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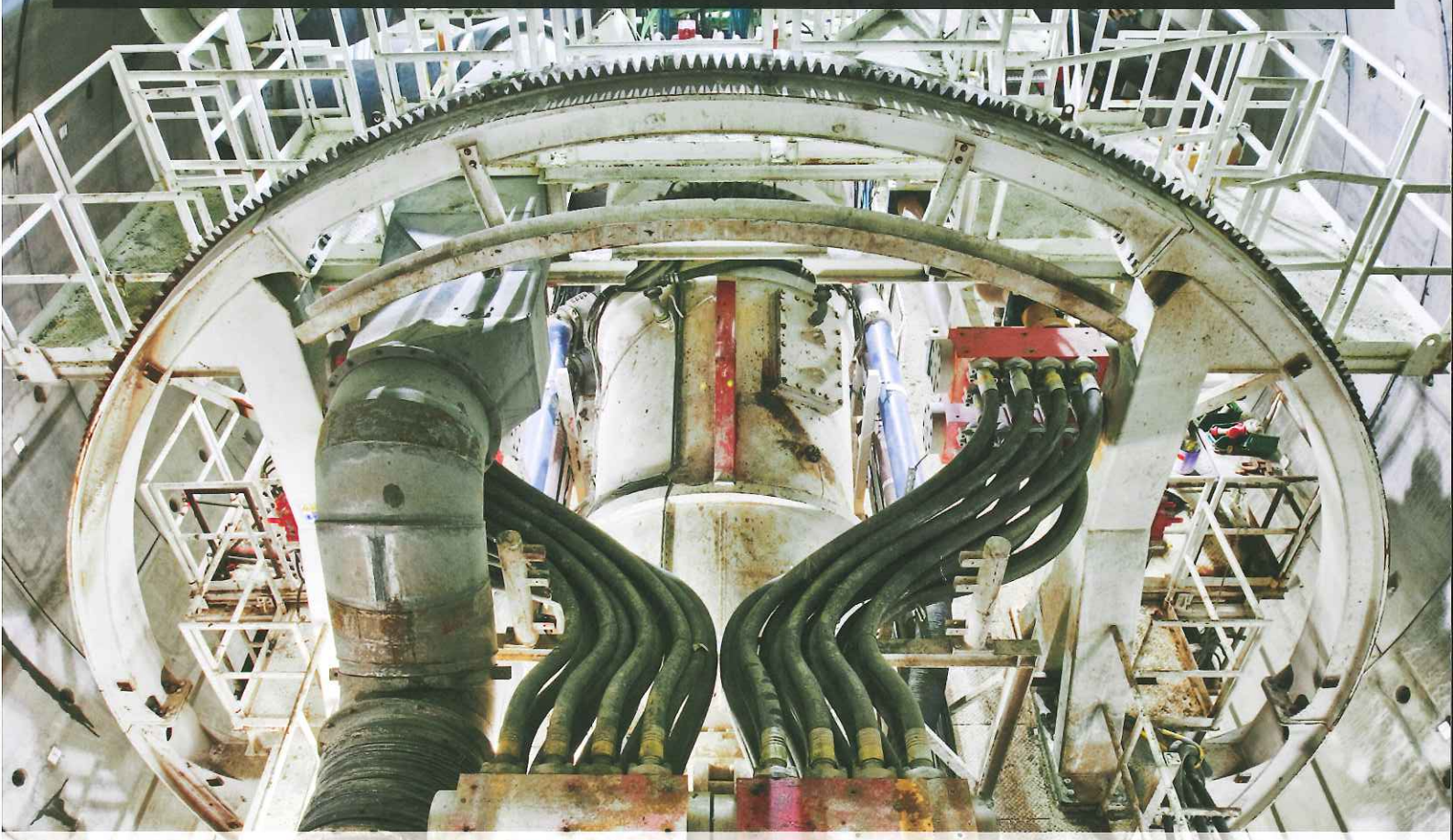

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May 2014

Tunnels AND TUNNELLING

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BRAZIL: BOOM OR BUST

AS THE tunnelling community descends upon Brazil for the World Tunnel Congress, it is worth taking stock of the country's state. The works in preparation for the Fifa World Cup, being held in June, have painted the Brazilian construction industry in a bad light, with a government looking equally shambolic. Major infrastructure projects, including transport routes intended to ferry football fans in June, have been stalled or been completely abandoned. The country ranks 32 out of 50 on the Timetric construction risk index. Others have run into incredible cost overruns. The country's political climate can be equally unpredictable. Despite being heralded as one of the up-and-coming BRIC countries, it has failed to stabilise its boom, inflation is out of control, government spending appears erratic, and its credit rating is wasting away.

Taking stock of Brazil's situation does not do much to boost the confidence of anyone looking to invest or work in the country. And yet the excitement about the opportunities Brazil might hold seems unrelenting. The infrastructure construction output was nearly USD 100bn in 2012 and is expected to rise to USD 155bn by 2017.

Ruchir Sharma of Morgan Stanley and author of Breakout Nations, says Brazil has ridden the coat tails of China, with its economic boom sucking up oil, iron ore and other exports from Brazil. China overtook the US as the biggest importer of Brazilian exports in 2009. Brazil did experience a boom; it pulled 40 million people out of poverty, achieved strong GDP growth. But the links between the two giants were too close, and if China sneezes, as it did in 2011, Brazil catches a cold.

Massive political and economic reform is now needed to stabilise the country. But the opportunities remain. Construction output is growing. Construction indicators such as cement output are still rising and predicted to continue well beyond the sporting events.

Skilled international project managers are needed to bring stability and guidance to the mega infrastructure project planned and underway throughout the country's major cities and rurally developing trade routes.

These international players must work side by side with experienced local engineers who are familiar with both the geology and the bureaucracy. Events such as the World Tunnel Congress are in place to build these partnerships. It is in everyone's interest that the construction climate in Brazil proves a stable and reliable one

editor@tunnelsonline.info

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

Jon Young
Editor

"Brazil has ridden the coat tails of China... But the links between the two giants were too close, and if China sneezes, as it did in 2011, Brazil catches a cold"

Cover
In this issue Tunnels covers the newly released ITA WG Five guidelines on refuge chambers

Next issue
In the next issue of Tunnels, the regional focus switches to Scandinavia, with project reports including the Ryfast undersea tunnel link in Norway. Also included is a focus on the grouting works required to successfully complete the Port of Miami Tunnel project

This month...

40 YEARS AGO

The happy and congenial atmosphere set by the Norwegians in Oslo has done much to ensure that the birth of the ITA happened as smoothly as it did. The years of careful preparation by the formulative committee formed in 1971 has come to easy fruition as representatives of national tunnelling societies from 15 nations met to discuss the formation of the association.

Under the able chairmanship of Britain's Alan Muir Wood, the representatives were taken step by step through the proposed statutes before the society was officially inaugurated., so that they all agreed on the precise nature, organisation, and function of the association before committing.

To quote the statures: "The aims of the Association are to encourage the planning of the use of the subsurface and to promote advances in the preparatory investigations for tunnels, and in the design, construction and maintenance of tunnels by bringing together information thereon and by studying questions related thereto."

The association fulfills its mission by: Interchange of information among member organisations, holding meetings at intervals, by co-ordinating studies and by publishing reports.

The excitement to begin co-operative work was perhaps emphasised best by Professor Ibukiyama of Japan, who admitted: "We are actually joining the Association two days before our own national organisation comes formally into being."

Tunnels and Tunnelling, May 1974, p.47

Contributors

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Desiree has worked for The Robbins Company for the past eight years as a technical writer. Documenting tunnelling projects for rail, water, sewer, road and other types of civil infrastructure. She has explored a wide variety of editorial topics in the tunneling industry for Tunnels, from projects under high cover to soft ground TBM design. In this issue she writes on the Fortaleza Metro project in northeastern Brazil, see page 23

DONALD LAMONT
Donald is an expert in health and safety matters for underground construction and is animateur of ITA Working Group Five: 'Health and Safety in Works'. He is also principal of Hyperbaric & Tunnel Safety Ltd, having retired from the UK's Health and Safety Executive in 2010. He writes in this issue on the new ITA refuge chamber guidelines, see page 29

MICHELLE VAN DER POUW KRAAN
Michelle is the 2013 recipient of the Dan Eisenstein Memorial Scholarship. It is awarded to a post-graduate student of Canadian citizenship planning to undertake post-graduate studies in the field of tunnelling at a university in Canada. She writes on GBRs with Mark Diederichs, see page 43

MARK DIEDERICHS
Mark joined Queen's University and the Department of Geological Sciences and Geological Engineering in 2001. Previously, Diederichs spent 10 years involved with numerous institutional and industrially supported research organisations, see page 43

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PERU AWARDS MEGA METRO

Peru A consortium led by Spanish construction company FCC and ACS has won a USD 5.66bn contract to design, finance, build, operate, maintain and transfer 35km of new subway line in Lima, Peru, the country's state investment agency announced last month.

An agency of the Peruvian Ministry of Transport, declared the technical proposal submitted by Consorcio Nuevo Metro de Lima to be a valid bid. The project is the largest in Peruvian transportation history and comprises 27km of underground metro for Line 2, which will link the Lima metropolitan area districts of Ate and El Callao, plus an 8km underground spur from Line 4 to the Jorge Chavez International Airport.

The winning consortium is headed by ACS Group subsidiaries Dragados and Iridium, and by FCC subsidiary Vialia, together with Italian companies Impregilo and Ansaldo. The latter will provide electromechanical equipment and rolling stock. Also participating is Peruvian company Cosapi. Metro de Madrid will act as advisor for the project. The Peruvian government will put some USD 3.8bn toward construction and maintenance of the project, with additional costs covered by the consortium.

Two other consortiums, including one formed by Brazilian construction firm Odebrecht and Peru's biggest builder Grana y Montero, failed to submit bids last week as expected, sparking concerns that the auction might be flawed. Proinversion said those groups pulled out after the government refused to raise the project's USD 6.62bn cost ceiling.

"I assure you the process has been serious, objective and the result has been positive," said Carlos Paredes, transportation minister. Paredes said the subway, which will complement an existing system of buses and above-ground trains, is fundamental to improving the quality of life in the capital that is home to some 10 million people, or about a third of Peru's population.

Some 35 new stations will also be constructed, seven mined and the remainder by cut and cover. According to preliminary designs, the tunnels will likely be designed as single bores with twin tracks. Excavation is anticipated to be completed in two stages, each requiring four EPBMs for a total of eight machines with a minimum TBM diameter of 9.2m.

The country needs to spend between USD 30bn and USD 88bn to close its infrastructure deficit, according to estimates by analysts and officials. Construction on the train line will start in May this year and is expected to be completed in five years.

Aerial survey for tunnel project kicks off

Bhutan The aerial feasibility survey of the 10.5km proposed tunnel between Thimphu and Wangduephodrang, in the Himalayan landlocked kingdom of Bhutan, began on 18 March. Prior to this, a team of experts conducted a test flight to calibrate the equipment.

Dowchu Drukpa, head of seismology and geophysics for the project announced there has had to be a change in the survey plan. "Now the survey will be conducted parallel and not perpendicular to the line between starting and end points of the tunnel."

SkyTEM, a Danish consultancy firm specialising in geophysics surveys, is conducting the survey using a helicopter and the latest technology. The survey is a joint project between Norwegian Geotechnical Institute (NGI) and Bhutan's Geology and Mines Department (DGM).

The helicopter hired by SkyTEM hovered over Thimphu carrying a large hexagonal metal ring as a test run for the feasibility test. The ring sends electromagnetic waves into the ground to gather resonance of varying magnitude from different materials underground. It helps experts collect a detailed picture of types of rocks under the earth.

The technology can map the near-earth surface in high resolution to depths approaching 500m.

DGM provided wind data of a past few years from the hydromet division to NGI officials for analysis.

Norwegian Agency for Development is funding the project worth USD 300k, and the delay does not cause additional cost to the project.

On completion of the aerial survey, drilling work would begin and a report will be submitted to the government.

DGM conducted the geological and preliminary studies in the first phase that included the 'walk on survey' of the proposed tunnel road between the two dzongkhags that begins from Yoesepang in Thimphu to Nabisa in Wangduephodrang.

Should the project come through, the proposed two-lane tunnel will reduce travel time to less than 30 minutes.

Plans for subway project set to be unveiled

Phillipines The Department of Transportation and Communications (DOTC), of Philippines, is set to present the master plan for proposed projects in the airports and railways sector, including the country's first subway.

Cosette Canilao, head of the public private partnership (PPP) Center, said in Manila on 18 March 2014 that among the projects to be presented to drum up interest from stakeholders is the Mass Transit System Loop, a 12km underground rail that will connect Bonifacio Global City, Makati Central Business District, and the Mall of Asia in Pasay City.

Transportation Secretary Joseph Emilio Abaya earlier said a feasibility study on the subway line would be financed by the Japan International Cooperation Agency (JICA).

Canilao said the DOTC forum "Invest Transpo PH", will target infrastructure and construction companies, airport operators, rail operators, and financing companies and aims to highlight investment opportunities under the PPP program of the Aquino administration.

"The DOTC will conduct a market sounding for the rest of the airports and some of the rail projects that they are doing right now," she said.

The forum will be held on 20 March 2014.

A JICA study showed that at least 200km of railroad and over 100,000km in road network are needed to address the congested metropolis.

With Metro Manila's rapidly urbanising cities, the DOTC plans to implement the project to improve inter-city linkage by providing a higher capacity public transportation system that would facilitate fast and convenient mobility of goods and services.

Given Metro Manila's current infrastructure, it was also determined that the rail line of approximately 12km would need to run mostly underground, making this the first metro in the country.

Layne secures 50M of tunnel projects

USA Layne Christensen Company announced on March 25 its wholly-owned subsidiary, Bencor Corporation of America, which operates as part of the Geoconstruction division, has received three separate contracts which have an aggregate value of approximately USD 50M.

The contracts include jet grouting for the Kaneohe-Kailua Sewer Tunnel Project, in Honolulu, Hawaii. Layne will also construct two deep shafts with slurry walls. Work on the project is scheduled to commence this month and should be completed by December this year.

Layne has already started work on a contract for the Northgate Link Extension, an LRT tunnel in Seattle, which includes building slurry walls for the station located in the Roosevelt neighborhood of Seattle. The work on the project should be completed by July.

The third contract is for the Blue Plains Advanced Waste Water Treatment Tunnel Project in Washington, D.C. For this project, Layne will construct six deep circular shafts using slurry walls that are designed to act as TBM launching shafts. Work on the project is scheduled to start this month and should be completed by January 2015.

Rene Robichaud, President and CEO of Layne, said, "Layne's Geoconstruction division is well-suited to handle the size, scope, and complex nature of these projects, each of which will have a profound and positive impact in their respective communities."

Robichaud concluded, "In the last five months, Layne's Geoconstruction division has announced new contracts with an aggregate value of approximately USD 150M. We remain confident about the positive outlook and improving performance for this business in 2014."

Slow progress on Ho Chi Minh City car parks

Vietnam Red tape and financial difficulties have delayed the construction of several underground car parks approved by the Ho Chi Minh City government in Vietnam. Though construction of two out of four parking lots began four years ago, progress is slow.

Construction of the USD 110M five-storey parking lot planned to be built under Le Van Tam Park in District 1, which is designed to accommodate 2,000 motorbikes, 1,250 cars, and 28 buses or trucks, has ground to a halt.

The Investment Development for Underground Space Corporation (IUS), investor of the project, explains that lengthy procedures and paperwork have prevented the project from being completed.

The company has spent months meeting with officials, completing procedures related to preserving and relocating trees in the park, and negotiating links with the metro station near Le Van Tam Park and others.

Le Tuan, general director of IUS told the 'Nguoi Lao Dong' newspaper that the company has had difficulties in obtaining a construction license due to the unnecessary complications of the procedure.

Nine years after the prime minister approved the parking lot, Tuan is still not confident about his company's project.

Similarly, another underground parking lot near Tao Dan Park, invested in by Indochina Group, has also ground to a halt due to issues in the design and bureaucratic procedures.

Another underground parking lot under Trong Dong Theatre has plans for eight stories underground and three stories above the ground. However, according to the Ministry of Construction's regulations, underground structures are not allowed to be built over five stories.

The HCM City's Department of Construction requested Indochina Group to get a second opinion and permission from the city's Department of Zoning and Architecture.

The parking lots were long ago approved by HCM City authorities to meet the increasing demand for parking in the city, but the projects have not executed due to petty procedural issues.

Since 2005, the city has zoned eight locations for building parking lots, including Lam Son Square, Chi Lang Park, Bach Tung Diep Park, Le Van Tam Park, Tao Dan Park, Hoa Lu Stadium, areas near 116 Nguyen Du and Sai Gon River's bank.

Later, two out of eight areas were withdrawn from the list. Currently, four underground parking lots in Le Van Tam Park, Trong Dong Theatre, Hoa Lu Stadium, and Tao Dan Park are under construction.

According to estimates from the city's Department of Transport, the four underground parking lots will only meet 20 per cent of the current demand in the city.

Jilin Province railway tunnel caves in

China Twelve workers were trapped on 2 April when a tunnel collapsed at a construction site for a key high-speed railway in Northeast China's Jilin province, the provincial government said on its official micro blog at Sina Weibo.

The Jilin-Hunchun High-Speed Railway under construction is expected to be completed and begin regular operation this year.

With a total investment of USD 6.6bn, the 359km-long railway will have nine stations and trains are designed for speed at 250km per hour. It runs from the city of Jilin in the province to Hunchun in the province's Yanbian autonomous county.
The collapsed tunnel, Xiaopanling No 1, is located in Yanbian.

The local government in Yanbian is mobilising police, firefighters and medics to the site for rescue.

An emergency command center has been set up at the provincial government and provincial Party chief Wang Rulin has arrived at the center to coordinate the rescue operation.

Deputy governor Gu Chunli is on the way to the scene of the incident.

EUROPE'S LONGEST TUNNELLED ROAD

Bulgaria The longest road tunnel project in Europe will be built along the new stretch of the Struma highway in Bulgaria. Located between Bulgaria's towns Blagoevgrad and Sandanski, the total length of the two tunnels will be almost 37km long.

