant penetration rate of 0.63mm/rev or 56mm/min was applied. The test was conducted by drilling stepwise to depths of 50, 100, 150 and 200mm. The reason for the stepwise drilling method was to achieve better mixing between the foam and soil.

- Dry soil application: In order to obtain a dry soil, the present soil samples were gently dried in a ventilated oven at 30°C for 48 hours.
- Humid soil application: Various amounts of water were added and mixed with the specimens to be tested in order to achieve homogeneous moist soil samples.
- Conditioned soil application: Foam with an expansion ratio FER = 10 (air/liquid ratio = 10:1) was applied on top of the compacted and humidified soil sample for the tests performed with additives. The foam injection ratio FIR = 30 per

Right, top: **Figure 5, soil abrasivity development for conditioned Soil 1;** Right, centre: **Figure 6, adjusted moisture content and soil abrasivity for Soil 1;** Right, bottom: **Figure 7, abrasivity for varying water contents with and without foam for Soil 2**







cent (foam:soil ratio = 300 litre per cubic metre) was used meaning that one litre of foam was utilised for excavating approximately 3.3 litres of soil. The foam used was BASF Meyco SLF41, which is a polymer enriched soil-conditioning additive. Generally the concept of using soil-conditioning foams is that their high surface area will confine fines in the soil matrix and subsequently reduce the friction between both soil grains and the interaction between the soil and steel tool.

As shown by Jakobsen et al (2009), and Rostami et al (2012), soil and rock abrasiveness increases up to a certain level generally expected with increasing moisture content. Subsequent to the abrasiveness' 'peak level' a general decrease of soil and rock abrasiveness occurs. A similar phenomenon is reproduced with the test apparatus described here. For Soil 1 the soil abrasiveness' peak occurs at approximately six per cent moisture content and then reduces as more water is added. The peak is assumed to be influenced by the soil's grading curve as well as general abrasion properties such as grain mineralogy and grain shape (see figure 5).

The testing performed with addition of soil conditioning foam leads to a reduction of the soil abrasivity peak (reduction shown in red shaded area in figure 5, page 43), and hence provides a good indication of the functionality of soil conditioners. However, at low moisture contents the introduction of soil conditioners in certain cases may intend to increase the abrasivity, here shown as green patterned area in figure 5. This phenomenon has also been observed at some EPB drives executed in dry soil open excavation in Switzerland and Germany where the introduction of small amounts of soil conditioners reduced the TBM cutter tool life.

The increase of soil abrasivity in low moisture contents is most likely caused by the introduction of additional moisture by using soil conditioning agents. Taking the total moisture into account, the soil-conditioning agent reduces the wear, except for the high moisture content area. The increased soil cohesion probably leads to a slower decrease of wear than just using water. The adjusted picture is shown in figure 6 (page 43).

Soil 1 and Soil 2 are quite similar with respect to the measured abrasivity properties according to the existing Soil Abrasion Test procedure, and the initial measurements by the new test. The quartz content is also in the same range. However Soil 2 has a more uniformly graded sieve curve that might cause a higher resistance, and thus higher steel wear on the excavating tools. In general a reduction of abrasive wear in the range of 25-45 per cent was observed by applying adequate soil conditioners to the soil samples.

Conclusions

The few tests conducted clearly indicate that moisture content influences the abrasive wear in a steel – soil interaction, similar to the Rostami et al (2012) findings. The introduction of soil conditioners reduces the potential abrasivity peak of the tested soil samples. However the current tests are so far only based on sandy soils, meaning that further testing on other materials is needed.

The introduction of an additional 'soil abrasion test' is, at present, not intended as a new index test. The idea of introducing this test procedure is to provide self-explanatory test results taking into account several in-situ soil properties.

Based on the promising results NTNU/SINTEF, together with BASF, intends to perform extensive testing in order to show the influence of various soil conditioners on abrasivity and TBM torque, as well as the effects of confinement pressures and soil compaction.

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Need for fire protection

Wilf Butcher, chief executive of the UK Association for Specialist Fire Protection, explains the benefits of passive fire protection

Many tunnels are constructed using either cast concrete sections in cut and cover or by lining of bored tunnels with concrete. There is a general perception that concrete will not burn and therefore will be fireproof. In the event of a fire however, concrete can suffer explosive spalling caused by the residual moisture in the concrete boiling and causing high pressure steam which, in trying to escape, will cause the concrete to crack and shatter, in some cases explosively.

This problem has been found particularly in high strength concrete. In 1976 the American National Institute for Standards and Testing (NIST) initiated research into concrete fire performance. Evidence was demonstrated in the Channel Tunnel fire of November 1996, where pictures of the railcars show their roofs sagging under the weight of spalled material.

NIST indicated that explosive spalling can be expected at temperatures of 300 - 450°C. Furthermore, work on bored tunnels using concrete linings in the Netherlands shows that explosive spalling can occur within 10-15mins at surface temperatures as low as 200°C. The Dutch experience claims that where the moisture content is over three per cent of the mass, the risk of explosive spalling is 100 per cent.

The Rijkwaterstraat (The Dutch Transport Ministry) takes the view, based on extensive research, that tunnels must be protected from fire in the 'worst case' scenario. Fire tests are required on an individual project basis and the tests are done to the special heating regime known as the RWS Curve. This has a maximum temperature of 1,350°C maintained for up to two hours.

The Dutch authorities require the surface temperature of the test piece to be restricted to 350°C and the temperature at 25mm cover depth to 250°C. Imposition of this limit leads to a need for fire protective insulation to the concrete lining, and tests of prospective materials must show no loss of bond, failure of fixing, or explosive spalling during the test.

To protect tunnels from the ravages of high intensity fires holistic solutions combining active measures, such as fire detection systems, and management systems, such as evacuation procedures and passive fire protection systems, should be employed after a detailed risk assessment has been carried out as part of the tunnel's design process. The use of proprietary systems should give confidence to the client and the insurer.

Passive fire protection systems used to protect tunnel concrete are easy to install. In case of fire such materials can result in the quick reopening of the tunnel as they are quick to replace in comparison to the reinstatement of fire-damaged concrete.

Typical systems include proprietary spray applied cementitious products and autoclaved calcium silicate boards utilising inert fillers. The mechanism for the protection of the concrete by cementitious and calcium silicate products is twofold. Firstly, they contain trapped moisture, which in a fire situation will boil, and keep the concrete temperature around 100°C until all the water has disappeared. Secondly, the product acts as an insulator.

Material benefits

The added insulation that these materials provide will, after a fire, eliminate repairs to the concrete since temperatures will not have reached a high enough level. Temperatures as low as 160°C can mean that repairs are needed, for example concrete containing polypropylene fibres will need reinstatement as these products will have melted.

Once temperatures reach 300°C the bond between the concrete and the rebar will have significantly reduced. At 380°C it is generally accepted that all exposed concrete will need removal and subsequent repair. Even smouldering fires can dehydrate the surface of concrete and, if a serious hydrocarbon fire follows, the level of explosive spalling is likely to be greater.

Secondly, passive fire protection coverings do not impinge upon the long-term durability of concrete as they have no effect on the porosity of the material, nor do they cause the formation of any cracks or channels that can admit agents harmful to rebar. Similarly, as proprietary passive fire protection products are placed between the concrete and the fire they have no effect on the properties of the concrete during placement or in its lifetime.

Above: **Wilf Butcher, chief executive of the UK Association of Fire Protection Specialists**

Another major benefit is that the products are specifically designed, factory manufactured, and assessed for their end use, and can be installed by companies that are members of third party certification schemes. Schemes are found in Approved Document B Fire Safety to the Building Regulations for England and Wales.