The tunnels are required for environmental reasons and will be dug at a depth of 30m below ground.

The total length of the highway stretch will be 65km. The projected cost is BGN 1.7bn (USD 1.2bn).

"This is the longest tunnel facility in Europe and the second longest in the world," said the Minister of Regional Development Desislava Terzieva at a press conference.

According to Terzieva the tenders for the construction will start by the middle of this year and will continue through 2014.

DELHI METRO CUTS UNDER RING ROAD

India A Delhi Metro Tunnel was successfully completed last month, running below the operational ring road on the Majlis Park - Shiv Vihar Metro corridor with the TBM breakthrough at Shalimar Bagh. The tunnel was built by DMRC engineers without any disturbance to the surface traffic running on the ring road above. The TBM completed the tunnelling of a 1,247m long tunnel from Netaji Subhash Place to Shalimar Bagh consisting of 1,037 rings with a diameter of 5.7m. The TBM was lowered in October 2013. The tunnel also crossed the elevated viaduct of the currently operational Dilshad Garden - Rithala Metro corridor near Netaji Subhash Place, which was a major challenge. This section of the alignment had passed below a drain near Netaji Subhash Place, where tunnelling had to be done 19m below the surface. While carrying out the tunnelling work, the engineers had to be careful about the piling work of a flyover, which is in progress currently above the tunnel on the Ring Road at Shalimar Bagh. The tunnel also passed below the Kasturba Polytechnic, which is another major landmark in the area. While this tunnelling drive was for the up line, the drive for the down line (parallel tunnel) is expected to start in April.

The 59km long Majlis Park - Shiv Vihar corridor of Phase 3 consists of some 14km of underground lines. Presently, five other TBMs are working in different parts of the corridor across the city. In total, 19 TBMs are operational for the tunnelling works of Phase III.

American water authority wins USD 35M insurance judgement

USA Following a four year legal battle, the Southern Nevada Water Authority (SNWA) has won an insurance claim that covers the cost of early problems on its USD 817M third intake project at Lake Mead, in the US.

According to the Las Vegas Review Journal, authority board members were briefed on the USD 35M judgment on in mid-March. An arbitration panel handed down the award in January following more than two years of depositions, document exchanges and deliberations.

"We've pretty much recouped our losses, so we're happy," said Marc Jensen, the authority's director of engineering.

Intake Number Three has been beset by delays and increased costs since construction began in 2009. In 2010, the team excavating the starter tunnel for the TBM hit a fault zone, causing water and debris to flood the work area. The area flooded twice more that year. The floods prompted the authority's board to add an additional USD 39.5M to the project's budget, the largest such change order in the agency's history.

The USD 35M the project's insurance carrier was ordered to pay is on top of USD 14.2M already paid out on the authority's claim. Jensen said that basically covers the cost of the 2011 change order, legal costs and interest payments the authority lost out on.

Dagachhu hydropower to run by mid-July

Bhutan With the completion of dam construction at the 126MW (2x63 MW) Dagachhu hydroelectric project – located on the left bank of the Dagachhu river in Dagana Dzongkhag, in the south-western part of Bhutan – and the river diverted to its original course through the dam, major civil works of the project at its intake is complete.

This, project officials said, means the project would meet its rescheduled deadline of mid-July.

The construction of 35.5m high and 26.7m wide dam began in November 2010 after the river was diverted to the diversion tunnel. Project officials said about 54,185cu.m of concrete was used to construct the dam.

Project deputy chief executive officer Sonam Wangdi said the river was diverted into the dam on 31 March.

He said the diversion of the river into the dam would facilitate plugging off of diversion tunnel and testing hydro-mechanical gates before monsoon rains. The gates, Sonam Wangdi said, were installed to divert water and flood passage.

He said the remaining civil works at the intake site was the final lining of the 7.78km headrace tunnel. "We're in the process of placing up concretes and spraying concretes," he said. "It'll be complete by June."

Project CEO Thinley Dorji said they also completed the construction of desilter, surge shaft, pressure shaft and underground powerhouse. "About 95 per cent of the works on installation of electrical and mechanical equipment are also completed," he said.

The project was due to be commissioned in May, but after a portion of the tunnel collapsed on 5 January, it was rescheduled.

News briefs

ISTANBUL

Istanbul Mayor Kadir Topbas has promised voters that the Unkapani Bridge over the Golden Horn (a major inlet of the Bosphorus) would be replaced with an underwater tunnel, which also crosses the Golden Horn and blocks the view of a major historic mosque. Mayor Topbas addressed supporters and Justice and Development Party (AK Party) members in Istanbul's Esenler district in March. Speaking from his campaign bus, Topbas announced that the Unkapani Bridge, built in 1836, would be demolished and an underwater tunnel built in its stead.

QATAR

Qatar's Prime Minister and Minister of Interior Sheikh Abdullah bin Nasser bin Khalifa Al Thani has set up a special committee to investigate the cause of the flooding in some tunnels on Salwa Road in Doha following heavy rains. The committee will study whether the waterlogging was caused by any technical defects. The panel is led by Minister of Municipality and Urban Planning Sheikh Abdulrahman bin Khalifa bin Abdulaziz Al Thani. The contracting company that executed the Salwa Road project could be held responsible if any engineering defect is found.

OMAN

Galfar Engineering and Contracting Co. has been awarded a OMR 22.67M (USD 58.88M) contract for the construction of tunnels along the existing Batinah road project by the Oman Ministry of Transport and Communications. The completion period for the project is 608 days.

Laing O'Rourke to launch new apprenticeship scheme

Great Britain Engineering firm Laing O'Rourke, is set to introduce a new apprenticeship scheme designed for Construction Assembly Technicians.
The company, a member of the construction industry steering group working closely with the UK's Department for Business, Innovation and Skills initiative confirmed its development of an 18 month programme.

"We are designing a new apprenticeship to respond to not only the present needs of the construction industry, but those of the future as well," said Alison Lamplough, head of operational training at Laing O'Rourke and chair of the steering group working on construction apprenticeships for the Trailblazers initiative. "Laing O'Rourke's Construction Assembly Technicians will be multi-skilled, delivering the modern methods of construction such as Design for Manufacture and Assembly (DfMA) and digital engineering, leveraging new technologies.

"Trailblazers will allow construction companies to work together to assess the skills we know we'll need. As a major employer, we believe it is important that apprenticeships are developed to recognised standards and are relevant to employer needs, while at the same time providing an exciting route for young people into the construction industry."

On completion of their 18 month apprenticeship, individuals will achieve an internationally recognised vendor qualification such as Assembly Technician Level 2 NVQ diploma, a Level 2 Diploma knowledge qualification and additional training modules for Slinger/Signaller, IPAF, PASMA and working at heights. Apprentices will also have achieved English and Maths at level 1 or equivalent.

Ashgabat metro project pondered

Turkmenistan Turkmenistan's capital Ashgabat is scoping out a subway system.

On an inspection tour of construction sites in early-February, Turkmen President Gurbanguly Berdymukhamedov invited the Ukrainian construction company Interbudmontazh to consider building a metro in Ashgabat, according to Turkmen TV.

"The Ukrainians are building railway and highway bridges over the Amu Darya River in eastern Turkmenistan, and a drainage and cable tunnel in Ashgabat; they compete with Turkish and French companies for new contracts in Turkmenistan," Construction Ministry official Amanmurad Khajiyev told Central Asia Online, predicting that the Ukrainians "would likely jump at the chance" to bid for building the subway.

Turkmenistan's ability to pay for massive projects makes it a desirable client for foreign contractors.

Hyundai bags USD 91M hydropower contract

Indonesia Hyundai Engineering Co., one of South Korea's leading builders, has won a USD 91.3M hydroelectric power plant contract in Indonesia, according to a story by Yonhap News Agency.

The company said the engineering, procurement and construction (EPC) contract reached with Rajamandala Electric Power is for building a 47MW facility near the city of Bandung, 150km southeast of Jakarta.

The new Rajamandala power plant aims to provide electricity to Jakarta and surrounding areas.

"Hyundai Engineering will be in charge of all facets of the project that include a water tunnel and the setting up of power cables," the builder said in a press release issued in Seoul on 31 March. Work on the project is expected to be completed around March 2017."

Indonesia has said it wants to upgrade infrastructure around the capital city by 2030, which is fuelling demand for power.

MMC-Gamuda denies linkway involvement

Malaysia The MMC-Gamuda JV has said it is not involved in the proposed USD 104M 'KL Sentral pedestrian linkway tunnel', according to Bernama (National News Agency of Malaysia).

The comments came in response to a recent report in MRT Watch, that said a costly and high risk linkway tunnel project would be built by MRT Corp and its Project Delivery Partner (PDP) for the MRT system, Gamuda Bhd.

The MMC-Gamuda JV is the appointed PDP and underground works contractor for the Klang Valley Mass Rapid Transit Project for the Sungai Buloh to Kajang Line (KVMRT SBK Line). In a statement issued in Kuala Lumpur on 24 March, it said the proposed pedestrian linkway is an integral part of the physical integration between the KL Sentral MRT Station and other KL Sentral stations.

"We would like to clarify that construction of the pedestrian linkway will be under the purview of the scope of PDP's contractual obligations, held by MMC Gamuda KVMRT (PDP) Sdn Bhd for the KVMRT SBK Line.

"But it will not be part of the underground works contractual scope held by MMC Gamuda KVMRT (T) Sdn Bhd, the underground works contractor for the project," it added.

PHILIPPINES METRO PLANS DETAILED

Philippines The Department of Transportation and Communications (DOTC) unveiled major rail projects, including the proposed PHP 135bn (USD 3bn) metro, at an investment and transportation forum on 20 March.

The planned 20km Mass Transit System will consist of a 16km underground tunnel and a 4km elevated railway to connect Makati, Pasay and the Bonifacio Global City (BGC).

The underground railway system aims to address the worsening traffic situation in the fast growing urban centers in Metro Manila.

The system will have 11 stations, five of which are underground, four interchanges and two elevated.

The DOTC may seek project approval from the National Economic and Development Authority (NEDA) in the second or third quarter of the year, after which the government will bid out the project in the second quarter of 2015.

Transportation Assistant Secretary Jaime Feliciano said the government is planning to increase urban mass transport ridership to 2.2 million per day by 2016 or 2017, up from the current 1.2 million per day under its Rail Transport Development Plan.

Feliciano said that under the plan, the DOTC will develop intermodal facilities and improve transport linkages and efficiency towards production and consumption markets.

DASU DAM CALLS FOR FOUR TUNNELS

Pakistan Pakistan's Water and Power Development Authority (Wapda) chairman Syed Raghib Abbas on 19 March told the Senate Standing Committee on Water and Power that the Dasu Dam (to be constructed on main Indus River in Kohistan District, Khyber Pakhtunkhawa Province) would cost USD 4.2bn and work on the mega project would start by the end of this year.

Abbas said a total of four tunnels would be constructed and the project would be completed by 2019. The World Bank is financing the dam. Germany's Deutsche Bank will provide USD 1bn and the Industrial and Commercial Bank of China (ICBC) will give USD 2bn for the project.

Abbas said work orders would be issued next month after the Pakistan Engineering Council establishes the categories of contractors. Of these, 70 per cent foreign and 30 per cent local contractors would be hired.

Separately, World Bank country director Rachid Benmessaoud said that the bank is expected to approve assistance worth around USD 700M for Dasu Hydel Power Project. He said this while talking to Finance Minister Senator Mohammad Ishaq Dar.

He said that the managing director of the World Bank Sri Mulyani Indrawati will be visiting Islamabad in the last week of March to discuss Pakistan's development projects.

The work on the Dasu Dam will be undertaken in two phases while two power units will be constructed.

Some 2,160MW of electricity will be generated from the first unit. After completion of both phases, the dam will be able to generate 4,320MW of cheap hydropower.

Azhar tunnel in doldrums

Egypt The Azhar Tunnel in central Cairo, neglected and compounded in administrative difficulties, will soon be the site of a disaster unless immediate action is taken, say officials.

Egypt's transportation minister Ibrahim El-Demery said that he regrets the government's decision to hand over control of the Azhar Tunnel to Cairo governorate, claiming the condition of the tunnel has suffered as a result.

El-Demery recently told journalists that the government invested EGP 150M (USD 21.5M) on fire resistant materials while constructing the tunnel. But, El-Demery added, despite all their plans, the tunnel's condition has deteriorated due to the absence of regular maintenance.

On 26 February, all the roads leading to the tunnel and the eastern district of Heliopolis were jammed. Traffic in downtown Cairo and around Opera Square came to halt, as traffic officers directed cars to use Al-Azhar Bridge, 6 October Bridge or the Autostrade as an alternative. Life in Opera Square stopped as Azhar Tunnel closed itself to traffic for the third time in less than two weeks.

The tunnel is the longest in Cairo, 2.6km long, and one of its most important, carrying thousands of cars every day. Its closure that day by the Azhar Tunnel Operating Authority for technical problems caused a chaotic scene in downtown Cairo and shifted traffic to other roads.

Waleed Ali, head of the tunnel's maintenance authority, said that the tunnel has been closed at least twice due to delays in securing vital spare parts, as well as for repairs on surveillance cameras and the tunnel's ventilation system.

The third time the tunnel was closed was due to a power cut, Ali said.

However, Cairo governorate officials have insisted that there are no problems with the tunnel.

"The tunnel is fine and there aren't any problems," said Cairo Governor Galal El-Saeed. The morning after the tunnel's closure, the head of the Azhar Tunnel Operation Authority, Ibrahim Samaha, announced his resignation, saying that there had been several technical issues in the tunnel and that requests to fix them had been ignored.

He also told the media that he couldn't afford to wait any longer - he feared a catastrophe in the tunnel and, as head of its authority, he would be blamed.

Ali, from the maintenance division, said that the ongoing problems weren't technical so much as bureaucratic, stressing that his team had to endure long waits for the delivery of key parts and that often his requests were ignored.

"The governorate is not a technical entity but rather an administrative entity," Ali said. "They don't understand the essence of time or providing these spare parts right away."

These difficulties were apparent on 26 February, when the tunnel was shut down for several hours due to repairs.

For Ahmed El-Hakim, professor of traffic and transportation engineering at Al-Azhar University, the problems with the Azhar Tunnel began in 2009, when its control was shifted from the National Authority for Tunnels (NAT), which operates under the transportation ministry, to Cairo governorate.

The NAT is a very "specialised entity", El-Hakim says, which also operates Cairo's metro lines as well, but he says that the NAT was spending money on the tunnel and not receiving any revenues, so the authority decided to let it go.

With mounting difficulties, the Cairo governorate has since offered to hand the tunnel back to the NAT, said El-Demery, adding that the NAT didn't manage the tunnel well.

Another option is to bring the tunnel's authority under the supervision of the transportation ministry, he said. Whoever is in charge, tunnel maintenance head Ali believes that something needs to be done, and fast.

"If these problems are not solved immediately, there will be a catastrophe," he said.

Mixed reactions to Philippines rail projects

Philippines Large conglomerates had mixed reactions to new railway projects the government recently unveiled, including an ambitious PHP 135bn (USD 3bn) subway system for Metro Manila, as some were keen on bidding while others kept a more guarded approach given the recent track record for major public private partnership deals.

As well as the subway system that would link Bonifacio Global City, Makati Central Business District, and the Mall of Asia in Pasay City, the Department of Transportation and Communication (DOTC) is also keen on tendering a USD 6.3bn north-south commuter line that would connect Malolos, Bulacan, to Calamba in Laguna via a 91.37km railway.

Based on Japan International Cooperation Agency (JICA)'s proposed design, the commuter express will have 27 stations. It will utilise elevated tracks from Malolos to Paco station in Manila. The line will then go underground from Buendia to FTI stations in Makati and Taguig, and will use elevated tracks from Bicutan to Sucat.

São Paulo's Metro – Line 4, Brazil

AECON TO APPOINT CEO

Canada Construction and infrastructure company, Aecon Group, has recently announced that its board of directors will appoint Teri McKibbon, currently president and COO, as the firm's president and CEO, effective June 2014.

The current chairman and CEO, John Beck will become executive chairman and will continue to serve the company on a full time basis.

"The board has been working toward our succession plan and is committed to ensuring a smooth transition," said Brian Tobin, vice-chair and lead director.

"We would like to extend our deep appreciation to John Beck and his leadership in bringing Aecon to its position today as Canada's premier construction and infrastructure development company. Teri McKibbon has proven himself as a strategic, disciplined and focused executive as well as being a collaborative leader."

John Beck added: "I have every confidence that Teri will lead Aecon with distinction and a relentless focus on execution.

"He has been at the forefront of our paramount objective of improving margins and consistent financial performance, and of Aecon becoming the Canadian-based partner of choice for large-scale construction projects."

In addition to his role as COO since March 2011, McKibbon, took on the role of president in June 2013.

He has been a member of the executive committee of the Aecon Group for nearly a decade – since 2006. McKibbon joined Aecon in 1996, and had previously led Aecon's Infrastructure business division.

Parsons acquires Delcan

North America Parsons announced on April 1 that it has acquired Delcan, an international multidisciplinary engineering, planning, management, and technology firm that provides a broad range of integrated systems and infrastructure solutions to the transportation market.

"In addition to increasing our presence in Canada and other key strategic geographies in the world, the acquisition of Delcan continues the progression of our corporate objectives through the expansion of our transportation and infrastructure business lines and our suite of technology offerings," said Chuck Harrington, Parsons chairman and CEO.

Over its 60-year history, Delcan has been providing transportation solutions within the rail and transit, road and highway, structures, water, freight, and intelligent transportation systems (ITS) markets, developing a reputation for exceeding customer expectations.

With revenues of approximately USD 126M in 2013, Delcan has 800 employees working from more than 25 locations across the globe, including the United States, the Middle East, and Hong Kong. Delcan's customers include governments, regional network and transit operators, port authorities, and freight and logistics companies.

With revenues of USD 3bn in 2013, Parsons is one of the largest transportation planning, engineering, and construction firms in the world, having successfully delivered 10,000+ miles of roads and highways, 4,500+ bridges, and 400+ airports worldwide. The corporation's extensive portfolio of diverse transportation projects includes rail and transit, road and highway, bridge and tunnel, and aviation infrastructure. Parsons' expertise encompasses all phases of transportation engineering operations, from the initial planning stage through final design, construction, commissioning, maintenance, and financing.

Morgan Sindall appoints managing director

Great Britain Construction, infrastructure and design company Morgan Sindall, has appointed Pat Boyle as managing director with overall responsibility for its construction and design businesses.

Reporting to Graham Shennan, Morgan Sindall's managing director, Boyle joined the company in early January from Lend Lease where he was recently head of their public sector construction business. Prior to this, he held various wide ranging senior level roles within Laing and Laing O'Rourke.

Boyle has been recruited to steer the expansion of Morgan Sindall's construction and design businesses, the company stated. He will work directly with the construction and design managing directors, to support them in ensuring the achievement of sustained profitable growth.

Atlas Copco opens new South African office

South Africa Atlas Copco will open a new distribution and service centre in South Africa that will benefit customers in the country and region, the company announced recently.

The facilities east of Johannesburg will be the hub for distribution of equipment from all four of Atlas Copco's business areas, such as compressors, rock drills, construction equipment and power tools. This will provide one-stop shopping opportunities for customers that may need a wide range of equipment. Service will also be carried out at the premises.

"South Africa is an important market to us. This investment in the new centre will benefit customers by giving them easier access to our products and improved service," said Ronnie Leten, president and CEO of the Atlas Copco Group.

Currently some 450 employees work at the premises, which are located on 20 acres of land and also host an administration building. The premises were built with high environmental standards in mind, including recycling of excess material excavated, and installation of solar water heating and low-energy lighting.

Arup sends boss to drive Australasia growth

Australia Robert Care will be relocating to Canberra, in the Australian Capital Territory (ACT), to oversee the growth of Arup's business in the ACT and its expansion in New Zealand and Indonesia.

The former chair and CEO of Arup in Australasia (2004 - 2010) and the UK, Middle East and Africa (2011 - 2013) will apply more than 40 years of experience across engineering, policy advice and leadership to develop key project opportunities and relationships with public and private clients for Arup.

Care has held the posts of chief engineer of the National Capital Development Commission and later head of ACT Public Works from 1986 to 1990 and being a past deputy chair of the Australian Construction Industry Forum.

Care will also be involved in the development of Arup's business throughout Australasia - particularly in New Zealand and Indonesia.

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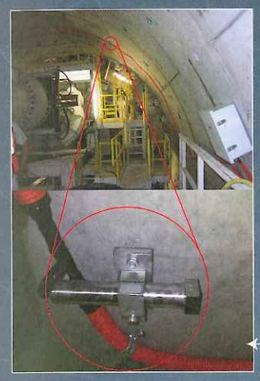

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TRELLEBORG

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

AS EVIDENCED by recent political events, public transportation in Brazil is a hot button issue. With the city of Rio de Janeiro alone regularly making the top 10 list of most congested cities in the world and other cities faring not much better, massive plans are in the works. The Brazilian national government is working to improve transportation in advance of this year's FIFA World Cup and the 2016 Olympic Games.

BRAZILIAN BOOM

Fortaleza's Metro is a Flagship Project for an Emerging Market

For starters, the country launched its largest-ever public transportation project in the northeastern city of Fortaleza, home to 3.6 million residents. With construction starting up in 2014, the new east line will be the largest public works project in the history of the state of Ceará, according to Marco Escóssia, the spokesman at Ceará's Infrastructure Ministry, SEINFRA. The new project will transform the city's small, localised two-line metro system into a high-speed, multi-track system for reduction of road traffic. The 12.4km long line is expected to carry 400,000 passengers daily when it opens in 2019. Twelve station sites (11 of them running underground) will be opened from Chico da Silva to Edson Queiroz station within Fortaleza.

To complete the line will require precision tunnelling below densely urban city blocks, a heavily trafficked main roadway, and an urban park, all while in complex mixed ground.

Below: The TBMs are equipped with versatile ground conditioning systems for mixed conditions

MASSIVE PLANNING

Construction includes the two parallel tunnels, each 8.5m in diameter, 11 new stations, an expansion of a station linked to two existing lines and work on bus terminals. The new line is part of a USD 1.3bn PPP evenly split between the federal government, the government of the state of Ceará, and the Caixa Econômica Federal, Brazil's government-owned bank.

Challenges on the project include performing work along a major urban corridor, Avenida Santos Dumont, without negatively affecting the city's population. To speed up the process, SEINFRA specified and purchased four Robbins EPBMs, nationally known as "tatuzões" (giant armadillos). "In April 2012 SEINFRA launched bid documents defining the key techniques and equipment for the desired performance characteristics. Robbins won the contest because the equipment offered met the expectations of SEINFRA and had the lowest price," said Escóssia.

17
The pressure, in mega Pascals, that the segments for the Fortaleza Metro can withstand

400k
The number of passengers, per day, that the line is expected to carry when it opens

Two EPBMs will start at the north end of the line in the city center, where the new East Line will connect with two other metro lines. Two more TBMs will be launched from the middle of the new line, where it will connect with a fourth, above-ground metro line, as well as the bus terminal.

Launching the TBMs from sites in heavily-trafficked and constricted areas presents challenges, as does tunneling the new East Line alongside a section of the existing and active West Line. In addition, boring of the launch shaft for the last two TBMs, which will be constructed at an intersection point between two lines, will have to occur without interfering with the structure and function of the active south line. A consortium of the Spanish firm Acciona and Brazilian engineering firm Centenco Engenharia won the contract in October 2013 for the East Line and construction of new stations. The USD 1bn bid was the largest urban transit contract ever signed in Brazil, according to Escóssia. Brazilian President Dilma Rousseff visited the site in November to kick off construction of the massive project.

VERIFYING GEOLOGY

Core drills underneath the city, taken by subcontracted drilling company Solotrat near streets, restaurants and from within Fortaleza's Central Park area, verified that challenging geology should be expected. Conditions included massive, abrasive basalt with an RQD of 90 per cent and low permeability silty sands, with a Standard Penetration Test score of 10 to 15. Water pressures average about 2 bar throughout with a tunnel depth of 20m.

Much of the tunnel will run near buildings and active utilities, but assessments on those structures and whether or not additional grouting is needed in those areas are still being made. "We are studying the risk of settlement and effect on surrounding structures and utilities in detail," said José Maria Diaz Alvarez, Brazilian sales manager for contractor Acciona.

CUSTOMISED EQUIPMENT

The machines are highly customised for the mixed ground project. Each machine is equipped with a durable mixed ground cutterhead powered by electric variable frequency drives (VFDs), and newly designed Robbins continuous foam and grouting systems for excavation in variable conditions. Behind each machine, Robbins continuous conveyors

will maximise the safety and efficiency of the muck removal process.

The segments will be installed in a 5+1 universal arrangement, and allow for 17MPa (2,500 psi) push pressure – the maximum push force of the machine. The exceptionally high maximum thrust force of nearly 62MN at 410 bar will enable the machines to keep moving even in sticky ground conditions. A trapezoidal ring configuration will allow the keystone to be placed at any one of 16 positions. Two onsite factories located near Chico da Silva station will produce up to 20 segment rings per day during construction.

The four EPBs were assembled in Robbins' new factory in Pudong, China using state-of-the-art components sourced mainly from European and U.S. suppliers. Two of the TBMs arrived in Fortaleza in November 2013, along with continuous conveyor systems. The 125m long, 737t machines were shipped in containers and are awaiting completion of the TBM launch areas. Construction of the starter tunnel and the enlargement of the Chico da Silva station are underway as of March 2014. According to the JV the starter tunnel will be large enough to launch the machines with a full backup system. The first machine is scheduled to be launched in October of this year and tunneling is expected to take about 17 months.

Above, top: Four Robbins EPBs were ordered for the Fortaleza Metro, with the first expected to launch in October

Above, bottom: Segments allow a very high push pressure in sticky ground

A MARKET PRIMED FOR TUNNELLING

Fortaleza's metro system is just the beginning: Brazil's tunneling market is one primed for a tunneling boom. "Given the size of its cities and Brazil's rapid growth, metropolitan transportation infrastructure has fallen behind and we need to tackle the problem now. I think subway tunnels have a great future in the country," said Diaz.

Rolando Justa, general manager of Robbins' South America office, seconded the opinion and added thoughts on South America as a whole: "This market is looking for an integrated and full solution. They are looking for customised designs to optimise the cost per meter of excavation, and the efficiency of the overall excavation process, not just the TBM." For Justa, the South American market is hungry for new options to expedite tunneling in difficult ground conditions. "Demand, particularly in Brazil, is of a much more sophisticated and synchronised scope than in years past. Our market gives us a daily challenge to innovate not only on quality, design, and capacity of the TBM, but also on new equipment in addition to the tunneling machine, in order to deliver a full solution"

A GUIDE TO REFUGE GUIDELINES

The ITA has recently published a guideline on refuge chambers for use in tunnels under construction. **Donald Lamont**, animateur of ITA Working Group Five reviews some of its main recommendations

IN 2011 ITA Working Group 5 'Health and Safety in Works', met in Helsinki and identified a need for guidance on the provision of refuge chambers in tunnels under construction. This guidance was to complement CEN standard EN 16191 'Tunnelling Machinery – Safety Requirements', which was expected to be harmonised in 2014, and which would require that refuge chambers should be provided on TBMs "where shown necessary by the tunnel project risk assessment". Even before EN 16191 has come into effect, tunnelling contractors have increasingly willing to provide a refuge chamber on a TBM as part of the project emergency procedures

Donald Lamont
Donald is animateur of ITA Working Group Five, and authored the guidelines

At present there is no one set of requirements for refuge chambers. In drafting the document, ITA WG5 considered likely incident scenarios along with the requirements for chambers, from different countries to produce what it hoped was an internationally applicable guidance document.

WHAT A REFUGE CHAMBER IS

A refuge chamber is an easily identifiable and readily accessible shelter acting as place of relative safety in a shaft or tunnel where tunnellers can be accommodated and provided with access to basic life support services until they are rescued or it is safe for them to exit the tunnel by the normal route. In large tunnels a refuge chamber is likely to resemble a standard shipping container whereas on smaller TBMs it is only a purpose built structure which can fit the available space. By providing a protected space in which personnel underground can ride out an emergency whilst in contact with the surface, if everyone underground is accounted for it removes the need for a rescue team to enter the tunnel whilst smoke or contamination is present. This obviously reduces the risk to the rescue team.

The main life support functions of chamber equipment included the provision of a respirable atmosphere in the chamber. This requires oxygen make up to replace oxygen used up through the breathing process along with the removal of carbon dioxide and carbon monoxide from exhaled breath. This can either be achieved by continuously flushing the chamber with air or by an air regeneration system which injects a precise dose of oxygen and filters out the CO2 and CO. Air temperature and humidity control is also important as the temperature inside the chamber can rapidly build up to dangerous levels without artificial cooling. Communications along with a power supply are also safety critical.

WHAT A CHAMBER IS NOT

More importantly in some ways for safety, is to know what a refuge chamber is not. Whilst a chamber is intended to be somewhere tunnellers can take refuge and be protected against smoke or atmospheric contamination in the tunnel it is never a substitute for escape to the surface. A refuge chamber is not designed to protect against direct exposure to fire, hence in the event of a fire near the refuge chamber, tunnellers should not use the chamber but should evacuate the tunnel. Likewise a chamber is not normally designed to provide protection against flooding or inundation. Similarly refuge chambers are not designed to withstand a lining collapse, ground collapse or a major rock fall. However in the event of personnel being trapped as a result of a collapse or rock fall, a chamber with its communications, water and supply line, would act a muster point for survivors.

As a priority, measures should be taken to prevent smoke or atmospheric contamination in the tunnel in the first place and to provide means of immediate escape to the surface. The use of the chamber should be looked upon as the last resort in mitigating the risk from these hazards.

3.5
The recommended internal TBM diameter in metres at which refuge chambers begin to be included

500
The length in metres below which tunnels may not necessarily require a refuge chamber, excepting complex excavations such as metro stations or deep shafts

150
The recommended minimum distance in metres a refuge chamber should be from the face, with 300m as the upper end to this 'sweet spot' range

WHEN A CHAMBER SHOULD BE PROVIDED

The need for refuge chambers should be assessed as part of the tunnel project risk assessment. However, ITA WG5 recommends that every tunnel should be presumed to require refuge chambers unless shown not to be necessary by the tunnel project risk assessment.

WHERE A CHAMBER SHOULD BE LOCATED

On a TBM drive, the refuge chamber should normally be located towards the out-bye end of the back-up equipment, in a location which is easily accessible on the TBM irrespective of whether trains or other vehicles are under the gantry. The refuge chamber should be located close to a stairway or other access from the tunnel invert. If the refuge chamber is located on an upper deck, it should be close to a stairway or ladder leading to all other decks. The refuge chamber should also be accessible by a rescue team coming from the pit bottom. The location and path to the refuge chamber should be clearly indicated using signs made from a retro-reflective material.

ITA WG5 took advice from both TBM and chamber manufacturers before coming to the conclusion that refuge chambers should be considered for installation on TBMs of 3.5m internal diameter and larger. However, for TBMs at the smaller end of the size range, chambers may have to be custom designed.

Tunnels of less than 500m in length may not require a refuge chamber. However, the need for chambers should be considered when assessing the risks associated with the construction of complex underground structures such as metro stations in which possibly no single tunnel exceeds 500m in length, and for tunnels involving deep shafts.

In conventional tunnels, ITA WG5 recommends that the refuge chamber should be located between 150m and 300m from the tunnel face. Where space is limited, it may be necessary to form purpose-built niches to house the refuge chamber. Measures should be taken in the tunnel to protect the refuge chamber and any externally mounted gas cylinders required for its operation, from vehicle impact. The refuge chamber door should not open towards traffic routes. Where blasting operations are being undertaken in the tunnel, the refuge chamber should be located clear of explosive magazines or other underground explosive storage facilities. Measures should also be taken on site to protect chambers from flyrock.

A refuge chamber should be available for every active face of a tunnel project unless workplaces are sufficiently interconnected or close together to share a chamber. The area around the chamber should be free from combustible material including non-essential power cables and hydraulic hoses. Where possible a chamber should not be located directly below points of constant leakage or inflow or where water can pond.

Depending on circumstances, a chamber could also be located in the base of a large or deep shaft.

The same assessment criteria for construction tunnelling could be applied when assessing whether or not to provide refuge chambers in tunnels being refurbished.

OPERATIONAL MODES

A refuge chamber should be capable of operating in three separate but complementary modes;

- Stand by
- Externally supported
- Stand alone

Standby mode

In this mode, no incident has occurred and the chamber is unoccupied but ready for immediate emergency use. No survival system is activated but electricity from the tunnel power supply is supplied to the emergency power supply which is kept charged and the communication systems are enabled.

A visible and audible warning device should be fitted outside the chamber to signal the interruption of the external air supply or electrical supply.

Externally supported mode

In this mode, an incident has occurred and the chamber is occupied with a respirable atmosphere in the chamber being provided by a reliable external compressed air supply from the surface. Prior consideration should have been given to the location of the air line to ensure it has a high level of protection from mechanical damage and fire.

The air flow rate needs to be sufficient for the number of persons in the chamber as well as flushing the chamber to remove heat, humidity, expired CO2 and CO.

The emergency power supply should be sufficient to power the chamber for at least 24 hours.

Stand alone mode

In this mode, an incident has occurred and the chamber is occupied but the external power and/or air supply has become disconnected. The occupants of the chamber now depend on life support from sources within the chamber. These should have the capability to provide full, independent life support to the occupants of the chamber including the immediate provision of a respirable atmosphere and the capability of conditioning the chamber atmosphere to maintain conditions inside the chamber within acceptable limits of heat and humidity for at least 24 hours. An uninterruptable power supply from batteries can be required to power the chamber.

Inspection, testing, maintenance

It is an essential part of keeping the chamber fully functional to inspect, functionally test and maintain the chamber in accordance with the manufacturer's instructions. Personnel undertaking the inspection, testing and maintenance should have been

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specifically allotted these tasks by site management. They should have been trained to the requisite standard set by the chamber manufacturer and have been tested to demonstrate their competence. Inspection, functional testing and maintenance activity should be recorded as part of the site QA procedures.

Inspection

Inspection is considered to be a periodic visual check of the chamber for internal cleanliness, and signs of obvious damage to or failure of the chamber and its systems. The inspection procedure should follow the manufacturer's instructions. Inspection results should be recorded along with details of when and by whom the inspection was undertaken. The inspection should ensure that vital parts of refuge chamber equipment such as the gas detector or handheld, air conditioning control unit etc have not been tampered with or removed.

Some contractors favour the routine use of chambers as crew welfare accommodation as they consider this gives a greater level of familiarity with the chamber. However experience has shown that such use quickly leads to the chamber becoming dirty, with items of safety-critical equipment becoming broken or going missing. Where a chamber is used other than for emergency use only, daily cleaning and inspection is essential.

Functional testing

Functional testing means demonstrating that the chamber and its systems are in working condition. Again it should be undertaken in accordance with the manufacturer's instructions. These should list the aspects of the chamber and its systems which require weekly testing and those which require more extensive monthly testing.

Remedial work

Any remedial or repair work on the chamber or its equipment which has been identified as needing to be done by inspection or testing, should be undertaken immediately and recorded along with the inspection or test report.

Maintenance

Some routine maintenance can be done by the contractor's site staff. Maintenance work should be done in accordance with and at time intervals set out in the manufacturer's instructions. Maintenance activity should also be included as part of the site quality assurance procedures.

Check and service by manufacturer

Manufacturers often recommend that a periodic check along with servicing of the chamber and its equipment is done by one of their service personnel. This activity should also be recorded along with the other chamber records.

Replacement of consumables

Consumables such as water or filter cartridges for the air regeneration unit, which are stored in the chamber should be replaced at regular intervals.

TRAINING, INSTRUCTIONS AND EXERCISES

General

Chambers can be relatively complex to operate and if incorrectly operated a chamber could become a death-trap for those in it. Hence it is extremely important for the safety of those who may have to use a refuge chamber that they are instructed and trained in its correct operation and that they have regular opportunities to put their training into practice as part of emergency exercises. Periodic refresher training may be required. Chamber operation, particularly in stand alone mode, can require a level of competence in the use of gas detection and air filtration equipment which can only be achieved through training. ITA WG5 recommends that the initial training in chamber operation could be linked with self rescuer training as part of the induction process.