The use of third party certified applicators for products has become even more important since the Regulatory Reform (Fire Safety) Order (RRO) became law in England and Wales in October 2006. The RRO places the onus of the fire safety on the shoulders of the Responsible Person who is either the employer, the person in control of the structure, the owner, or any other person who to any extent exercises control over the structure. The Responsible Person is required to ensure that an assessment of the risk of and from fire is undertaken. Identified hazards must be removed, or reduced, so far as is reasonable and special consideration shall be given to the risks posed by the presence of dangerous chemicals or substances and the risks that these pose in case of fire. Special consideration will also be given to any group of persons who may be especially at risk in case of fire.

Fire shields and other guardians

Maurice Jones examines methods and materials used for passive fire protection in tunnels

The materials and methods collectively described as passive fire protection for tunnels are of varied types and mixed benefits. The importance of passive fire protection is often not just a matter of reducing recovery costs by protecting the tunnel structure. Most types only come into play at higher temperatures when life in the tunnel is, hopefully, saved.

It is also worth noting that the strict fire controls practiced by the Netherlands (RWS curve fire design basis) have a lot to do with the consequences of tunnel fire. Severe structural damage to tunnels below sea level can cause collapse and widespread flooding damage.

Tunnel users cannot survive a sustained fire due to lack of oxygen, high levels of heat and the possibility of toxic substances. The first priority of the fire and rescue services is to save life by aiding rapid evacuation. In the vital minutes immediately after a fire takes hold, tunnel users may have to save themselves by reaching the nearest refuge or escape route. It is here that passive fire protection can perform a role in holding back the worst heat and so preserving life until an escape or rescue can be made. Passive fire protection can also promote fire life safety by preserving separate ventilation ducts.

The general principles of passive fire protection are outlined in separate articles in this issue's review (Butcher, page 42 and Appleton, page 46) and also by some of the references below. Despite their robust nature in normal conditions, both concrete and ferrous materials should be shielded from the highest temperatures in order to survive a major fire.

Primary means of passive protection employed in tunnels are:

- Fire resistant panels shaped and cut to fit the tunnel profile
- Sprayed-on linings with the same function
- Internal protection for structural concrete in the form of thin polymer fibres to deter concrete spalling
- Various forms of fibrous fleece that can sometimes be used to wrap around important ducts and cables to prolong the useful life of services and communications if threatened by fire, but rare in tunnels
- Increasing the thickness of permanent concrete lining can limit structural damage from fire in percentage terms but necessary extra excavation and concrete will likely make this impractical. Spalling could be even more unsafe.

Strength loss

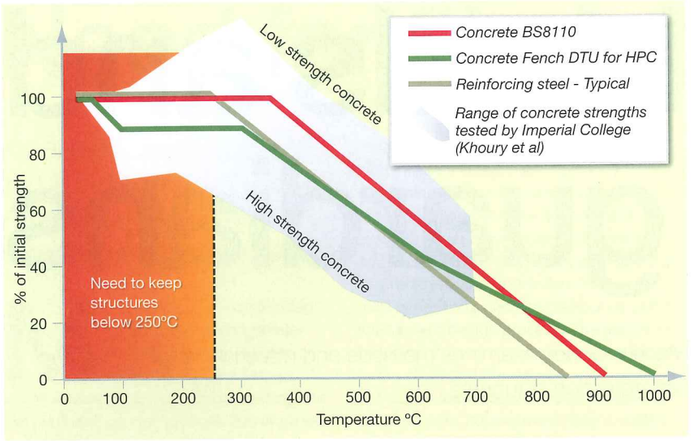
It has been pointed out (Clement and Focaracci, 2011) that the improvements achieved in concrete tunnel lining design life by forming high quality, dense concrete can be detrimental in fires due to a higher tendency to spall, despite low thermal diffusivity. Spalling can be explosive and unpredictable (Bruenese, 2009).

Sprayed lining

Another approach in creating fireproofing barriers is spraying fire-resistant material onto the surface to be protected. Advantages include a close fit to the structure or service lines to be protected.

Today, sprayed on products are based on materials that resist heat themselves or form heat insulation of the material (concrete and steel) beneath, perhaps, as with expanding vermiculite, initiated by the heat of a fire. According to chemical giant BASF Meyco vermiculite-based products are relatively weak and require mechanical bonding to the tunnel structure such as by

Below: **Xella Hebel aerated concrete panels used to line portal areas for the N57 Walcheren canal tunnel near Middelburg, Netherlands**



Left: Figure 1, graph of loss of concrete strength due to heat [after Clement & Focaracci 2011 – BASF Meyco & Prometeoengineering

stainless steel mesh. Its own cement-based product, Meyco Fireshield 1350, is claimed as six times the compressive strength of a typical vermiculite-based product.

Using advanced robotic applicators such as the Meyco's Robojet, applying the correct thickness of lining in the correct places can also save costs and achieves tolerances that are impossible with manually applied products. Application rates at 150-250m² per hour depending on the specified thickness. Recent applications of Fireshield 1350 have included the Bodio section of the Gotthard rail base tunnel and the Soderledtunnel safety upgrade in Stockholm, Sweden.

Morgan Thermal Ceramics' main product used in tunnels is FireMaster Firebarrier, a cementitious material that can be sprayed or cast onto surfaces to be protected. Firemaster Firebarrier 135 is a special formulation for tunnel protection that has passed a large range of tests including on prestressed large concrete slabs under RWS fire conditions. It provides an easily cleaned, high-quality surface finish.

Another sprayed material is Promat's Cafco Fendolite MII (see feature, page 46).

Panels

The principle of protecting a tunnel's structure from fire and possible physical damage has long been established, although the days of using asbestos in insulating fire protection materials have long gone for good health reasons.

Today, panels employ various methods and material to create sufficient heat insulation, durability and ease of installation, as well performing other functions not associated with fire. These include ceramic refractory fibres, aerated concrete and vermiculite-type minerals.

Two main types of panel produced by the German Xella group have been used for tunnel fire protection. Contractor Multiclad Facade Systems installed 45,000m² of Xella Fermacell Aestuver lightweight, sandwich-panel, cement board in Brisbane's dual-highway Clem Jones Tunnel.

Subsequent to Rijkswaterstaat tests, Xella Hebel panels were chosen for the N57 road beneath the Walcheren canal near Middleburg. The Hebel panels are 150mm thick and consist of aerated concrete to line sheet steel walls at the portals.

Promat offers Promatect H boards as used in the Westerscheldetunnel and Velser Tunnel in the Netherlands. These sub-water applications have shown the ability of the board to be unaffected by water leakage but still reveal 'wet spots' to facilitate inspections. Promat Vermiculux is designed for structural steel fire protection.

Confidence in modern passive barrier fire protection, whether panels or sprayed, is demonstrated by a non-traditional and more economical means of creating an escape route. The suspended emergency escape route, which is trapezoid or rectangular in section and fixed to bars or bolted plates in the tunnel crown is made of concrete and/or steel and covered with passive fire protection. Tunnel users access the escape route via stairways from lay-bys. Tests have shown that temperatures in the escape tube can be limited to acceptable levels by insulation.

Fibres against fire

Another fairly recent development is the use of polymer fibres within the concrete mix to be cast with it. Unlike other forms of passive fire protection that form an insulting barrier between the fire and the material to be protected, thin (monofilament or micro-) polymer fibres work internally to prevent greater damage to concrete in a high-energy fire. They are therefore mainly a safety measure, as the concrete affected will still need replacement or repair.