Operating Instructions

As it is likely that those using the refuge chamber in an emergency would be experiencing abnormally high levels of stress, clarity and simplicity to avoid human error is of utmost importance. This should be remembered when compiling the operating instructions. Full operating instructions for the refuge chamber, set out in as clear and simple a format as possible, should be available inside the chamber. The instructions should be in each of the languages normally spoken on site. Consumables such as the CO and CO2 filters should be clearly and distinctively labelled. Labelling the filters by their function rather than by their contents, can be more important and hence should be more prominent. The use of colour coding and colour consistency e.g. for identifying each of the filter systems, should also be considered by the chamber manufacturer. Control panels labels and instructions should be fully legible even in poor light.

The guideline recommends that the refuge chamber manufacturer should agree with the user over the use of pictures, colour coding, pictograms or numbering systems to aid clarity.

Training

Training should be done either by the refuge chamber manufacturer or by site personnel nominated by site management to do so. Site-based trainers should have their competence certified by the refuge chamber manufacturer.

Everyone regularly working underground, should be individually trained in the operation of the refuge chamber in both externally supported and in stand alone mode. Regular training exercises should be undertaken to ensure everyone underground is fully familiar with the refuge chamber and its operation. Following training exercises, a review of the exercise should be undertaken and any changes to procedures identified as necessary by the review should be put into practice. Those working underground should be made aware of these changes.

Records of all training, exercises and reviews should be kept as part of the site quality assurance procedures

Emergency refuge chambers are playing an increasing safety role in the tunnelling sector. **Patrick Reynolds** speaks with **Mike Lincoln**, global general manager for MineARC Systems

WHILE MORE established in the mining industry, portable emergency refuge chambers are increasing being employed in the tunnelling sector. The growing demand for such engineered safe havens also sees the International Tunnelling Association (ITA) on the cusp of introducing new guidelines on the

technology.

Within the last 10 years, and after much effort on research and development, the refuge chamber concept has significantly advanced. The norm now is to order bespoke, portable sealed cells to meet the different project needs, and deployments, in the underground construction and mining industries.

Dozens of portable refuge chambers have been used on tunnelling projects, for which manufacturers are finding greater demand, says Mike Lincoln, general manager of one leading company, MineARC Systems.

The Australia-headquartered group has a global reach, and has provided emergency refuge chambers for a variety of tunnel projects since 2003, including: Brisbane North South bypass; the West Drainage and Express Rail Link projects, in Hong Kong; the Klang Valley Metro Project in Kuala Lumpur; and, most recently, it has a large order for Phase 1 of Doha metro. The portable chambers can be fixed to tunnel floors or mounted on TBM backup gantries.

"We're seeing an increased proportion of work coming from the tunnelling industry," says Lincoln.

Safety is sponsored by MineARC Systems

Strata Worldwide, another refuge chamber manufacturer, says that the international tunnelling sector is becoming increasingly important market for the firm. No details on its tunnel projects were made available.

However, while of increasing importance, refuge chambers are but one – albeit a key – part of risk management planning for underground industries, and others with potentially hazardous environments, such as petrochemical processing.

"Emergency refuge provision is just one part of the wider risk assessment process' on tunnel projects," notes Lincoln.

REFUGE TRANSFORMATION

Potential hazards vary on underground projects, and can include risk of fire, toxic gases, collapses, blasts, and water ingress.

Traditionally, workers carry self-contained self rescuers (SCSRs) in attempts to escape such sudden dangers, or at least to support their efforts to reach an uncompromised fresh air base.

While the broad concept of refuge chambers has been around from decades in mining, and various types have been used in that sector, effort in the last couple of decades then progressed to employ modified sea containers.

The strong, portable boxes were fitted with SCSRs and basic first aid supplies.

There were no further life support systems, as would come from R&D and technological advances, such as: positive air pressure systems to seal off and protect the environment; independent oxygen supplies; air scrubbing, and of course

Below: Occupant-generated heat and humidity must be taken into account

cooling systems.

"Essentially, they weren't equipped to provide any kind of reliable long-term refuge," says MineARC's Lincoln. "They were merely a staging point to try and regroup and exit the mine, or tunnel, if indeed possible."

The emergency refuge chambers have come a long way in terms of technology, robustness and sophistication. Today, as more of safe havens are provided underground, the refuges are either in the form of portable temporary chambers or permanent structures, built-in behind bulkheads.

While both types are employed in mines, only the former have been used in tunnel projects, and almost always only for the construction phase.

Customised refuge chambers for the tunnelling sector are typically smaller than used in the mining industry, says Lincoln. Typically, there is less scope for modularity in units, expect for possibilities on some metro/subway projects. Both underground sectors, though, require the chambers to function as secure safe havens for minimum periods, set by the local industries and countries.

"Whereas in the mining industry we have a fairly standardised range of chamber models, increasingly for the tunnelling industry no two projects are ever the same," adds Lincoln.

In the tunnelling sector, the portable refuge chambers are mounted on TBMs, stand alone or, less common, fixed to other infrastructure such as rails.

R&D continues to be pursued, and the primary message that MineARC hears in tunnelling, especially given the sector's requirement for customised solutions, is the need for as much flexibility as possible. A constant challenge for its customers is the tightness of the available space in tunnels as well as the curvature of the walls, notably in TBM-bored circular tunnels.

"However, we may get a few one-off requests for, say, fire resistance," says MineARC's marketing manager, ben Johnson. "It really just depends on specific requirements of the client and project."

Strata Worldwide's spokeswoman, in commenting on the difference between chambers for the mining and tunnelling sectors, says the concept and operation for each are the same. However, she adds, for tunnels "the size is much smaller and often slightly unique to fit onto TBMs."

She continues: "These factors make the engineering a lot more challenging. For example, implementing the backup services and breathing air equipment, etc, is more involved because of the very tight footprint."

On another underground hazard is water. MineARC's Lincoln notes that such risk could be designed by drawing upon its models of powerless refuge chambers, and non-electrically powered life support systems, to produce a customised chamber. Depending on the degree of water ingress, or flooding, risk underground then further aspects of design to address include the structural integrity and adequacy of the seals to meet the anticipated potential head of pressure.

No matter the hazard, though, monitoring of the environment, inside and outside of the chamber, is vital to ensure safety for the minimum designed occupancy period.

TUNNEL PROJECTS

Portable refuge chambers can be used in all types of tunnel projects, and customers are commonly TBM manufacturers and construction contractors, says MineARC's Johnson.

"If it's a project where TBM-mounted refuge is determined most suitable then, obviously, the TBM manufacturer will initiate' the procurement," he says.

Johnson adds that chambers can be provided to support safety plans on "virtually any size or constraint requirements, to suit any excavation method" – including roadheader, and drill and blast.

Customers for its refuge chambers in tunnels have included TBM manufacturers and also construction contractors, says MineARC.

The companies include Herrenknecht, Robbins, Caterpillar, Hitachi, Nishimatsu Construction, Dragages, Bilfinger Berger, Leighton, Bouygues, and Penta Ocean.

DOHA METRO

In March, MineARC announced that had a contract to supply custom-made emergency refuge chambers for 11 of the TBMs that Herrenknecht is manufacturing for Phase 1 of Doha metro. Herrenknecht is supplying a total of 15 TBMs to bore twin tubes in the three sections of the Phase 1 awarded so far.

The three sections awarded in Phase 1 are: Red Line North underground section (2 x 11km); Red Line South (2 x 13.8km); and, Green Line (2 x 16km).

The fourth section of Phase 1 is the Gold Line (2 x 13km underground section), and the contract is expected to be awarded later this year.

Further parts of Doha metro to be developed include extending the Green Line, and also constructing the 17.5km long underground stretch of the semi-circular Blue Line extending to Airport City and West Bay Central.

MineARC says, in a statement, that on the Doha metro works much of the project work will be completed underground with only one point of entry. "This fact alone," it adds, 'highlighted the importance of having

Emergency refuge chambers

The emergency refuge chambers are strong cells with a range of life support systems, and the entire package is designed to satisfy the risk profile of individual mines or tunnels. Space requirements per person differ with industry and region, depending on guidelines and legislation.

Key life support systems, as recommended by MineARC, include:

- Compressed air supply: filtered and regulated, at least, and capable of being isolated should the airline fail in emergencies;
- Secondary oxygen supply: medical grade cylinders, sized to provide oxygen for maximum occupancy. MineArc notes: 'In the tunnelling industry, where dedicated compressed air line running through the project is uncommon, air cylinders are most often the primary source of air supply to the refuge chamber.' It adds that a third source of oxygen is 'strongly recommended', in the form of a sodium chlorate O2 candle.
- Carbon dioxide removal: the scrubbing system needs to remove at least 24 litres of CO2 per person, per hour to keep gas concentration less than one per cent during the engineered duration of the refuge;
- Carbon monoxide removal: the scrubbing system must keep levels less than one per cent;
- Cooling & Dehumidifying: the cooling system should have a nominal capacity of 130W per person to mitigate heat loads from occupants and additional heat sources, and also be capable of dehumidifying the chamber;
- Electrical Equipment: provide a battery backup system to power all electrical systems in the chamber;
- Atmospheric Monitoring and Pressure: sensors to monitor gases and pressures inside and outside of the chamber. Nominally keep the internal pressure 200 Pascal more than the exterior pressure to prevent ingress of toxic gases;

In addition to offerings from refuge chamber manufacturers, monitoring equipment is also available from firms like Trolex. It has the TX6377 environmental monitoring system, designed especially for use with mining refuge chambers, but recently introduced the TX6378 Sentry 8 Area Monitor to work with units custom-designed for the tunnelling sector. The new monitor is based on the Sentry 8 Sensorstation, and is a self-contained system able to detect up to eight different gases.

MineARC's further recommendations for equipment include: emergency beacons (strobes); sirens; and communications systems.

Portable refuge chambers and systems are delivered to sites as single units, and then transported underground. The units are then commissioned by the manufacturer, key personnel are trained, and supporting operational information is provided in print, digitally, and on information signs within the chambers.

Any emergency drills are then conducted under the safety regime of the mine or tunnel project.

Permanent refuge stations

Where 'permanent' refuge chambers, or stations, are employed in mines they are effectively walled-in, fixed structures in a tunnel. The stations are formed behind engineered, bulkhead walls, each with secure access doors.

Like portable, temporary chambers, they are safe havens but their benefits come from the ability to shelter many more workers, and they offer a solution when frequent re-location of refuges is not required, says MineARC. The stations can also double-up as lunch rooms for the underground complexes.

However, unlike portable refuge chambers, each possibility for a specifically-located, permanent station calls for a host of factors to be assessed, the company adds. The prime factor in designing the station is the volume-to-occupancy ratio, it says, adding that it is 'critical' for determining other factors, such as: the 'dead air' space available; compressed air flow regulation; the size of the scrubber; and the amount of metabolic heat generated for sizing a cooling and battery backup system.

Other key factors for designing permanent refuges include the volume of the station, the number of people to be accommodate, the minimum time they are to be sheltered, the type and thickness of the bulkhead material, the maximum external pressure, and the geology.

While MineARC's patented system for permanent refuges can be designed to shelter up to 150 people or more, it notes that some recent applications in Australian and Turkish mines called for two 80-person and two 30-person stations, respectively.

refuge chambers on board the TBMs.'

The chambers will be housed on the back-ups trains. Their specification includes a minimum protection time of 30 hours, and each refuge chamber is to be large enough for 20 people.

The life support systems include primary and secondary oxygen supplies, and a scrubbing system to deal with carbon monoxide and carbon dioxide. Automatic overpressure systems are also included in the specification, to ensure the chambers are sealed against the risk of contaminated air from outside. Sensors monitor the internal and external pressures to help maintain a minimum level of overpressure.

MineARC says the safety specification is in line with the latest standards that have been in development for emergency refuge chambers, including the imminent introduction of the ITA guidelines.

OTHER TUNNEL PROJECTS

MineARC was established in 1999 and the following year began manufacturing refuge chambers. Its first unit for the tunnelling sector was made in 2003, for the Dublin Port Tunnel project. In total, across all industries, it has manufactured close to 1,800 refuge chambers – and, since 2012, the total for the tunnelling sector alone is almost 30.

Other projects where MineARC has delivered emergency refuge chambers include: the Malmo-Gothenburg Rail Project, in Sweden; the Castle Peak project, in Hong Kong; Brightwater and Yucca Mountain projects in the US; and, the Brisbane Legacy Way Project, in Australia.

In 2010, a couple of MineARC's refuge chambers were in place and were used in earnest as safe havens for 30 workers when a compressor fire occurred in the Niagara Falls Diversion Tunnel project. All workers escaped unharmed after sheltering in the chambers until the smoke cleared.

Strata Worldwide started supplying the tunnelling sector seven years ago, providing a refuge chamber to a construction/tunnelling contractor in Canada, says the spokeswoman.

"The year prior to that sale, the firm had begun supplying chambers to the coal mining sector – first by providing an inflatable unit, and later a powerless, steel walk-in chamber," she says.

"We have worked with and continue to work with both TBM manufacturers directly as well as contractors the manufacturer has appointed," she says, and adds that TBM manufacturers "have been seeking cost effective solutions with refuge chambers to be used in their operations."

She continues: "Each chamber is uniquely built to suit each TBM," and adds, "they are normally much smaller and compact compared to general refuge chambers."

BEYOND TUNNEL CONSTRUCTION

Although TBMs are associated primarily with the tunnelling sector, there is an interesting cross-over for portable refuge chambers when the shields are elected for use in mining. MineARC recently confirmed a contract to supply two TBM-mounted units for the Grosvenor coal mine in Queensland, Australia. TBMs have been chosen as the most cost effective method of excavating the decline for the mine.

Once excavations are finished, however, and the portable refuge chambers are de-commissioned, it is up to the customers to decide what happens to the units – perhaps re-use them, or sell, dismantle, scrap, or possibly adapt some to be safety training simulators.

MineARC has donated a permanent refuge chamber to the Colorado School of Mines. It is also exploring what might be possible to do with portable refuge chambers to support training in the tunnelling sector, says Johnson.

There have been a couple of instances of reuse/resale of chambers in the mining sector, notes Johnson. It is less likely in the tunnelling sector, he comments, as most chambers are "more than likely highly customised" units.

Looking beyond the excavation phase – though noting that is the stage that is the focus of the draft ITA guidelines – it is possible to incorporate refuge chambers in the live, operational phase of a tunnel project.

Johnson notes one such instance, at the Bunol High Speed Railway, in Spain, where a rail-mounted refuge chamber is on standby should it be needed to be driven underground to help tunnel maintenance workers.

In terms of planning for future tunnel projects, or mine developments, Johnson says that sometimes requests come seeking advice. Manufacturers, therefore, can be part of the consultative process to establish the emergency risk management plans for underground projects.

While refuge chambers are "a relatively recent introduction to the tunnelling industry,' says Johnson, "we've found the adoption and proactivity of the industry very encouraging"

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EXPECTED GROUND

Michelle van der Pouw Kraan, and **Mark Diederichs**, Queen's University, Kingston, Ontario, consider incorporating rock mass failure mechanisms in geotechnical baseline reports

Michelle van der Pouw Kraan
Michelle is the 2013 recipient of the Eisenstein Memorial Scholarship.

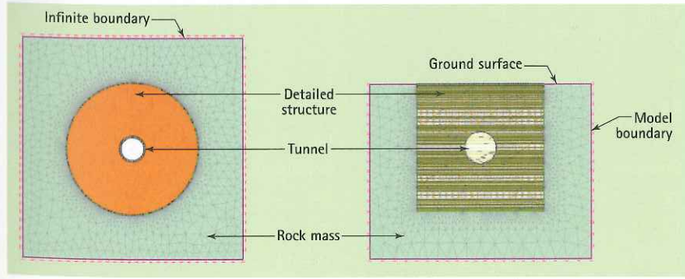
Mark Diederichs
Mark is a professor of geological engineering at Queen's University in Ontario.

THE EXPECTED ground conditions are one of the most important parts of tunnelling projects. Suggested guidelines from the ASCE for Geotechnical Baseline Reports (GBR) for underground construction state that a GBR should include the "criteria and methodologies used for the design of ground support and ground stabilisation systems, including ground loadings" and the "anticipated ground behavior in response to construction operations within each soil and rock unit" (Essex, 2007). However, these points are not always considered in tunnelling projects. In particular, the latter is often absent, replaced with a listing of rock mass properties based on intact rock testing and rock mass classification schemes.

Evaluation of the rock mass quality along an alignment using empirical design tools, such as the Rock Mass Rating system by Bieniawski, and the Q system by Barton, is limited in scope, as physically different rock types are grouped together with the same quality rating. These are termed 'equivalent materials' and leads to rock mass behavioral uncertainty. As a result, the equivalent materials are assigned the same rock support class, without consideration of the rock mass failure mechanism. To establish the importance of including structural controls on failure and the rock mass failure mechanism in GBRs, 'semi-discontinuum' Phase2 finite element models were used to investigate the impact of five different behavioral 'equivalent materials' on a standardised tunnel and rock support design (RocScience, 2013):

i. A 700m deep hydrostatic tunnel in altered, weak rock with three "smooth, undulating" joint sets with "slightly altered joint walls [and] non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc." The weak rock is "squeezing rock; plastic flow of incompetent rock under the influence of high rock pressures" (Barton et al, 1974).
ii. A 20m deep tunnel in a bedded and cross jointed sedimentary sequence. Three "rough or irregular, planar" joint sets with "silty- or sandy- clay coatings, small clay fraction (non-softening)" in "low stress, near surface" conditions have in-situ stress ratio (σ_H / σ_V) K of 1.5 (Barton et al, 1974).
iii. A 1,300m deep tunnel in massive rock with three "rough or irregular, planar" joints with "unaltered joint walls" (Barton et al, 1974). The high stress environment, with K of 2, results in "moderate slabbing after > 1 hour in massive rock" (Barton and Grimstad, 1994).
iv. A 600m deep tunnel with anisotropic in-situ stress (K of 1.7) in a heterogeneous foliated metamorphic rock. The cleavage planes are "slickenslided, undulating" with "softening or low friction clay mineral coatings, i.e., ...chlorite, graphite" (Barton et al, 1974).
v. A 300m deep tunnel with four "smooth, planar" joints with "silty or sandy clay coatings, small clay-fraction (non-softening)" form a "sugar cube" rock mass. The highly disturbed mass had a K of 0.75, and a 25m water pressure head to represent the "high stress" and "medium inflow or water pressure" conditions, respectively (Barton et al, 1974).