Such fibres are also designed and supplied to reduce surface cracking of the concrete during curing but as far as fire protection they will melt at a temperature lower than that causing concrete damage. The calcium hydroxide in cement dehydrates with heat from the fire, so increasing the vapour pressure in addition to any free moisture within the concrete. The small passages created by the melting of the fibres allow this excess pressure to be dissipated and released without serious deterioration in concrete strength. Increasing internal pressure would cause serious, possibly explosive, spalling.

A number of manufacturers and distributors supply thin polymer fibres for use in fibre protection including Propex (Fibermesh 150 etc) and Adfil. These fibres should be distinguished from macrofibres, the purpose of which is mainly structural.

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Shielding tunnels with built-in fire protection

Passive fire protection is an essential requirement for any type of transport tunnel, but as Promat's marketing manager, Sean Appleton explains, choosing the right passive protection is not an easy task

While tunnels make a major contribution to modern transport networks, they also pose some significant challenges when it comes to protecting them from fire. Yet that protection is an essential requirement, given that the limited scope for escape and a lack of easy access means that a major tunnel blaze can have potentially disastrous results.

The notorious 1999 Mont Blanc tunnel fire provided a horrifying illustration of these results. A fire on a truck located 6km in from the Italian end of the tunnel eventually spread to 35 other vehicles. It created high levels of heat and toxic fumes, killing 39 people and causing extensive damage to the roof and road surface of the reinforced concrete tunnel structure. As modern vehicles continue to use more flammable materials from toxic plastics to exotic resin-bound materials, the risk from this type of event continues to grow.

In addition to the human cost, the other effects of a tunnel fire can be enormous. A blaze in the Channel Tunnel, which cost some EUR 87M (USD 111.7M) in direct repairs, eventually led to a total cost of EUR 211M (USD 271.0M) once other factors such as lost business and the replacement of infrastructure were calculated. This makes it even more important that such fires are prevented if possible, and that every effort is made to limit their impact.

Nature of danger

The nature of tunnel fires can vary widely, ranging from a cellulosic blaze involving burning materials such as paper, through to high-intensity hydrocarbon fires involving petrol or propane. In the latter case, a small ignition source in a vehicle can quickly lead to a blaze which engulfs a fuel tank, and this can generate temperatures of up to 1350°C plus heat fluxes up to 300kWm^2. The transportation of hazardous goods through tunnels, and the general increase in traffic volumes, mean that the risk of this type of incident continues to increase.

To make the situation worse, various operational procedures, safety standards and structural requirements exist in different countries. It was the need to unify these and introduce minimum standards that led to the introduction in 2004 of Directive 2004/54/EC of the European Parliament and Council on 'Minimum Safety Requirements for Tunnels in the Trans-European Road Network'. The document aimed to make stakeholders fully aware of the risks to life, and the effects, both economic and environmental, associated with the operation of unsafe tunnels.

Active or passive?

Active fire protection is undoubtedly an effective step towards making a tunnel safer. However this solution does depend on each active element, whether it be fire detectors, sprinklers or a hypoxic oxygen reduction system, operating effectively when required. Any damage to water supplies, operating mechanisms or wiring can seriously limit the degree of protection, making it unwise to construct a tunnel's fire defence around active measures alone.

Passive fire protection measures for tunnels usually involve either mechanically fixed boards or spray-applied coatings that add fire-resistance to the structure. They require little or no maintenance, no human intervention, no power or water, and they cannot be turned off. They play a crucial role in helping a tunnel maintain its structural integrity and minimising the prospect of any collapse.

Passive fire protection will slow the spread of fire and limit the damage caused by high temperatures, thus providing more time for occupants to escape. They inhibit the escalation of a fire and can also be used to protect elements of an active system such as power supplies or pipe work. Many passive measures also offer thermal and acoustic insulation benefits, which makes them even more attractive.

Method choice

The first step to choosing the most appropriate passive fire protection is to examine the tunnel's construction and the processes involved in a blaze.

There is a common but inaccurate misconception that a concrete tunnel will somehow be inherently more fire resistant than other types.

A major fire will induce concrete spalling that can take many forms and have many causes, such as slow heating of the concrete (1°C/min), or fast heating of the concrete (250°C/min). Spalling can be explosive, or be more gradual, sometimes even stopping when it encounters a reinforcement layer within the concrete. Concrete containing calcareous aggregate can even suffer spalling when the fire is cooling down, caused by the rehydration of CaO to Ca(OH)^2 after cooling. The resulting

Developments in vehicle technology such as LPG fuel and lithium batteries have driven the need for more effective fire protection systems in recent years

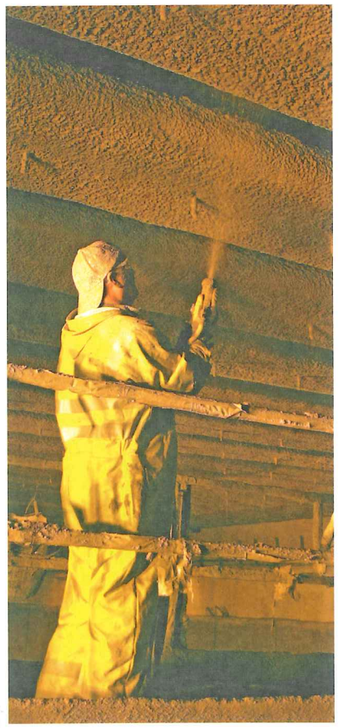
Left: The ability to offer high levels of structural strength, dimensional stability and fire protection are just some of the many benefits which fire protection boards can provide for tunnels

40 per cent expansion in volume generates severe internal cracking, which can rob the concrete of its strength.

Whatever the cause, the end result is likely to be a reduction in the structural integrity of the concrete, and potentially of the entire tunnel.

A similar misunderstanding often surrounds structural steelwork found in tunnels. Steel is also vulnerable to fire, and above a certain temperature it will lose its strength and buckle.

If both the concrete and steelwork are badly affected by fire, the prospect of a progressive collapse in the tunnel begins to rear its head.



Other considerations

The development of a fire must also be considered when choosing passive protection. Much laboratory and field research has been done in this area and the resulting data has helped create a series of time/temperature curves that give a good starting point from which to determine a fire's likely behaviour.

A tunnel's construction will also affect a fire's progress. A bored tunnel fitted with concrete segments can present significantly different challenges than a blaze in a cut and cover structure. Even the tunnel's gradient can have a direct bearing on a fire. Where there is no perceptible gradient, heat and smoke will spread in the same direction as the prevailing ventilation, and a low ventilation speed will allow heat and disproportionately high temperatures to build up at the location of the fire.

However, a gentle slope as little as five per cent will encourage the heat and smoke to climb up-grade to exits. If the ventilation is moving in the same direction, heat will be drawn away from the source of fire much more rapidly, and this can therefore have a significant bearing on the type of passive protection required.

Protective options

Once these and many other factors have been considered, the choice must be made between using either a spray-applied protective coating or fire protection boards.

Protective coatings usually feature an exfoliated vermiculite aggregate that can be applied manually, or more commonly, by spray. This provides the thermal performance and resists the thermal shock cycles caused by exposure to fire and then the water used to fight it. They can be applied directly to a concrete or steel substrate or to a secondary expanded lath where complex shaped linings are involved, making them extremely versatile. Delivering up to 240 minutes of protection they usually produce no smoke or toxic fumes and offer high resistance to impact damage.