Below: Figure 1, at depth and near surface



INPUT PARAMETERS

Design approach using Q

The Q system, developed by Barton, Lien, and Lunde combines the joint block size, joint shear strength, and active stresses to calculate the rock mass quality with the equation:

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

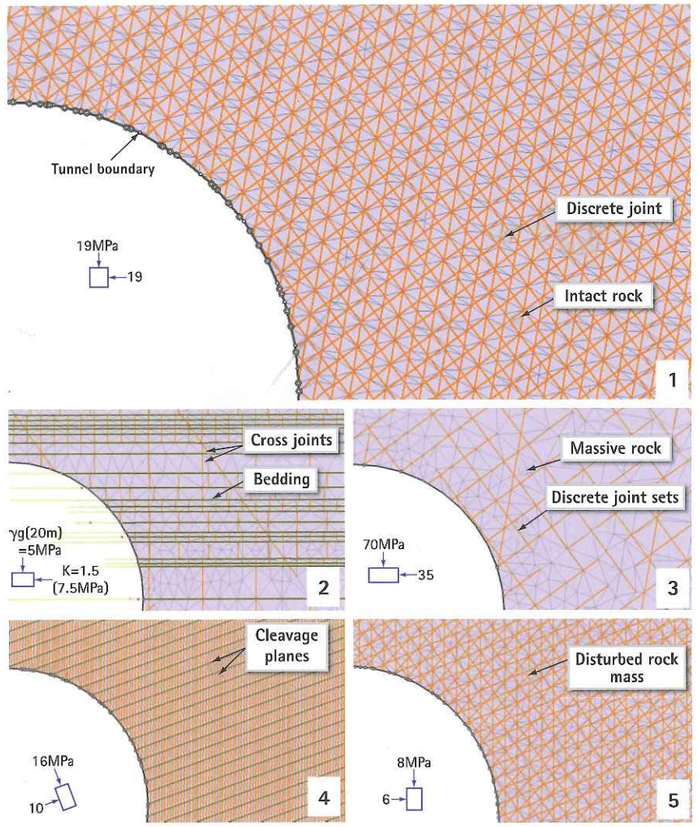
RQD is the Rock Quality Designation by Deere, Jn is the joint set number, Jr is the joint roughness number, Ja is the joint alteration number, Jw is the joint water reduction factor, and SRF is the stress reduction factor. These parameters are typically obtained from a project site investigation to determine the rock mass quality. The five 'equivalent material' case specific Q parameters, intact rock properties, and joint set spacings are presented in Table 1. A Q value of 1.1 – 1.2, or 'poor rock', equates to GSI 40.

Rock strength parameters

Rock strength parameters were calculated with the Hoek-Brown strength criterion, except those for Case 3, which were calculated according to the "damage initiation and spalling limit" approach developed by Diederichs. The rock mass deformation modulus was calculated using the Hoek-Diederichs equation. Joint set spacing was calculated using the Priest and Hudson methodology, which correlates RQD and joint frequency. Joint strength and stiffness were quantified using the Barton and Bandis slip criterion, and the approaches by Barton and Kulhawy, respectively.

Tunnel and rock support design

Two excavation methodologies, a 10m diameter TBM tunnel and a 10m span drill and blast arch tunnel, were used



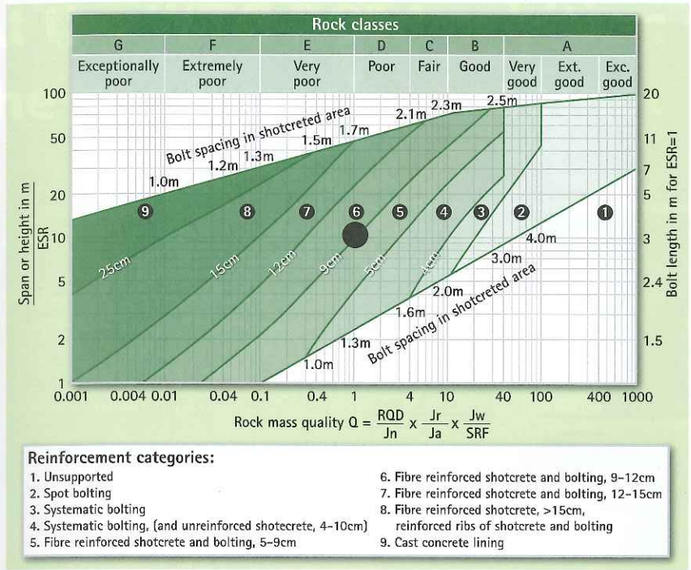
Above: Figure 2, structural rock mass

to determine the impact of each rock mass case behavior on the tunnel and rock support design. In the circular tunnel, rock support was installed behind the cutterhead, at 4m from the face, while in the arch tunnel, assumed 4m long drill and blast rounds permitted support to be installed on average 2m from the face. Good quality blasting was assumed for the arch tunnel analyses. Rock mass models are shown in Figures 1 and 2.

In accordance with the poor rock mass quality and an Excavation Support Ratio of 1 for "major road and railway

Table 1. Case specific equivalent material Q parameters, intact rock properties, and joint set spacing

	Case 1	Case 2	Case 3	Case 4	Case 5
RQD	55	70	90	40	40
Jn	9	12	12	6	15
Jr	2	1.5	1.5	1.5	1
Ja	2	3	1	4	3
Jw	1	1	1	1	0.7
SRF	5	2.5	10	2	0.5
Q	1.2	1.2	1.1	1.2	1.2
Rock Type	Limestone	Sandstone	Diorite	Amphibolite	Sandstone
UCS (σci)	75	75	125	175	75
mi	7	17	25	26	17
Joint spacing (m)	0.3	0.1 - 2	0.9 - 5	0.1 – 0.4	0.4



tunnels", permanent rock support consists of 3m long bolts spaced 1.7m in plane, with 90mm of fibre-reinforced shotcrete (Figure 3) (Barton and Grimstad, 1994).

In the numerical models, the 19mm diameter tieback bolts had a 0.1MN tensile strength, and a 100 per cent grouted bond length with bond strength of 50MN/m. The shotcrete layer was modelled as an elastic liner in order to calculate overstress, with a compressive strength of 40MPa, and a tensile strength of 6MPa to account for the steel fibers.

Above: Figure 3, Q rock support is shown with the black dot

UNSUPPORTED MODEL RESULTS

Case 1: Squeezing

Squeezing is a ductile failure mechanism which occurs in high in-situ stress environments in weak rocks. On excavation, shear zones develop around the tunnel. Squeezing is exacerbated when clay minerals are present.

The influence of the excavation methodology on a squeezing rock mass is clearly demonstrated in the contrasting circular and arch tunnel results (Figure 4). While both tunnels experience extreme squeezing (Hoek and Marinos, 2000), in the circular tunnel squeezing is restricted by the influence of the surrounding rock mass, resulting in some 8 per cent strain. In contrast, the arch tunnel excavation shape permits greater strain to occur, on average 15 per cent, in the crown and sidewalls.

For each tunnel, displacement is on the left, and element yield is on the right. Material that has deformed greater than 0.25 to 0.3m has been assumed to have fallen out or removed, and is shown in white. M = deformation magnifier.

Case 2: Stratified structure

Failure in shallow bedded and jointed sedimentary rock tunnels occur when the bedding plane weight is greater than the strength along the bedding or joint planes, causing fall-out.

In both tunnels, thick bedding planes fail until approximately 3m above the tunnel crown, where thinner beds are encountered. Additionally, failure along a non-persistent joint located in the left tunnel wall allows sliding rock deformation into the tunnels. The tunnels' close proximity to surface does not permit the in-situ stress to become a failure instigator. While the same amount of failure occurs in both tunnels, the arch tunnel excavation shape provides greater structural stability than the circular excavation, as the arch tunnel undermines fewer bedding planes above springline. Also, in the TBM excavated tunnel, the greater time-lag between the excavation and rock support installation allows for a greater amount of rock fallout to occur due to time, TBM vibration, etc.

Case 3: Slabbing / spalling

Slabbing or spalling is a hard rock brittle failure mechanism that can occur in deep tunnels.

Tension cracks form where the induced stress concentrations surrounding an excavation are greater than the intact rock strength (Diederichs, 2007). In both tunnels, induced stress concentrations in the crown and invert cause rock mass tensile and joint failure. Stress relaxation occurs along the sidewalls, creating wedges. However, the induced stress results are more pronounced in the arch tunnel, due to its shape. It is obvious that a circular tunnel is best able to mitigate the effects of high in-situ stress.

Case 4: Metamorphic structure

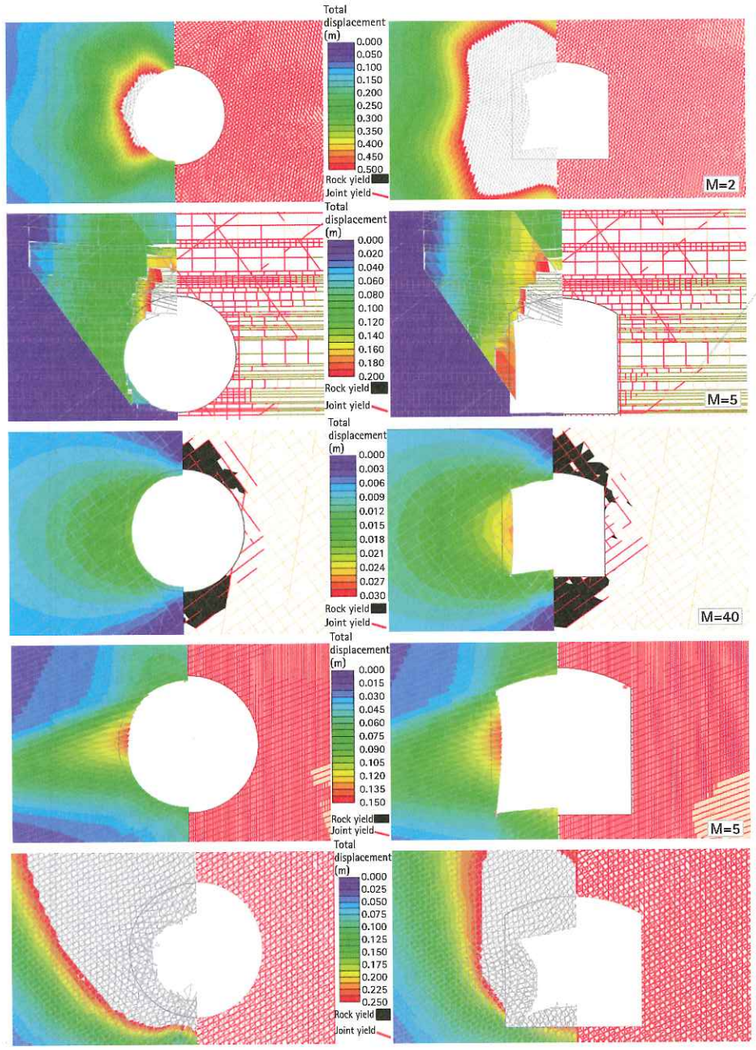
In foliated metamorphic rocks under high stress, the cleavage planes provide preferred failure paths. The major principle stress orientations and the in-situ stress anisotropy significantly dictate the deformation extent. In both tunnels, the perpendicular orientation of σ_1 to the inclined cleavage plane causes approximately 0.15m of inclined shear displacement. Neither the circular nor arch tunnel shapes mitigate the extent of structural failure.

Case 5: Raveling

Raveling occurs in a completely disintegrated rock mass with a small block size and nearly zero cohesion (Marinos, 2012).

The ravelling extent is influenced by the joint frictional strength and the presence of water.

In the circular tunnel, deformation in the crown and sidewalls propagates upward several tunnel diameters. Deformation is steered left due to the interaction between the joint network orientations and the in-situ stress. In comparison, displacement appears restricted in the unsupported arch tunnel as the deformation in the crown and right sidewall do not connect and propagate.



Above: Figure 4, Top to bottom: squeezing, sedimentary structural failure, spalling, foliated metamorphic structural failure, and raveling

SUPPORTED MODEL RESULTS

As shown in Figures 5-8, standardised rock support is inadequate for the majority of cases. Overall, the majority of the rock bolts reached the maximum axial load and the shotcrete liner is inadequate for the squeezing, metamorphic structure and raveling rock mass behavior cases. Both tunnels in the squeezing rock mass are unable to withstand the rock mass failure mechanism. About 33 per cent of the bolts fail in the circular tunnel, and nearly all the bolts fail in the arch. The liner capacity is exceeded in both.

In the bedded sedimentary the support is adequate in both the excavations. However, the arch tunnel shape is more structurally stable as rock support, scaling or both is required over a greater circumference in the circular than in the arch tunnel.

In the slabbing/spalling circular tunnel excavation while nearly all the bolts fail along the joint planes, the compressive strength of the liner is maximised and is able to sustain the high in-situ stresses. In the arch tunnel, high stress concentration corners cause liner failure, and sidewall wedges cause large liner bending moments.

In the foliated metamorphic rock mass, as the rock mass and rock support failed similarly in both tunnels, the critical design item is not the excavation shape, but to design appropriate rock support for the rock mass behavior.

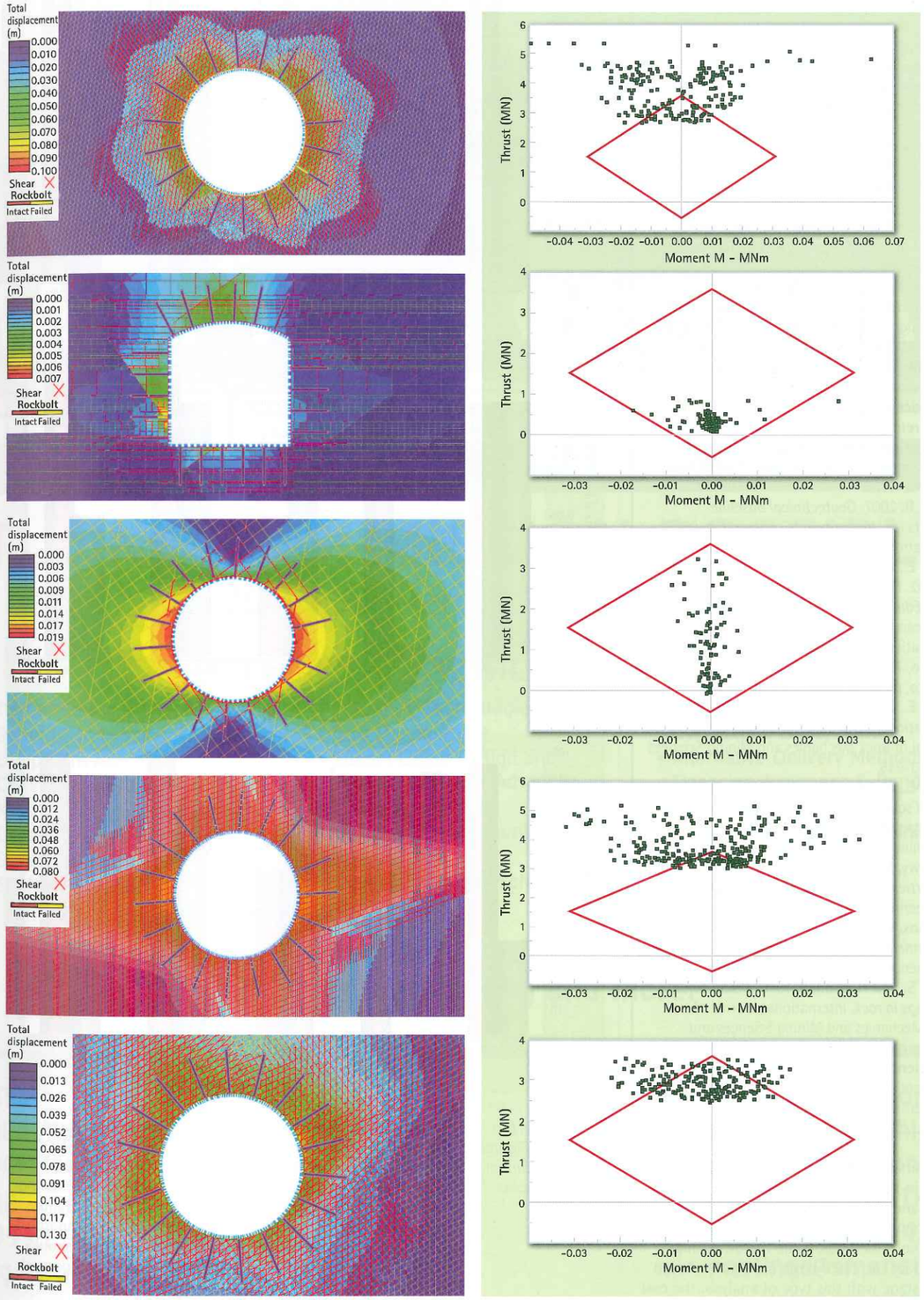
In raveling rock masses, support should be installed as soon as possible to mitigate rock deformation. While the unsupported circular tunnel experienced a greater amount of deformation, the circular liner is more effective at restraining the rock mass than the arch tunnel, due to its shape.

CONCLUSIONS

Developing a tunnel and rock support design based on the results from a standard rock mass classification system and intact rock properties alone is limited in scope. It neglects to consider the failure mechanism, the rock mass - rock support interaction, and generates behavioral uncertainty. The five 'equivalent material,' behaviorally different models demonstrate that the recommended support for a poor rock tunnel proves inadequate once the rock yielding behavior, in-situ stress, rock mass structure and the groundwater pressure are incorporated in the rock behavior. As these factors control the failure initiation location, magnitude and propagation direction, they should be a key component in determining tunnel and support design.