Left: Tunnel linings with a protective coating will suffer considerably less damage from long exposure and multiple fires

Superior systems can also withstand regular jet washing at 100 bar of pressure at 1m distance, making them easy to maintain. Repairs are easy to achieve by cutting away and then replacing the damaged area.

A protective coating often represents a cost-effective way to combine good performance with minimal maintenance requirements. It can prevent the temperature of the tunnel's concrete (or steel reinforcement) from reaching its critical level, and it will typically keep a normal strength concrete (35MPa) below 380°C during the prescribed exposure period. By inhibiting the temperature build up in the concrete the coating prevents the rapid build-up of internal pressure that results in spalling. On cut and cover and immersed tube tunnels, a protective coating can also prevent steel reinforcement from exceeding the sort of temperature levels that could trigger a progressive loss of strength.

Boarded solutions

Alternatively, board-based protection offer many benefits for tunnel applications. The non-combustible mineral-bound core of the boards makes them light in weight, so they are easy to handle, cut and work using ordinary hand tools. They also offer a clean installation process compared to spray-applied alternatives.

Many boards have British Board of Agrement certification, and are proven to deliver high levels of structural strength, dimensional stability and fire protection. They can withstand high temperatures and frequent temperature changes, making them ideal for use in an exposed tunnel environment.

This is supported by their resistance to the effects of moisture, as many boards will not deteriorate when exposed to the damp or humid conditions often found in tunnels. They also offer great installation flexibility, as they can be laid as lost shuttering, installed by the lost formwork method or applied once the tunnel is constructed

.

Shared research

Tunnel fires have been the subject of considerable research, and much of the resulting knowledge is now available through FITS - the European Thematic Network on Fire in Tunnels. The 33 members are drawn from 12 European countries, and share their research to help establish a pool of knowledge that can be used to improve fire protection design for tunnels. When considering the expected life of a tunnel and the fire protection that will be required, planners and designers must consider many varied factors, and the FITS resource can be an excellent place to start. One thing is certain though: as we place ever greater demands on our tunnels we can be sure that the need for more robust fire protection systems will continue to grow for many years to come.

Case studies

Promat offers the following examples of applications of its products in tunnels.

Sweden's 3.5km Oresund Tunnel is the world's largest immersed tunnel and carries a four-lane motorway plus a dual-track high-speed rail line. It is constructed from 20 precast concrete elements each weighing 55,000 tonnes and it connects the artificial peninsula at Kastrup to a man-made island in the Oresund Strait.

The tunnel's 180,000m² of concrete with steel reinforcement are protected against fire by Promat's spray-applied Cafco Fendolite MII passive fire protection. This is designed to prevent the surface of the concrete from exceeding a temperature of 380°C after two hours of exposure to a hydrocarbon fire, where temperatures can typically reach 1350°C within just a few minutes. Other solutions were created to protect the segment and immersion joints within the tunnel, and also to seal between compartments within the service tunnel.

Fendolite MII was selected for this project after an exhaustive evaluation had been completed of all the available fire protection systems and solutions.

Extensive testing has shown that the system can prevent concrete spalling, even after four hours of continued hydrocarbon fire exposure.

The Holmesdale Tunnel on the M25 London orbital motorway is one of the busiest road tunnels in Europe. A recent project to widen and refurbish the tunnel included the application of Promat's Cafco Fendolite MII to improve protection.

Given the severe nature of hydrocarbon fires, the design team turned to protective materials that used on offshore oil and gas production installations, eventually settling on Fendolite MII.

This was the only material that fully satisfied the project's rigorous fire performance, durability, maintenance and light reflection requirements. The spray-applied material now ensures that the tunnel's roof beams, outer and central dividing walls are protected from collapse for a minimum of three hours, even under the most extreme conditions of a major hydrocarbon blaze.

Acknowledgement

This article is edited from information supplied by Promat, a leading supplier of fire protection materials.

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Nazzano method

The first tunnel in the world to be widened during continued traffic is revisited. Pietro Lunardi of Lunardi's Geo-Engineering Office, Mario Cangiano of Stone and Andrea Belfiore of Rocksoil tell the prolonged story of a twin bore motorway tunnel widening through complex geography

The requirement to increase the capacity of a section of road tunnel first emerged at the start of the 1990s, during a study to widen a 40km section of the A1 Milan-Naples motorway between Orte and Fiano Romano, near Rome, Italy.

A 337m-long twin bore tunnel already existed in the section, in the municipality of Nazzano and various constraints were faced which restricted design choices.

Considering the volume of traffic already flowing, it was not possible to close one carriageway of the motorway, even temporarily, to divert the traffic onto the adjacent carriageway.

Conversely, the situation meant that construction of a new tunnel would be very difficult. And would mean a third bore for vehicle transit, with substantial changes to the motorway route in very close proximity to the Tevere-Farfa Nature Reserve.

The only solution was finding a way to increase the capacity of the existing tunnel by widening, but without interrupting traffic flow, and so expand it to three lanes plus an emergency lane in each direction, giving a net road profile of 14m in width and 4.5m in height.

Below: **Figure 1, the Nazzono tunnel is located north of Rome**

The challenge to tunnel designers was not simple. A construction system had to be devised to allow the necessary work without affecting the traffic flow or the safety of users passing through a complex underground construction site.

The design concept of this project was developed by Pietro Lunardi during the construction of the 'Baldo degli Ubaldi' single vault underground station for the Rocksoil-designed extension of Line A of the Rome metro between Ottaviano and Battistini stations.

The construction system adopted to excavate the crown of the tunnel - approximately 20.5m in width by 9m in height - included two important new features:

- The use of advance reinforcement of the core-face with fibre glass structural elements combined with mechanical precutting technology and an 'active arch' lining;
- A high degree of works mechanisation.

Active arch lining

Active arch lining refers to a lining that produces immediate confinement of the surrounding ground, without waiting for it to deform and push down on the extrados. A lining of this type is formed by erecting an arch of prefabricated reinforced concrete segments. This is immediately rendered a load-bearing structure by two opposing flat jacks inserted in the key segments which artificially apply the axial compressive stress needed to contrast the loads to be borne.

A special machine was fabricated and used to combine the above technologies into a single, highly efficient system. It consisted of a large steel portal frame with a geometry designed to fit the profile of the crown of the station tunnel. This was supported on stabilisers set on longitudinal beams installed in the side-drifts excavated for the side walls of the tunnel in order to allow it to traverse longitudinally. In addition to the equipment needed to perform the mechanical precutting, the equipment for handling and erecting the prefabricated concrete segments of the final active arch lining was also installed within the portal.

It was observed that during operations to construct the vault (the volume of ground below the springline of the tunnel, which had a cross section similar to that of a normal motorway or mainline rail tunnel) was unaffected by the construction operations. It was determined that the Nazzano road tunnel could be widened in the same way without the need to close it to traffic, naturally as long as appropriate safety measures were taken to protect tunnel users.

It therefore clearly emerged from a study of the design and construction used for the 'Baldo degli Ubaldi' station on the Rome metro, that the technology existed to widen a tunnel while it remained in service, at least in terms of advance ground improvement and reinforcement and the placing of the preliminary and final linings. All that was needed was an appropriate system to protect traffic travelling on the motorway below, under the active construction site.

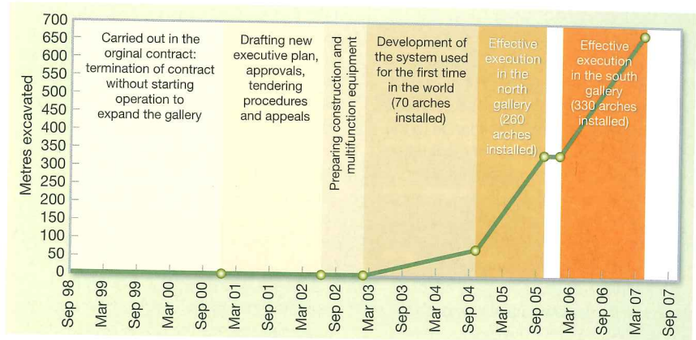
Traffic protection shield

To achieve separation of the construction from traffic, a steel tunnel shield approximately 60m in length, termed a 'Traffic Protection Shield' was constructed and placed inside the existing tunnel with an appropriate structural design.

Vehicle traffic on the motorway would therefore be able to run under the protection of the protective shield in the opposite direction to that of the advance of the widening works in order to avoid producing the irritating sensation of a narrowing field of vision for tunnel users passing from a section of widened tunnel to a section still to be widened.

The key factors in the basic idea for widening a tunnel without interrupting traffic consisted of a traffic protection system and

Right: **Figure 2, project timeline**



appropriate operating technology to allow works to be performed operating exclusively inside that protection system, without interference with traffic.

Once these had been identified actual design itself of the whole works consisting of the project to widen the section of motorway running through the Nazzano Tunnel could then begin.

The first design (1996-1998)

Background

The lot consisting of the Orte-Fiano Romano section on the A1 Milan-Naples motorway was 1,200m in length running from km 522+000 to km 523+200 and also included two artificial portal tunnels for each carriage way, waterproofing works, walls to confine excavations at the portals, support walls, surveys, trenches and auxiliary works for access to working areas. The widening works also included improvements to the central reservation between the two carriageways, lighting systems and service systems to manage motorway traffic.

Geology of the site

The ground through which the Nazzano Tunnel passes consists of yellow silty marine sands, with fine to medium granulometry and density increasing with depth. A layer of silty clays is present below the level of the tunnel invert. The overburdens range from a few metres to a maximum depth of 45m and the water table is located, net of seasonal fluctuations, at the level of the tunnel wall.

The main sandy formation showed values for an angle of friction of greater than 30° with maximum values of 37 to 38° and cohesion of 0.02MPa, in relation to the presence of the silt fraction.

The widening programme

The widening works were to be performed according to the following general programme. First one of the tunnel bores (stage one) would be widened in the presence of traffic and a temporary invert constructed in the widened section.

Then both flows of traffic, in a north and south direction would be diverted into the widened tunnel with two lanes in each direction (stage two).

At this point (stage three), the second bore would be widened free of traffic, completing it with the casting of the tunnel invert. Traffic is then moved into the second, widened bore with two lanes in each direction and the invert is cast in the first bore.

Section types and basic advance cycle

The initial design for the enlargement of the Nazzano tunnel included two tunnel section types: a principal type with advance ground reinforcement using mechanical precutting technology, and an alternative section type where the advance ground improvement consisted of a double ring of jet-grouting in advance around the cavity. The latter could be employed if problems arose with the integrity of the precut, given the predominantly sandy nature of the ground.

In both cases the section type was completed with the installation of a final lining consisting of 19 prefabricated concrete segments approximately 1m. in length longitudinally, to be assembled at a short distance from the excavation (4m).

The sequence of basic operations performed for each advance cycle consisted of the following:

- A mechanical precut (length 4.5m, thickness 300mm, overlap 1.5m);
- Assembly of the first arch of the lining with prefabricated concrete segments (length 1m);
- First advance excavation of 1m and simultaneous demolition of the existing tunnel;
- Assembly of the second arch of prefabricated concrete segments (length 1m);
- Second advance excavation of 1m and simultaneous demolition of the existing tunnel;
- Assembly of the third arch of segments of 1m in length;
- Third advance excavation of 1m and simultaneous demolition of the existing tunnel.

The distance between the face and the final lining of prefabricated concrete

Above top and bottom: **The tunnel widening machine cuts and supports the new bore with live traffic passing underneath**

segments was of fundamental importance both for the stability of the system and for the definition of working space. It was to vary between 4m after the installation of the concrete segment arch and 5m at the end of the advance excavation.

Finally, the initial design involved excavating the first 5m from the tunnel portal under the protection of a concrete shield, to create an artificial tunnel, in order to pass through the portal of the existing tunnel in safety. On that basis, the design for the tender was delivered at the end of 1997 in time to put the project out to tender in the first half of 1998.

The first contract and dispute (1998-2001)

The first contract was won by a Spanish company with a bid 25 per cent lower than the specified contract value. The contractor had presented a substantial change to the design, abandoning the use of mechanical precutting and adopting a single tunnel section type using jet-grouting.

This offer was accepted by the client. However, it made final approval of this solution subject to the results of field tests to be carried out in situ after the handover of the site for the works at the end of August 1998.

After construction site yards were prepared at the portals of the tunnel to be widened, a field test was performed in an area facing a natural cavity overlooking the yard at the south portal. Results were not reassuring.

Although the performance in terms of the diameter and the strength of the columns of improved ground complied with expectations, substantial problems emerged with the migration and escape of grout through the ground even at a distance of several metres.

This phenomenon, concerning the use of jet-grouting technology in stage one of the works (widening of one bore with the adjacent bore in normal service) made the tunnel section type chosen by the contractor unusable, which resulted in a request by the client to return to mechanical precutting technology. The escaping grout could in fact have entered the roadway of the adjacent tunnel in service even though it was lined, with significant and uncontrollable risks for the safety of traffic.

While the client and the contractor disputed over payment of the costs resulting from the inability to use jet-grouting technology, the works continued intermittently on operations outside the tunnel itself.

In January 2001, after lengthy negotiations, the parties agreed to withdraw from the contract, with the traffic protection shield already positioned over the carriage way of the motorway and with the multi-function equipment, which should have performed the precut, the widening excavation and the demolition of the existing tunnel, as well as the active arch for the lining, ready at the portal of the tunnel to be widened.

On the date of the withdrawal from the contract, two years and six months had passed since the construction site opened, without a single metre of the tunnel having been widened.

The second design (2001-2002)

As soon as the administrative formalities were complete for the handing back of the site areas and the removal of the preparations already in place, a new design was prepared for a new tender.

This had to take account of external works and the important facts that had emerged for design during the first contract. This refers to the unusability of the tunnel section types with jet-grouting in a context of two adjacent tunnels in service, and the need to employ a conventional tunnel invert instead of slabs to join up with the tunnel invert of the old widened tunnel.

During design the safety measures for the management of interferences between traffic and construction site were improved with the introduction of support elements for the traffic protection shield. These were in concrete, firmly cemented into the ground, with a New-Jersey barrier shape on the roadside and with dimensions sufficient to resist any type of impact from light or heavy vehicles in transit.

Finally, after around five years had passed since the first cost estimates were prepared for the works, new estimates were performed for the completion of the project based on up-to-date prices.

Completed in April 2001, the new design was approved by the client ANAS in July 2001. The new tender with a basic contract value of approximately EUR 37.5M (USD 47.6M) was launched in April 2002 with bids on unit prices. It was won by a group of companies led by Cossi Costruzioni. The site was handed over to the contractors at the end of July 2002, exactly four years after the first work began.

The second contract (2002-2008)

Work on the northern carriageway: the preliminary preparation stage

The programme of works attached to the second design estimated the time needed to perform the set of operations preparatory to the widening of the northern carriageway at seven months.

Those operations also comprised the acquisition of the multi-function equipment that would perform the tunnel advance works (mechanical precutting, active arch lining, excavation and demolition).