This type of analysis, while not able to capture all the variations in the ground conditions, is useful in determining the expected ground behavior. However, there are a few issues which require industry discussion. With regards to tunnelling contracts, one issue to consider is which party should be responsible for carrying out this type of analysis. Typically this would depend on the type of project delivery method, and how ground risk has been allocated. On a design-bid-build project this type of analysis may prove difficult as typically the selection of excavation means and methods is done by the contractor. However, if the results of this type of analysis are included in a GBR, it may lead to decreased bid prices as the rock mass behavioral uncertainty is reduced, and less claims due to unforeseen ground conditions during construction. On a design-build project, typically the contractor carries a greater portion of the ground risk. Should the contractor perform this

Below: Failure modes: a) Squeezing; b) structural failure; c) Spalling; d) Foliation shear /buckling; e) Ravelling



References

Barton, N. 1972. *A model study of rock joint deformation.* International Journal of Rock Mechanics and Mining Sciences 9: 579-602.

Barton, N., and Bandis, S. 1990. *Review of predictive capabilities of JRC-JCS model in engineering practice.* In Rock joints: Proceedings of the International Symposium on Rock Joints, Loen, Norway, 4 – 6 June 1990. Balkema, Rotterdam, pp. 603-610.

Barton, N., and Grimstad, E. 1994. *The Q-system following twenty years of application in NMT support selection.* Felsbau 12(6): 428-436.

Barton, N., Lien, R., and Lunde, J. 1974. *Engineering classification of rock masses for the design of tunnel support.* Rock Mechanics 6(4): 189-236.

Bieniawski, Z. 1989. *Engineering rock mass classifications.* Wiley, New York.

Diederichs, M. 2007. *Mechanistic interpretation and practical application of damage and spalling prediction criteria for deep tunneling.* Canadian Geotechnical Journal 44: 1082-1116.

Essex, R. 2007. *Geotechnical Baseline Reports for Underground Construction.* ASCE Publications, Virginia.

Hoek, E., Carranza-Torres, C., and Corkum, B. 2002. *Hoek-Brown Failure Criterion – 2002 Edition.* In Proceedings of the North American Rock Mechanics Symposium – Tunnel Association of Canada Conference, Toronto, Ontario, 7-10 July 2002. University of Toronto, Toronto, pp. 267-273.

Hoek, E., and Diederichs, M. 2006. *Empirical estimation of rock mass modulus.* International Journal of Rock Mechanics and Mining Sciences 43: 203-215.

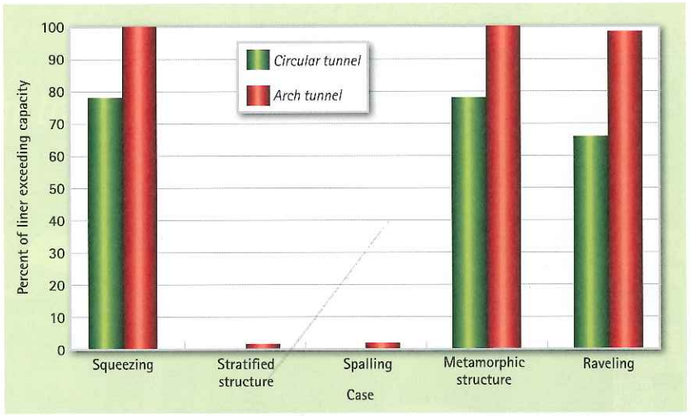
Hoek, E., and Marinos, P. 2000. *Predicting tunnel squeezing problems in weak heterogeneous rock masses.* Tunnels & Tunnelling International, December 2000.

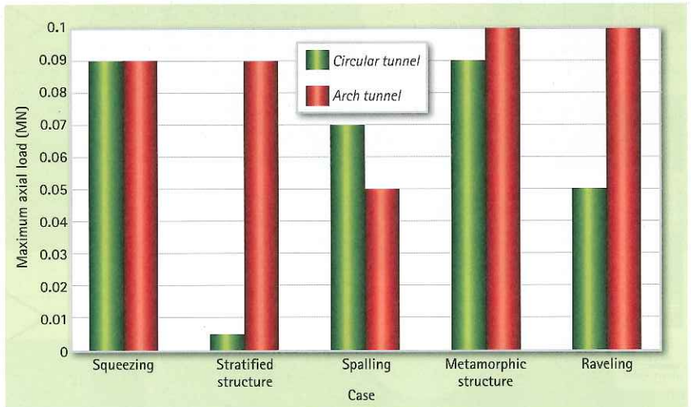
Kulhawy, F. 1975. *Stress Deformation properties of rock and rock discontinuities.* Engineering Geology 9: 327-350.

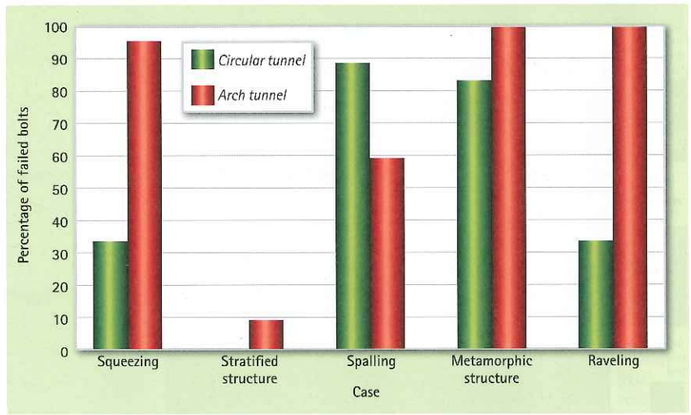
Marinos, V. 2012. *Assessing rock mass behavior for tunnelling.* Environmental & Engineering Geoscience 18(4): 327-341.

Priest S. and Hudson, J. 1976. *Discontinuity spacings in rock.* International Journal of Rock Mechanics and Mining Sciences and Geomechanics 13: 135-148.

RocScience. 2012. Phase2 Finite Element Software. Toronto, Ontario, Canada. www.rocscience.com.







Below: From top to bottom, Figures 6, 7 and 8: tunnel shape and case results

analysis, the knowledge gained may aid in the selection of excavation means and methods to reduce the failure mode severity, and the project risk. For both methods, while the owner may face increased costs during the design stage with this type of analysis, the cost savings during construction outweigh this initial increased cost. If rock mass failure occurs during tunnel excavation, both the owner and the contractor are better prepared from a contract and construction perspective, mitigating or lessening disputes and delays, and aids in determining cause of failure. As expected ground conditions are one of the most important aspects of a project, the rock mass failure mechanism should be incorporated into GBRs in describing the expected ground behaviour

PRACTICAL TBM EXCAVATION DATA PROCESSING

In this paper on the measurement and processing of machine data from shield tunnelling for analyses of the excavation process, the authors intend to give practical guidelines for the processing of TBM data and for some important steps in preparing for proper data interpretation. These steps need to be followed, particularly when the data is used for making (or defending against) claims of differing ground conditions

DATA COLLECTED during shield tunnelling are frequently used for understanding the interaction between machine and the ground. Of paramount interest are those parameters which directly reflect the contact between machine and soil or which describe the excavation process itself. These parameters include:

- Thrust force on the cutting wheel [kN]
- Total thrust force [kN]
- Torque on the cutting wheel [MNm]
- Penetration [mm/rev] as a calculated value from the parameters:
  - Cutting wheel speed [rev./min]
  - Advance speed [mm/min]

Changes in recorded machine data for these parameters are frequently attributed to changes in ground conditions. However, the machine data are influenced by numerous factors such as the physical condition of the cutting wheel, the steering of the shield machine as well as errors or tolerances in measurements. This paper deals with the quality and the processing of raw machine data. The status of the geotechnical documentation of and at the site as well as the effects of certain ground conditions on machine behaviour or machine data are not discussed. Possible sources for errors in raw data as well as remedial measures are given. Thus, it is possible to define excavation-specific data components of machine data which are assumed to be independent of technical or human influence. We limit the analysis of machine parameters directly connected to the movement of the cutting wheel or the shield. Additional information are given in Düllmann et al. (2013) and the effects of cutting wheel design and ground conditions are discussed in Hollmann et al. (2013).

CURRENT PRACTICE OF DATA ANALYSIS

A huge amount of machine data is continuously recorded in shield tunnelling. Some 200 to 400 raw machine data items are recorded at a typical interval of 10 seconds. This data is called 'instantaneous data' (Maidl et al., 2011). General statistics are applied to this data (average, minimum and maximum value etc.) for each segment. Because of the huge amount of instantaneous data, analysis is performed only over short periods. For the analysis of longer distances, the use of average values is more appropriate. There are numerous information systems for data management and data processing (e.g. 2doc, CBP, PROCON, SISO, TPC) (Maidl et al., 2011).

Some raw data is significant for evaluating the interaction between machine and ground conditions and refer to either the shield progress (advance, penetration rate, thrust forces, cutting wheel rotation speed, cutting wheel torque) or face support (face support pressure, density of the support media) (Maidl and Nellessen, 2003). Sudden changes in the mentioned data may reflect a change in ground conditions as the data directly or indirectly depends on those conditions. However, this data must be separated in

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active and passive parameters:

- An active parameter is given by the operator and is thus a pre-determined value. Active parameters include cutting wheel rpm as well as advance speed and pressure of thrust cylinders, which push the TBM forward. As the calculated product of advance speed and cutting wheel rpm the penetration rate sometimes is called active, too. Additional active parameters are face support pressure and slurry flow rates with the use of mix-shields or the rotational speed of the screw conveyer with EPB shields.
- Passive parameters such as thrust force on cutting wheel or torque of cutting wheel are the result of active parameters. The determination of values for active parameters first of all aims for a specified penetration rate under given site conditions. The cutting wheel torque and thrust are, however, not target rather than limiting values for active parameters. For example, increasing resistance to excavation results in an increase of torque and thrust force. These increases may also indicate disturbed excavation process due to tool wear or clogging (Maidl et al., 2011).

Immediate observation of instant values is mandatory during operations. This, however, cannot be achieved with the use of standard spreadsheets, making specialised tunnelling information systems necessary (Maidl and Nellessen, 2003). The data of the active parameters are already displayed in real-time in the operator's cabin (Maidl et al., 2011). Typically, it is the operator who has continuous access to and supervises these parameters. Additionally, some data is automatically compared to limits which is specified before shield drive (Stahl and Babendererde, 2009). During operations this data is of particular interest which is important for safe tunneling with small settlements (i.e. face support pressure, delivery, densities and pressure for backfill grouting). Of similar importance may be a sudden increase in cutting wheel torque and thrust force while the penetration remains the same or is decreasing. This observation may indicate the need of either a cutting wheel inspection with respect to tool wear and clogging (cf. Thewes and Burger, 2004; Hollmann and Thewes, 2013) or a change in ground conditions.

Subsequent analysis of machine data may be used for better understanding of the excavation process. Here the use of commercial spreadsheet software is useful as those programs allow for unlimited insertion of external data (i.e. ground conditions). Focus of post tunnelling analysis may be placed on unexpected situations such as face collapse or similar (Maidl and Nellessen, 2003). Other applications involve the evaluation of risk scenarios as well as claims (Haid and Maidl, 2007). Naturally, the owners tend to interpret the changes in machine data towards operators skills, level of maintenance as well as the choice of excavation tools.

Contrary, the contractor might like to interpret the same changes in machine data with changed ground conditions compared to the contractual prognosis.

MEASUREMENT AND STORAGE OF DATA

Today's TBMs integrated automatic data logging systems are based on sophisticated measurement methods. Hundreds of sensors are placed on various locations of the tunnelling system and continuously transmit analogue electrical signals (typically voltage in mV). The signals are processed by analogue to digital (AD) converters into physical units such as pressure. Each sensor features a specific range of application (e.g. pressure sensors with a range of 0 to100 bars) as specified by the manufacturer. Outside the specified range the converted values may be erroneous. With significant overloading, even for a very brief time, above the sensor's design range the device may be damaged or destroyed. In any case, electrical zero or the linearity of the sensor may experience an offset leading to a need for a recalibration of the sensor (which in many cases is never done).

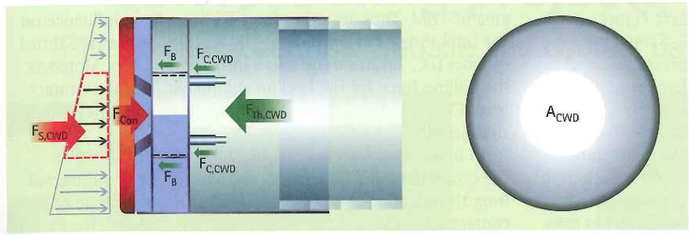
Thus, the use of under-dimensioned sensors may lead to erroneous measurements which cannot be compensated for later. Over-dimensioned sensors negatively affect the accuracy of a measurement as a sensor features error margins as a function of its dimension (e.g. ± 0.5 per cent FS (of the full scale)). In addition, the resolution of the measurements is coarser by using only a small part of the allowable range.

The calibration (the correct reflection of the actual physical status) of the sensors is typically done ahead of tunneling operations. Control and re-calibration during operations are difficult because of the large number of sensors. This may lead to unnoticed zero-shifts and changes in linearity of the sensors. Comparable sensors in laboratory practice need to be checked and re-calibrated on a regular basis because zero-

Table 1. Excavation-specific and excavation-independent data components of machine raw data.

Machine raw data			
Excavation-specific data components		Excavation-independent data components	
Influence from resistance to excavation	Influence from state of cutting wheel	Technical components	Human components
- Influence from ground conditions (e.g. soil density)	- Design of cutting wheel (diameter, degree of aperture, type of tools) - Actual state of tool wear and clogging	- Influence from face support - Influence from friction forces	- Operator's skills (adjustment of active parameters

Source: Authors



Above: Figure 1, Schematic presentation of forces acting on cutting wheel of a hydro-shield machine, for an engineering drawing with all acting forces refer to Festa et al. (2013)

shifts and changes in linearity occur even without exceeding the sensor's limit (manufactures specify long- term accuracy of sensors in the range of 0.1 per cent FS per year). Compared to the controlled laboratory conditions, the sensors on a TBM are exposed to very adverse conditions. They include large variations in temperature and humidity, vibrations and damages by force as well an extensive cable length. The sensors endure these conditions over a period of several months which may have negative effects on the sensor's accuracy. The reliability of the recorded machine data suffers and re-calibration of the sensors is necessary. It is necessary to install sensors adapted to these conditions.

Additional to the measured values there are many calculated values to be stored in the database. For example, the thrust force of the cylinders is a calculated value from the oil pressure and section area of the ram. Similar procedures are carried out when calculating the penetration rate from the advance speed and the cutting wheel's rotation speed.

MAIN PARAMETERS AND DEFINITION OF EXCAVATION-SPECIFIC DATA COMPONENTS

Ground conditions as well as the current state of the cutting wheel influence the machine raw data and their change by trend. The actual effect of these two factors may only be assessed by additional investigations. We introduce the excavation-specific data component, combining both (ground conditions and state of the cutting wheel) as the respective effects on the raw data cannot be clearly distinguished. Additional influences on raw data stem from operator's skills, face support pressure and friction forces. These effects are independent of the excavation processes. The raw data in the database therefore consist of excavation-specific and excavation-independent data components as specified in Table 1.

It is obvious that machine raw data has to be partially revised to allow for meaningful interpretations of interactions between TBM and ground conditions.

First attempts have been carried out by Festa et al. (2012) and Jung et al. (2011). The design of total thrust force magnitude of a TBM as described in Maidl et al. (2011) is rooted in a very similar consideration of different components.

Thrust force on the cutting wheel

For shield tunneling without face support, the parameter thrust force of the cutting wheel (FTh, CWD) represents the sum of internal friction forces of cutting wheel displacement cylinders (FC, CWD) and the guidance of main bearing (FB) and the contact force of the cutting wheel at the tunnel face (FCon) (cf. Fig. 1). Parameter FTh, CWD is also used for analysing ground conditions when applying face support. The raw data (FTh,CWD) summarises the forces of the individual cylinders, which are calculated from the pressure and the cross-section of the rams. Three groups of cylinders, each equipped with 2 or more individual cylinders, allow with many TBMs controlled displacement and tilting of the cutting wheel. The cylinders are, depending on their position, pressurised differently due to the weight of the cutting wheel. They also transmit the forces from the cutting wheel and cutting wheel drive to the shield. With face support, the pressurised chamber is separated from the area with atmospheric condition by the submerged wall. For EBPMs in closed mode the excavation chamber between submerged wall and the face is completely filled with the support muck. With hydro shields a two chamber system is used. The excavation chamber is completely filled with slurry while the working chamber is only partly filled with slurry, the remainder is an air bubble by which the face pressure is controlled.

For all shield types with face support, the face support pressure acts not only on the face itself but also on the area of the cutting wheel drive (ACWD) (see Fig. 1). This force (FS,CWD) acts opposite to the drive direction and has to be compensated for by the cutting wheel displacement cylinders.