The machine provided by the previous contractor, which was still parked on the construction site at the north portal of the tunnel, was acquired by the new contractor who performed the necessary overhauls and idle running tests, without making any substantial modifications.

The traffic protection shield was installed on the new reinforced concrete supports over the roadway at the same time as the machine was overhauled.

When site preparation was completed, the first widening excavations commenced in January 2003.

Significant problems were immediately encountered in relation on the one hand to the poor mechanical properties of the sandy ground in the portal zone, which had been disturbed considerably by the excavation of the previous tunnel, and by functional deficits in the multi-function equipment which had not been properly prepared to produce the minimum performance required in terms of production capacity.

The former problems meant that the ground did not possess the minimum required ability to support itself during the precutting operations, not even for the few moments needed to clean the cut and fill it with grout. This resulted in frequent and unacceptable over excavation.

The problem with the multi-function equipment was that it was unable to deliver sufficient power during the erection of the concrete segments in order to be able to handle them quickly and easily.

In addition to these two problems, which were serious and not easy to solve, a series of difficulties due to with the very limited space available were encountered as advance works commenced. This made excavation, demolition and spoil removal operations particularly slow and laborious.

Faced with these problems, for many of which no precedent existed to which reference could be made to identify rapid and appropriate technical solutions, the widening works advanced at less than 0.1m per day for approximately seven months. Difficulties arose at all stages of the works.

At the end of August 2003, after having widened just a 25m length of the tunnel, the consulting engineer and the project manager, in agreement with the client, commenced a reassessment of the operating procedures in order to solve the problems that had arisen.

In order to ensure the stability of the face and that the cavity would support itself, above all during the precutting stage, ground improvement in advance was performed with selective and repeated injections of cement and chemical mixes through valved pipes.

These operations, which initially extended for 25m ahead of the face were performed for an area above the tunnel where it was possible to create a working yard without excessive earthworks.

Right: Cutting and segment erection by the multifunctional machine at Baldo delgi station

At the same time, the contractor started a series of substantial overhauls and replacements to the multi-functional equipment to improve its ability, especially in terms of the installed power.

To deal with the confined space and the soil removal operations, the most important change to operating procedures was made. The multi-functional equipment would only perform the precutting and active arch erection operations.

Excavation at the face, demolition of the lining of the existing tunnel and spoil removal would be performed using conventional methods, with roadheaders and mechanical shovels on wheels. Even the erection of the side wall segments of the active arch was to be performed using a crane on wheels and not the multi-function equipment, given the difficulty of installing these segments, which, because of their size and weight, placed the equipment and structure of the machine under considerable stress.

In order to achieve this, a special area for protected parking was constructed outside the tunnel over the roadway where the multi-functional equipment would be able to park during excavation and demolition work; a system for transporting the machine to and from the face as rapidly as possible was designed; finally, a self-propelled steel shield was constructed under the machine to prevent oil and other material from falling onto the roadway.

The whole complex moved on rails, which were to be extended to follow the excavation face. The machine was to move on rails as far as possible to then advance to the face using its own propulsion.

In order to further improve production, the maximum distance between the face and the final lining was extended from 5m to 6.5m to significantly increase the working space, one of the most critical aspects of the system.

Finally, the tunnel advance cycle was modified by reducing the excavation and lining erection operations to two instead of the previous three.

It was expected that significant benefits would be obtained from these changes, thanks to the more streamlined and efficient management of the works, made possible by increasing the available space, reducing down times for moving and parking the machine, two movement and parking operations instead of three, and employing two sprayed concrete operations at the face instead of three.

The main problems which had affected production had been addressed and tunnel advance works resumed in March 2004 using the new operating procedures. The results were positive and immediately visible to the team.

Advance beneath improved ground was carried out immediately, with production rates increasing by five-fold compared to the previous operating procedures, from 0.1m per day to 0.5m per day.

Construction of the north bore: improvements to the design

After a few tens of metres of advance without problems for traffic below or accidents to site personnel, caused by the sudden fall-in of loose material, tunnel widening advance finally reached constant production rates of close to 0.7m per day.

The results of the ground improvement in advance were positive, with the elimination of all problems relating to the integrity of the cut performed.

Georadar surveys carried out in the section of tunnel still to be widened to detect the presence of cavities adjacent to the precut zone were negative.

As a consequence it was decided to introduce a further improvement by replacing the precut blade with a length of 4.5m with another 5.5m in length, to be able to increase the length of each advance cycle from 3m to 4m, while maintaining the overlap between successive shells and the maximum distance between the face and the last lining ring erected unchanged.

This produced substantial benefits in terms of reducing down times required to move and park the multi-functional equipment. In fact since there was little difference in the time taken to create both 4.5m and 5.5m precut shells, production rates increased by almost 25 per cent.

Above: The material surrounding the existing tunnel held one of the greatest challenges as it had been loosened by the original drive

The remaining part of the tunnel (approximately 200m) was completed without incident, in approximately nine months, between February and November 2005, with production rates varying between 0.7m per day and 0.8m per day.

Out of seven years since the site opened, 75 per cent of the widening of the north bore was completed in one year.

Construction of the south bore

The works to widen the north bore were completed successfully. They had proceeded at very acceptable and regular advance rates, once the problems that had emerged in the first 80m of tunnel advance had been solved.

This persuaded the client to perform an in-depth assessment of the advance methods to be used for the widening of the south bore of the tunnel, with a view to minimising inconvenience to road users travelling on the only point on the Orte–Fiano Romano section of the

motorway not yet widened to three lanes.

The initial proposal, to widen the second bore in the absence of traffic by deviating traffic flow onto the four lanes of the bore already widened, had been formulated ten years earlier, when the volumes of traffic present could still be dealt with in this manner without running into serious problems.

Ten years later, however, the situation had changed considerably and the capacity to absorb traffic provided by just four lanes appeared totally inadequate, especially during the summer and the major public holidays in spring and autumn.

It was therefore decided to apply this method to widen the south bore, while keeping it in service.

Four lanes in the north carriage way (three running north and one south) and two lanes in the south carriage way would always be open to traffic, to give a total of three lanes in each direction and a traffic flow capacity of approximately 4,000 vehicles per hour in each direction instead of approximately 2,600 to 2,800 vehicles per hour.

The validity of the decision to widen the south bore while traffic was flowing, with a considerable improvement in the functional use of the tunnel during construction, was borne out by a further study of the project, necessary because the original contract specifications concerning the operational procedures to be followed to widen the second bore had undergone a number of substantial change.

After approximately three months (January-March 2006) spent moving construction plant and operations to the south bore and installing identical safety measures for traffic, works commenced.

Experience acquired during the widening of the first bore was used to immediately achieve even faster average production rates of close to 0.9m/day, with peaks of around 1m per day, which enabled widening of the entire bore to be completed by May 2007, just 15 months.

The entire works were completed without any significant disturbance to traffic.

Completion of the two carriageways

In order to maintain at least two lanes open to traffic on the carriageway affected by the works, concrete was poured in longitudinal sections with the consequent adoption of connecting couplers between reinforcement rods, while the safety of traffic and site workers was constantly guaranteed by appropriate methods to separate the in-service road area from the adjacent construction site.

The work to cast the tunnel inverts, which first began in the south bore and then continued in the north bore, lasted for around six months from June until December of 2007.