In order to evaluate the excavation-specific data component (contact force of the cutting wheel at the tunnel face (FCon)), the force of the slurry on the area of the cutting wheel drive (FS,CWD) has to be considered. FS,CWD may be calculated by the following equation:

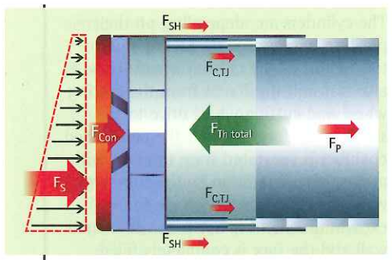
1. $F_{S,CWD} = P_{Ax} * 100 * A_{CWD}$

   $F_{S,CWD}$ = resulting force of face support pressure acting on area of cutting wheel drive [kN]

   P_{Ax} = face support pressure on horizontal machine axis level [bar]

   A_{CWD} = area of cutting wheel drive [m²]

Additional forces to be taken into account are several frictional forces. These forces include friction of guidance within the main bearing of the cutting wheel drive and inner friction of the individual cylinders for cutting wheel displacement. It is neither possible nor useful to distinguish between single frictional forces. However, they amount to significant magnitudes as may be seen when closely analysing instantaneous data of cutting wheel displacement without face contact. Several bars of oil pressure are necessary to move any piston (FC, CWD) as well as the cutting wheel drive (FB). This pressure is termed oil pressure for idle movements of a thrust cylinder. The 'idle pressure' has to be converted to constant frictional force. This force has



Left: Figure 2, Schematic presentation of forces acting on shield and cutting wheel of a hydro-shield machine, for an engineering drawing with all acting forces refer to Festa et al. (2013)

to be included in the analysis of raw data. The constant friction force has to be added to the raw data because parts of contact and face support forces are compensated by those friction forces. As discussed above the calculation of the contact force of the cutting wheel at the tunnel face (contact force CW) may be summarised in the following equation:

2. $F_{Con} = F_{Th,CWD} - F_{S,CWD} + F_{C,CWD} + F_B$

F_{Con} = contact force CW [kN]

$F_{Th,CWD}$ = thrust force on cutting wheel raw data [kN]

$F_{S,CWD}$ = resulting force of face support pressure acting on area of cutting wheel drive [kN]

$F_{C,CWD}$ = internal friction force of hydraulic cylinders [kN]
FB = internal friction forces of guidance within main bearing [kN]

Total thrust force

In this section, processing of total thrust force raw data is presented. In a very similar way to dealing with the thrust force on the cutting wheel, the total thrust force comprises many different components and forces within the cutterhead and the shield of a TBM (Maidl et al., 2011). Different forces are displayed in figure 2 and have to be in equilibrium. Evaluations of the total thrust force are aiming for the calculation of shield friction force as an excavation-specific data component. An additional resistance to the cutting edge of the shield is neglected due to the overcut, resulting in the diameter of the excavation being larger than the diameter of the shield (Maidl et. al, 2011). As shown in figure 2 it is obvious that for processing of FTh total many different components have to be considered. The resulting force of the face support pressure (FS) and the friction forces of thrust cylinders (FC, TJ) are crucial. In this case, the face support force acts on the total cross sectional area of TBM. Thus, resulting force FS has a large influence on the total thrust force raw data. The friction force of the thrust cylinder (FC, TJ) has to be taken into account, too. Moreover, the pulling force for the backup equipment (FP), the contact force CW (FCon) and the shield friction force (FSh) have to be subtracted.

In order to move the TBM shield friction force (FSh) as the excavation-specific data component has to be subtracted from the raw data of total thrust force. The magnitude of the contact force CW was discussed under the subhead 'thrust force on cutting wheel'. There are other forces such as friction between brush seal and segments which should be included; their magnitude is however considered negligible. Theoretically, the shield friction force may be calculated as follows:

3. $F_{Sh} = F_{Th\ total} - F_S - F_{C,TJ} - F_{Con} - F_P$

F_{Sh} = shield friction force [kN]

$F_{Th\ total}$ = total thrust force raw data [kN]

F_S = resulting force of face support pressure acting on area of TBM cross section [kN]

$F_{C,TJ}$ = internal friction force of thrust cylinders [kN]

F_{Con} = contact force CW [kN]

F_P = pulling force of backup equipment [kN]

Torque of the cutting wheel

Often the raw data 'torque of cutting wheel' has been used for interpretation of the ground conditions (e.g. Gwildis et al., 2010). It should be considered that the idle revolution of the cutting wheel without any face contact leads to considerable magnitude of torque. This torque is termed "idle toque of cutting wheel" and may be measured during the startup of the TBM without face contact or from factory approval.

By supporting the tunnel face with slurry or other support media, the idle torque increases and has to be considered as the "effective idle torque on cutting wheel". It may be measured during constant revolution of cutting wheel within the support media but without face contact. Those situations may occur shortly before or after tool inspection.

To analyse machine data, raw data of torque on cutting wheel has to be reduced by subtracting the effective idle torque on cutting wheel, measured for actual excavation conditions (open modus, slurry modus, full or semi-filled).

4. $M_{spec} = M_{raw} - M_{eff}$

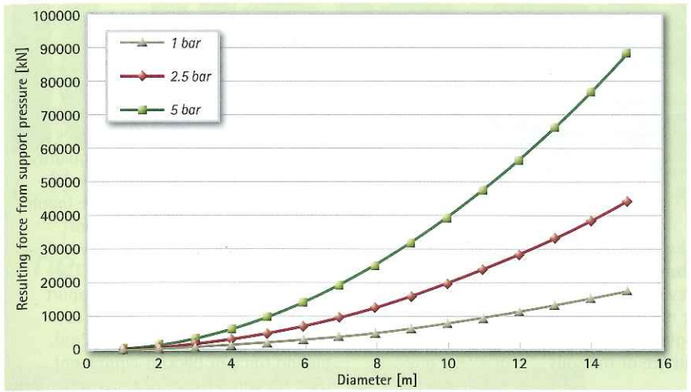
M_{spec} = specific torque on cutting wheel [MNm]

M_{raw} = torque on cutting wheel raw data [MNm]

M_{eff} = effective torque on cutting wheel [MNm]

Additionally, it has to be mentioned, that differences of shear strength or density of the support muck in the excavation chamber as well as irregular clogging on cutting wheel may influence magnitudes of torque.

Penetration



Above: Figure 3, Resulting force from face support pressure at different pressures, depending on cross section diameter (size of effective area)

Below: Figure 4, Presentation of face support force portions on total thrust force raw data (friction forces are not respected) for different hydro-shield projects under various geological conditions, different machine sizes and with different face support pressures

The fourth parameter discussed in this paper is penetration of the cutting wheel. The analyses of the excavation process using the raw data it is not meaningful without regarding other parameters because penetration is directly influenced by the active parameters (see subhead 'current practice of machine data analysis'). A change of penetration magnitude during excavation hints first of all only a change of active parameters by the operator.

To receive an excavation-specific data component in this case, not the technical but the human influence has to be identified. For that reason, scaling of penetration to the contact force CW is suggested and the obtained parameter is called specific penetration (Wanner and Aeberli, 1979).

5. $Pen_{spec} = Pen_{raw} / F_{Con}$

Pen_{spec} = specific penetration [mm/U/kN]

Pen_{raw} = penetration raw data [mm/U]

F_{Con} = contact force CW [kN]

EXCAVATION DATA COMPONENTS QUANTIFIED

Thrust force on cutting wheel

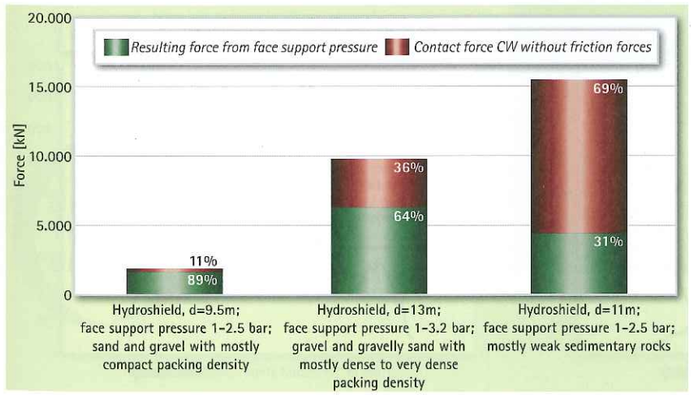
The resulting force of face support pressure and friction forces were described as excavation-independent data components and contact force CW as excavation-specific data component under subhead 'thrust force on cutting wheel'. Even at low support pressures a significant influence of face support force on raw data is evident. The resulting face support force increases in a nonlinear way with the diameter of machine (see figure 3).

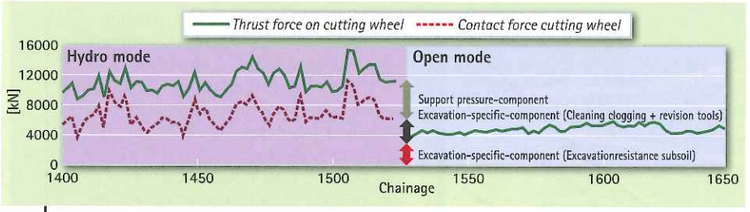
It seems to be useful to use the air bubble pressure in hydro-shields for calculation of face support force if the level of slurry in the working chamber is approximately on horizontal machine axis. The values for air bubble pressure can be checked easily and the sensors are not influenced by mechanical stresses or clogging like those in the excavation chamber, so that only infrequently measuring errors or malfunctions occurs. If slurry level is above or beneath the axis, pressure distribution within the excavation chamber has to be evaluated by comparing values of sensors at different levels with the air bubble pressure. Slurry density and slurry level have to be taken into account. Then the effective pressure on the area of cutting wheel drive in submerged wall can be calculated.

Such calculations have been carried out by the authors for three different projects and the findings are presented in Fig. 4. The column charts show average values for whole project distance. Raw data of thrust force on cutting wheel represent 100 per cent and calculated forces from face support pressure are given as a percentage of these raw data (friction forces are not considered).

It was found that in any case of face support, independent of machine type, geology or used pressures, the influence of face support force on raw data is significant. Similar results were found by Festa et al. (2012). Additionally, the results given in figure 4 show a trend to lower portions of face support force with increasing excavation resistance of the ground.

Figure 5 shows data of a project which has been carried out by a hydro-shield machine with face support up to chainage 1530. After modification to open mode the excavation was continued without any face support beyond chainage 1530. The continuous line represents the raw data of thrust force on cutting wheel. It is obvious that with modification from hydro-mode to open-mode values are decreasing instantly from 12,000 to 4,000kN. The reason for this difference is the missing support pressure in open mode. The dotted line represents the excavation-specific data component of the contact force CW (support pressure and friction forces considered). The difference





between the dotted line in hydro-mode and the continuous line in open-mode (marked by the midway arrow) represents the results of cleaning works (clogging) and revision of tools during modification of TBM. Additionally, the more fluctuating magnitudes in hydro mode are results of clogging. The lowermost arrow describes the remaining influence of the soils at the beginning of open mode drive.

Clearly, the excavation-specific data component (contact force CW) does not only depend on ground conditions. The importance of cutting wheel conditions should always be taken into account. Additional information may be delivered by tools with integrated force measuring sensors.

In a next step it was tried to identify friction forces under similar conditions (similar slurry density, no face contact of cutting wheel, similar cutting wheel rpm) by processing raw data of a hydro shield project. However, no consistent values could be found for pushing the cutting wheel forward or pulling it backwards. Fig. 6 shows two situations and displays the difference.

In first case, figure 6 (left-hand), the cutting wheel was pushed forward by a force of 600 to 700kN. In second case, figure 6 (right-hand), a force of 1,400 to 1,600kN was needed and movement of the cutting wheel stopped although acting forces of more than 1,000kN occurred. Even when including analyses from two additional, similar situations in the same project no consistent data for friction forces could be found.

These findings were confirmed by processing the data of other projects, so that for further estimations friction forces had to be assumed.

Above: Figure 5, Decreasing of thrust force on cutting wheel after modification of a TBM mix-shield machine from hydro mode to open mode without face support (point of modification marked by arrows)

Below: Figure 6, Movement of cutting wheel under different levels of forces

Total thrust force

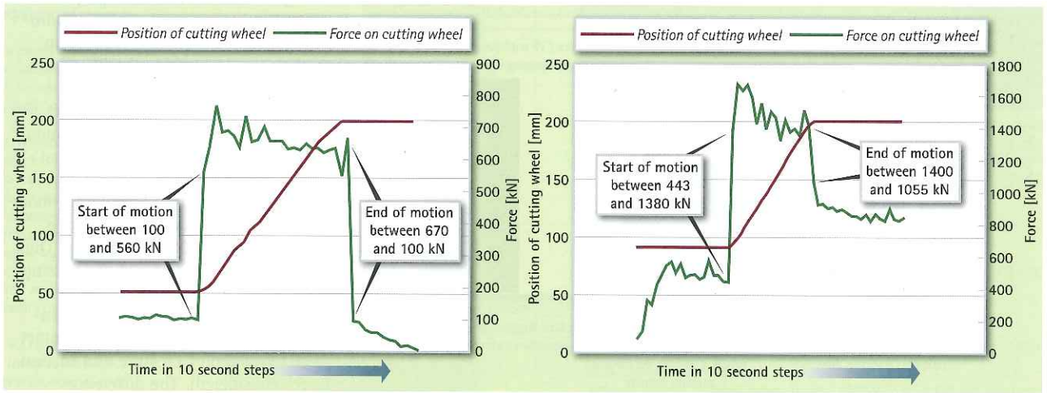
In the same way, raw data of total thrust force first of all depends on the magnitude of face support pressure. Face support pressure in this case is acting on the whole cross section of a TBM so that the resulting force is increasing rapidly with machine size (see Fig. 3).

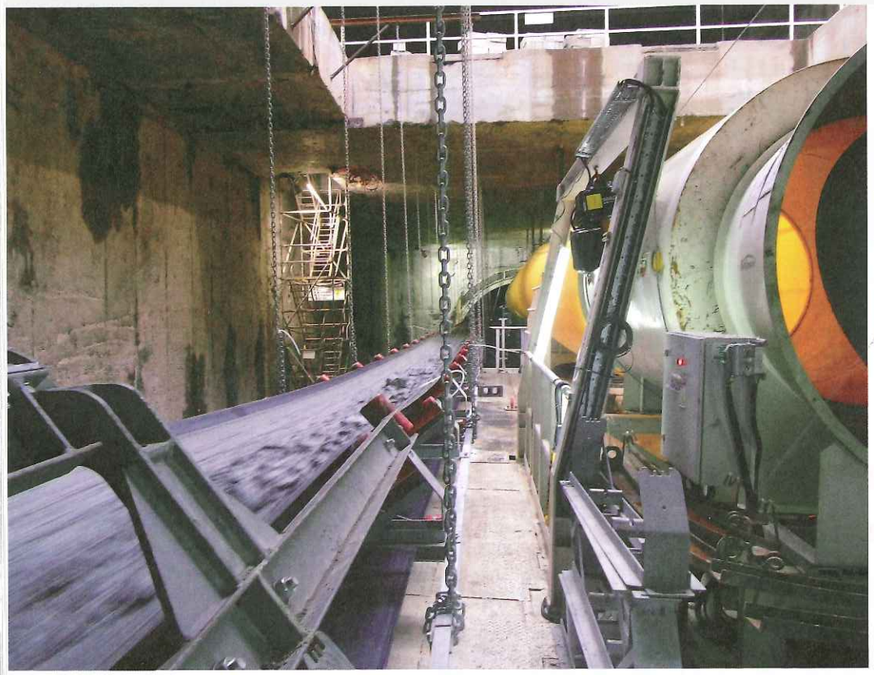
It was found that in most cases values of the excavation-specific data component (shield friction force) were much lower than values of resulting face support force. The respective percentages may be different in special situations like very high ground stresses and jamming of the shield. Suggestions for a theoretical calculation of shield friction forces are given in Herzog (1985). The regularity of support force portion on raw data is shown in Fig. 7, left side. The graph represents calculated face support force percentage on raw data, which is represented by 100 per cent. The difference between the face support force (FS) and raw data (FTh total) comprises contact force CW (FCon), pulling force of backup-equipment (FP), frictional forces of thrust cylinders (FC,TJ) and shield friction force (FSh). In this case the average amount of these different components represents only approximately 24 per cent of raw data.

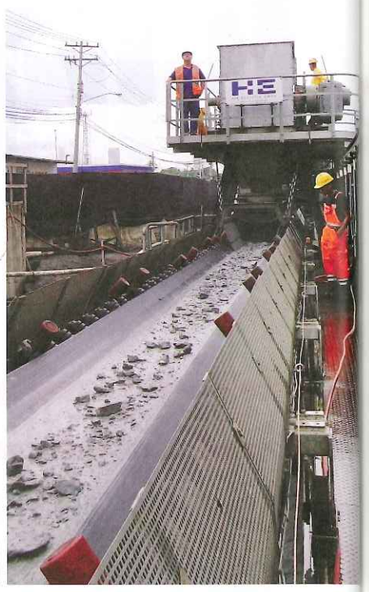
It was attempted to evaluate frictional forces of thrust cylinders from data of another project. Figure 8 shows two situations of cylinder movement during segment erection. In the first case, a pressure of approximately 1 bar (moving started at > 0.7 bar < 1.4 bar) was needed to push the cylinder forward. Calculating the resulting force leads to a value of approximately 7kN for one cylinder, or 392kN for all 56 cylinders.

In a second case, the necessary pressures are quite higher and range between 2.5 and 4.1 bar. Resulting friction forces show values of 23.3kN for one cylinder or approximately 1,300kN for all cylinders.

It has to be taken into account that measuring tolerances of ± 0.5 per cent FC of a sensor may affect such evaluations negatively (see subhead 'measurement and storage of data). Measuring accuracy may be too low to identify values of only a few bars, so that reliable calculations may not be possible. Additionally evaluations were hindered because in many cases idle







Supporting the first Metro Line in Panama.

Panama, Panama City. Central America's first metro network will be built in Panama City. The largest infrastructure project since the construction of the Panama Canal is scheduled to be completed in 2014, when line 1 will be opened to traffic. It will have a length of 13.7 km and will serve twelve stations. Line 1 will run from the "Albrook Bus Terminal" in the south to the "Los Andes Shopping Mall" in the north, passing through downtown Panama City. During this tunneling project, the challenge for H+E was to guide the tunnel conveyor system safely through the narrow S-curve. Booster stations solved this problem to the utmost satisfaction of our customers and made the project a success.