Overall distribution of construction times

The period of eight years and nine months between September 1998 and May 2007, from the start to the finish of works was spent as follows:

- Some 44 per cent on the difficulties of the first tender and the formulation of the procedures necessary for the second tender;
- Some 25 per cent on preparation of the construction site for the north bore after the second handover of the site from the first contract to the second contract, and problems with the fine tuning of the construction systems to overcome difficulties related to the characteristics of the ground and the first time ever use of the operating methodology;
- Only 31 per cent of the remaining time was spent on excavation to widen the two bores of the motorway tunnel.

There is probably no more valid evidence to the success of the method than the one hundred percent reliability record in terms of public safety.

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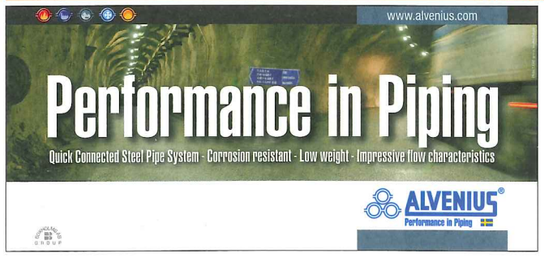

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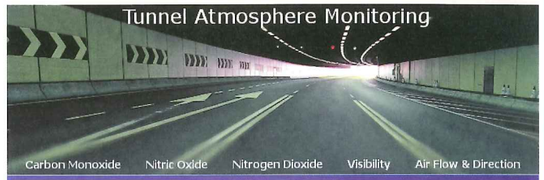

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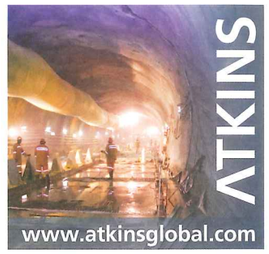

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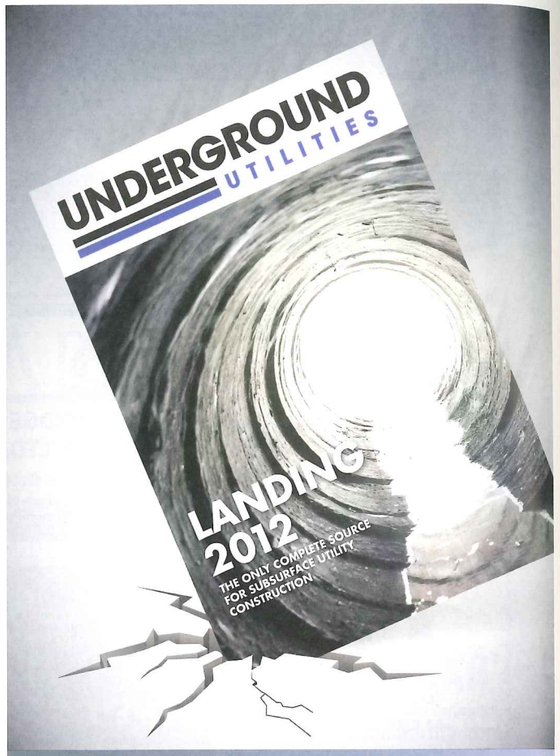

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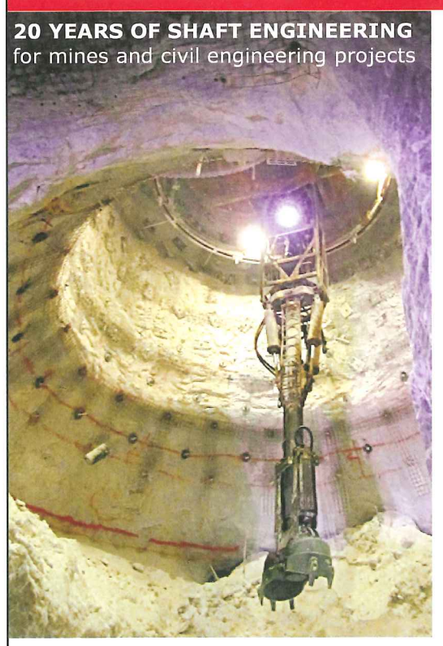

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dates & events

21 JUNE 2012
Tunnels in the LAV Barcelona-French border
High-speed railway study day in Barcelona organised by AETOS and the ADIF. See www.aetos.es

24 - 27 JUNE 2012
North American Tunneling Conference (NAT), JW Marriott, 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 is be available on http://uca.smenet.org, or email meetings@smenet.org, or tel.: +1 303-948-4200.

27-28 JUNE 2012
Safety of Life in Tunnels (SOLIT2) international conference, Scandic Hotel, Berlin, Germany
Organised by IFAB (Ingenieure fur angewandte Brandschutzfirschung GmbH) with support of the ITA Committee on Operational Safety of Underground Facilities. Proceedings in German & English including speakers from Fogtech, STUVA, Ruhr University Bochum, CETU and Eurotunnel. Contact IFAB in Rostock on tel.: +49-381-8115545, email contact@solit.info or see www.solit.info

27-29 JUNE 2012
Underground City Forum, Corinthia Hotel, St Petersburg, Russia
'Integrated Development of City's Underground Space' intl forum concentrating on the transition from indiscriminate construction to elaborate models for using underground space. Organised by the Tunnelling Association of Russia and other national bodies. For more info tel. +7 812 325 05 64/65, email info@undergroundcity-forum.com or see www.undergroundcity-forum.com

10-11 SEPTEMBER 2012
Baku Tunnelling Congress, Azerbaijan
'Tunnels & Underground Infrastructure of Urban Areas' including extension of metros and tunnels in Azerbaijan, Russia, Kazakhstan, etc. Full paper submission deadline 1 June. Organised by the Azerbaijan Tunneling Assoc with the French Tunneling and Underground Space Association (AFTES). For more info email baku.conference2012@azta-asso.com or view www.azta-asso.com.

18 - 21 SEPTEMBER 2012
'The Tunnel Connects' Eastern European Tunnelling Congress, Budapest, Hungary
The Hungarian Tunnelling Association is organising this 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 or contact Diamond Congress Ltd., tel.: +36 1 2250210 or email diamond@diamond-congress.hu.

8-10 OCTOBER 2012
Intermat Middle East, Abu Dhabi National Exhibition Centre
See www.intermat-middleeast.com or tel.: +33 1 76 77 12 08

17-20 OCTOBER 2012
Montreal TAC 2012, Canada
'Tunnels & Underground Spaces: Sustainability & Innovations: Sustainability & Innovations', organised by the Tunneling Association of Canada. For more info contact Wayne Gibson, conference manager, c/o Gibson Group Association Management, Richmond, BC, tel: +(604) 241-1297, email info@tac2012.ca or see www.tac2012.ca.

7 - 9 NOVEMBER 2012
13th World Conference of ACUUS, Marina Bay Sands, Singapore
ACUUS presents 'Underground Space Development – Opportunities and Challenges' to focus on new opportunities in developing underground space as sustainable development. More info from E-Quezt Concierge, Singapore tel.: +(65) 6271 2453, email info@acuus2012.com or see http://www.acuus2012.com

22 JANUARY 2013
11th George A Fox NY Construction Conference
Graduate Center, City University of New York, US. Organised by the SME - Society for Mining, Metallurgy & Exploration and sponsored by the Underground Construction Assoc of the SME. For more details tel.: +1 (303) 948-4200, fax: +1 (303) 979-3461, email meetings@smenet.org or see www.smenet.org

18-20 MARCH 2013
TU-Seoul 2013
Intl Symp on Tunnelling & Underground Space Construction for Sustainable Development. Full papers due 31 July 2012. Visit: www.tunnel.or.kr.

31 MAY- 7 JUNE 2013
WTC 2013, Geneva, Switzerland
World Tunnel Congress at International Conference Centre. Organised by Swiss Tunnelling Society. For more information tel.: +41 (0)81 725 31 32, email sia-fgu@swisstunnel.ch or see www.wtc2013.ch

23-26 JUNE 2013
Rapid Excavation & Tunneling Conf (RETC), Washington DC, US
Marriott Wardman Park. Organised by the SME - Society for Mining, Metallurgy & Exploration. DEADLINE for conference paper abstracts **30 June 2012**. For more details tel: +1 (303) 948-4200, fax: +1 (303) 979-3461, email: meetings@smenet.org or see www.retc.org.

16-19 JUNE 2012
Strait Crossings Conf, Norway
At Radisson Blu Royal Hotel, Bergen. Organised by Norwegian Public Roads Administration and features extreme crossings and new technologies.For more details tel: +47 22 94 75 00, email siri.engen@tekna.no or see www.SC2013.no

BRITISH TUNNELLING SOCIETY

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.

14 JUNE 2012 (A WEEK EARLY)
Thames Water Lee Tunnel - London's Deepest and Largest
A presentation on the current status of the 7.2m i.d. and 6.9km-long Lee Tunnel in east London, part of Thames Water's Tideway mega-sewer project by Roger Mitchell (CH2M Hill), Scott McFadzen (Morgan Sindall), & Jean-Christophe Galan (Vinci Construction)

2-6 JULY 2012
BTS Tunnel Design & Construction Course, University of Warwick, England
In-depth introduction to the majority of tunnelling-related subjects, presented by industry experts. Ideal for young consulting and contracting engineering starting a career in tunnelling, and others (eg clients and insurance professionals) with an involvement in tunnelling.

20 SEPTEMBER 2012
URUP - Ultra Rapid Under Pass - An innovative shield tunnelling technology
Makoto Kanai - vice-president - & Akhiro Nicihimori - senior tunnel engineer, both of Obayashi, present the URUP shaftless shield method, especially for congested area, challenging ground conditions and stringent physical and environmental constraints.

OCTOBER/NOVEMBER
Annual Health & Safety Course
At ICE, London. Details to be announced.

18 OCTOBER 2012
Tunnel Security and Blast Analysis
Blast protection design of transport tunnels. Speaker to be announced.

15 NOVEMBER 2012
EPBM & Slurry Tunnelling Principles
Safe operational protocols for full-face TBMs, Speaker to be announced.

20 DECEMBER 2012
Debate: 'This house believes tunnel projects in the UK are over-staffed and over-specified'

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:
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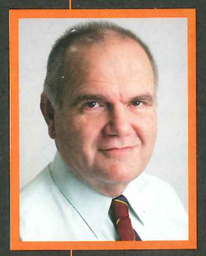

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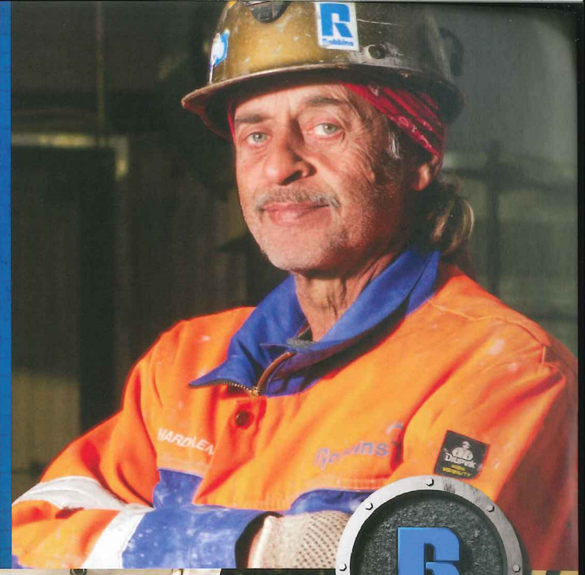

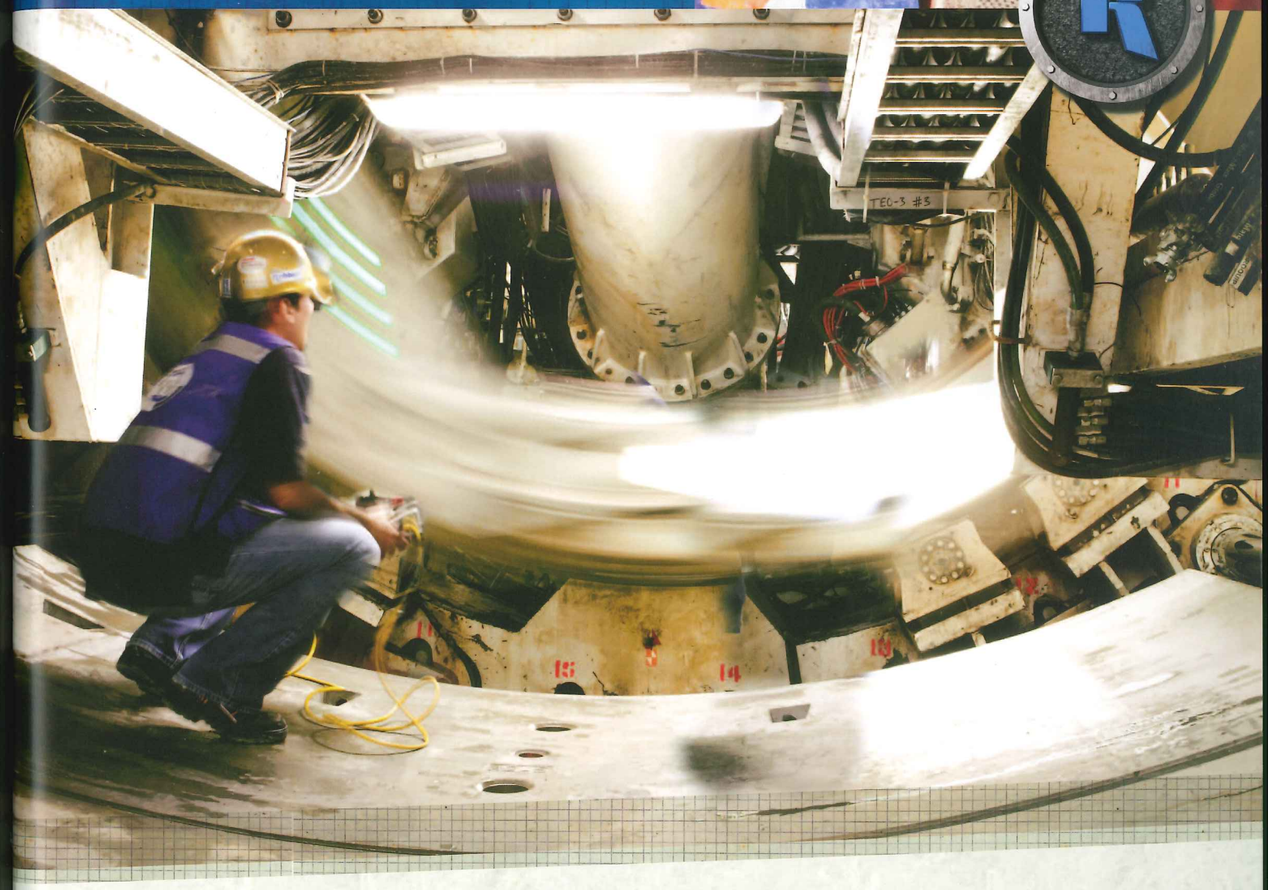

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