Technical data:

- Tunnel diameter: 8.70 m
- Conveyor length: 4,225 m/ 3,398 m
- Belt width: 1,000 mm
- Capacity: 1,200 t/h
- Installed power: 5 x 160 kW
  1 x 90 kW
  4 x 160 kW
- Belt storage capacity: 2 x 600 m
- TBM: EPB
- Installation: 2012

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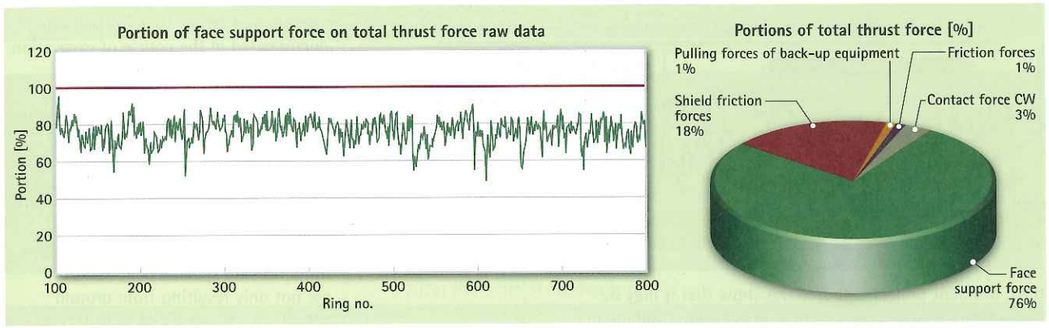
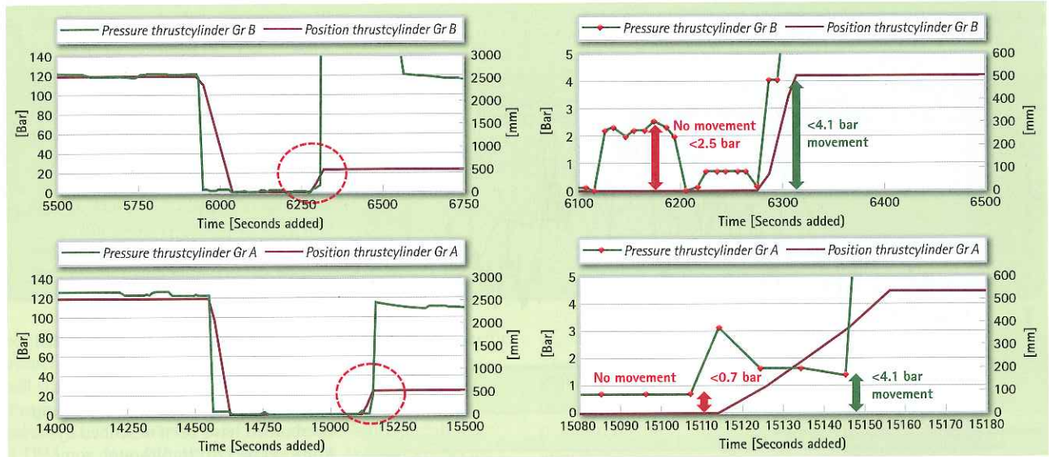




pressures increased from 0 to > 25 bars within the 10 seconds data logging intervals. For further evaluations, idle pressures of thrust cylinders had to be appraised. Values of about 1 or 2 bar seem to be realistic. Processing of total thrust force raw data (FTh total) was carried out for one project and the average portions of face support force (FS), friction force (FC,TJ), contact force CW (FCon), shield friction force (FSh) and pulling force of backup-equipment (FP) are summarised in figure 7 (right-side).

Above, top: Figure 7, Left side: portion of resulting face support force on total thrust force raw data; Right side: calculated average values for each component

Above, bottom: Figure 8, Movement of one thrust cylinder group during segment erection at two different stations

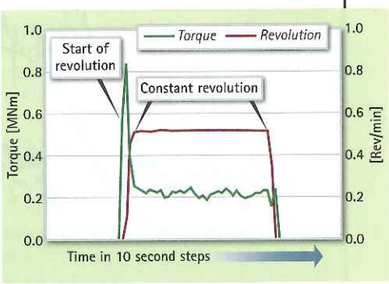
Right: Figure 9, Instantaneous values of torque on cutting wheel raw data [MNm] and speed of cutting wheel revolution [rev/min]

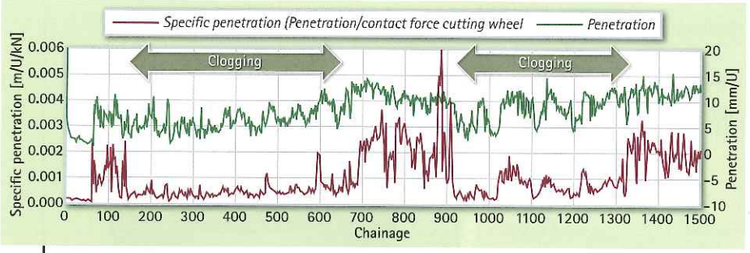
Torque on the cutting wheel

The effective idle torque of the cutting wheel was evaluated by analysing the instantaneous data of a hydro shield driven project. The cutting wheel was not in contact with the tunnel face and the excavation chamber was completely filled with slurry. As shown in figure 9 an initial torque was needed to start the revolution of the cutting wheel. To keep the revolution constant an effective idle torque of about 0.2 to 0.25MNm was necessary.

Related to subheaded section 'torque of cutting wheel' it has to be mentioned that additional influences on raw data such as clogging effects may occur. Continuous documentation at project site is required to consider those effects. Every project has its particular cutting wheel design and changing cutting wheel conditions like tool wear and clogging. An individual evaluation of those conditions is essential and the assumptions have to be checked in the course of construction. However, it seems to be questionable to achieve reliable values for the specific torque, resulting only from the contact between cutting tools and tunnel face. Only the evaluation of trends appears to be useful as long as influences of the cutting wheel state are considered as well.

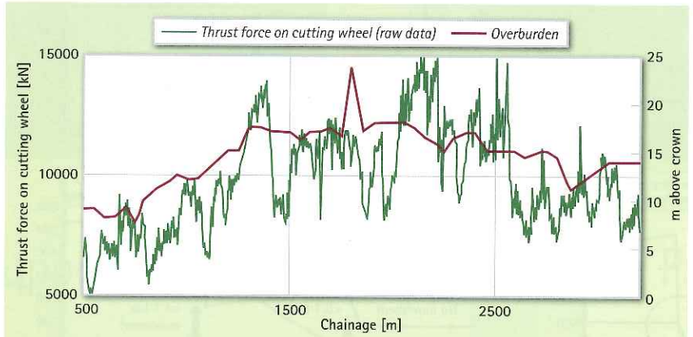
The relationship between specific penetration and rock mass conditions (uniaxial compressive strength UCS, discontinuity spacing) is well known for TBM projects in hard rock conditions and can be used even for advance rate estimations (Alber, 1996). Therefore the use of specific penetration values for analysing shield driven tunnel projects is not a reinvention. Processing of penetration raw data is not a splitting of different components but a combination of an active and a passive parameter. Related to evaluations of

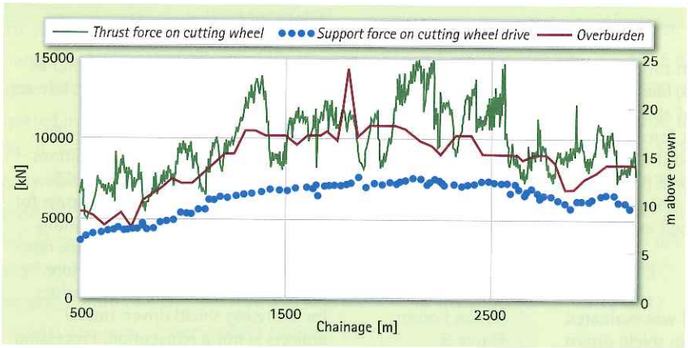


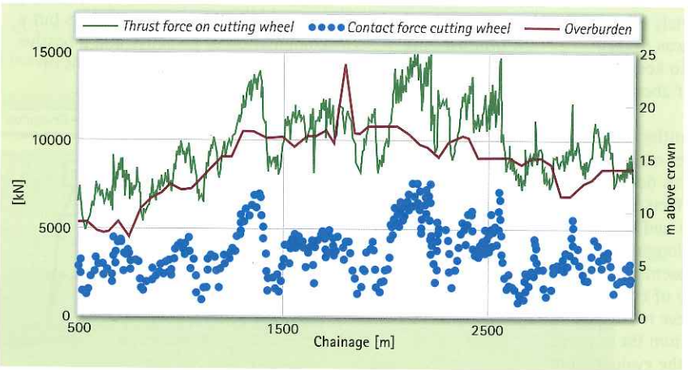


three different projects the findings show that it may be much easier to use specific penetration as one combined parameter as analysing two or more parameters separately (e.g. penetration, contact force CW and slurry density).

Data of a mix-shield project with heavy clogging are presented in figure 10. Clogging was documented in the course of excavation and correlates with the significant trends of specific penetration values. Specific penetration is much lower when heavy clogging was found whereas penetration raw data does not show relevant variations. Clogging may occur between cutting wheel and tunnel face, so that target values for penetration require more thrust force to be reached. Influences on specific penetration are not only resulting from ground conditions. Assumptions of tool wear and clogging have to be included and the significance and accuracy must be checked prior to such evaluations.







POTENTIAL MISINTERPRETATION

The importance of the data processing for analyses of subsoil-machine-interactions can be demonstrated by an illusory correlation between subsoil and TBM raw data. Without any processing and isolation of excavation-specific data components the raw data of thrust force on cutting wheel of a hydroshield drive in sandy gravels shows a correlation to the overburden (figure 11).

For sandy gravels higher degrees of the packing density with increasing overburden have been described by Köhler et al. (2012). Although some geological settings allow even very dense gravels at shallow depths (e.g. erosion of former overburden, preload by glaciers) it seems comprehensible to transfer the general relation between overburden and packing density of non-cohesive soils to the investigated project. Then a correlation between the packing density – as an indicator for the excavation resistance – and the thrust force on cutting wheel could be expected.

However, in the case of figure 11, the correlation between overburden and machine raw data of thrust force on cutting wheel is not depending on the depth of the drive below the surface. More likely it is a function of the face support pressure which was set by the operator in reaction to varying groundwater- and earthpressure. For that reason, a very close connection between overburden and the excavation-independent data component of face support force, being the major component of raw data, is obvious. Instead, in the chosen example the contact force CW, as the excavation-specific data component with only little influence on raw data, shows little or no correlation with the overburden at all (figure 13). Local variations of

Table 2. Suggested work flow for future projects

Before the start of excavation
Calibration and check of all sensors measuring excavation relevant parameters (linearity and zero shift for AD conversion) *
Determination of idle torque by cutting wheel rotation without face contact for every single excavation mode Idle torque without support media = open mode of TBMs
Determination** of internal friction forces within the main bearing of cutting wheel and hydraulic cylinders by moving the cutting wheel forward and backward
Visualisation of excavation-specific data components in operator's cabin as an additional tool for excavation survey
After the start of excavation
Check of all sensors measuring excavation relevant parameters at regular intervals and recalibration if needed (linearity and zero shift for AD conversion)
Determination of idle torque by cutting wheel rotation without face contact for every single excavation mode Idle torque in support media = hydro-mode or EPB-mode Idle torque in semi-filled excavation chamber support media/compressed air = semi-filled mode of Hydro- and EPB shields
Regular checks** of determined values for internal friction forces within the main bearing of cutting wheel and hydraulic cylinders by moving the cutting wheel forward and backward
Regular checks ** of determined values for internal friction forces within the thrust cylinders by moving each singe cylinder group forward and backward (idle pressures)

** Adequate dimension of sensors has to be considered in course of TBM development*
*** Logging frequency should be raised for determination and check of internal friction forces*

Source: Authors

contact force CW are probably forced by the excavation-specific influences. Additional to several other factors these changes will surely be triggered by variations of packing density. The illusory correlation in this case shows how easy analyses of subsoil-machine-interactions could cause misinterpretations, if TBM raw data without extraction of the excavation-specific components will be used.

SUGGESTIONS FOR TUNNELLING PRACTICE

In this paper, options and limits of processing and analyzing of machine data were demonstrated. Parameters acting on cutting wheel and shield movement were observed. It was shown that the relevance of automatically generated raw data without further processing is very limited for interpretations of soil conditions or even be particularly misleading. Various influences on TBM raw data are shown in figure 14.

Raw data may be split into different components. Excavation-specific data components (influences of soil conditions and cutting wheel state) in many cases show only little portions on raw data, whereas excavation-independent data components like face support force or friction force show major influences. Thus, it is recommended to separate excavation-specific data components as accurately as possible. Although theoretical approaches are given, subsequent evaluation of significant values is difficult because of very alternating conditions in the course of shield driven projects.

Measuring errors may occur as a result of strong vibrations, temperature and moisture deviations in addition to large cable length, influencing complicated measurement setups. Frictional forces may change in course of construction as a result of wear effects and entry of fines (mud, dust, clogging). Thus, the significance of processed data is influenced negatively and subsequent estimations, or even corrections can barely be realised. Despite this persistent inaccuracy, processing of raw TBM data is very useful, because soil conditions will show larger influence on excavation-specific data components as on the raw data. Variations of machine data may be promptly

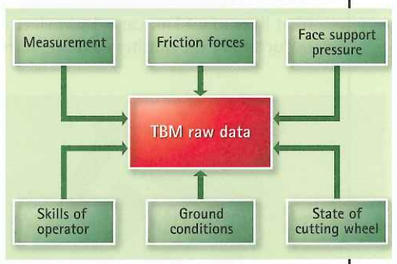
Opposite from top: Figure 10, Significant deviation between penetration raw data and specific penetration

Figure 11, Gravel dominated section with correlation of thrust force on cutter wheel raw data and overburden

Figure 12, Correlation between overburden and support force on cutter wheel drive

Figure 13, No correlation between overburden und contact force CW

Right: Figure 14, Various influences on TBM raw data sets in mechanised tunneling projects



detected as a result of technical or excavation-specific reasons on the one hand. On the other hand, little variations of excavation-specific data components will not lead to any variation of raw data. Continuous observation of the excavation-specific data components may form the chance to recognise critical influences (e.g. clogging) much earlier. For future TBM projects, suggestions are offered in Table 2.

It is strongly recommended to use excavation-specific data components for all kinds of analysis focusing on the interaction of machine data and ground conditions. After identification of technical and human influences it has to be regarded that excavation-specific data components are influenced by ground conditions and state of cutting wheel as well. Cutting wheel design has to be taken into account when comparing different projects. Influences of tool wear and clogging have to be regarded on every project. For exact determination

WTC 2014

The **World Tunnel Congress** heads to Brazil's Foz do Iguacu this year, and hopes to showcase an industry waking up from a long period of sleepy growth to match the demands of metropolises and global sports events

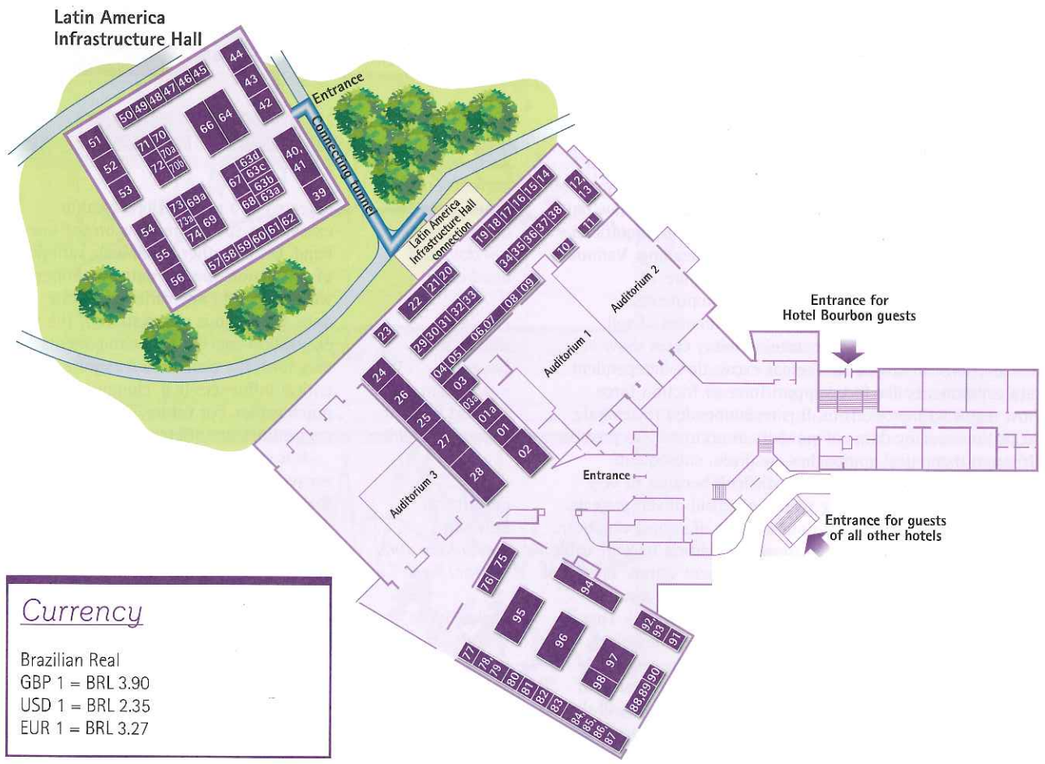
WTC 2014

Foz do Iguacu, Brazil
Bourbon Cataratas Convention & Spa Resort
12–14 May (exhibition)
www.wtc2014.com.br

BRAZIL IS experiencing a moment of huge growth that began 10 years ago. It is estimated that this sustainable growth will continue during this decade. Not even the recent financial crisis, which affected the whole world, was able to prevent this progress. Brazil dealt with the crisis and stayed on its course of development. In the main cities, the subway lines are undergoing expansion projects, especially in São Paulo and Rio de Janeiro. São Paulo, Brazil's main city plans to have a 200km long subway by 2018 – which means tripling current lines of 74 km. Large hydroelectric plants are under construction in the northern region. In the Northeast, other important construction projects are under way, such as the transposition of the waters of the São Francisco River.

Being the venue for two forthcoming internationally relevant sporting events, the FIFA World Cup in 2014 and the Olympic Games in 2016, provides additional motivation for Brazil to grow, involving as it does the construction of soccer stadiums, roads, ports and airports.

Against this backdrop of optimism, Brazil will host the World Tunnel Congress 2014 (WTC 2014), organized by the Brazilian Tunnelling Committee (CBT) of the ABMS (Brazilian Association of Soil Mechanics and Geo Engineering)



Currency

Brazilian Real
GBP 1 = BRL 3.90
USD 1 = BRL 2.35
EUR 1 = BRL 3.27

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Asserc Representações e Comércio Ltda.	14/15/16/17
Atlas Copco Atlas Copco Underground Rock Excavation is a division within Atlas Copco's Mining and Rock Excavation Technique business area. It develops, manufactures, and markets a wide range of tunneling and mining equipment for various underground applications worldwide.	52
Babendererde Engineers Babendererde Engineers is a worldwide engineering and consulting company specializing in underground works.	80
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Bekaert NV Bekaert is a world market and technology leader in steel wire transformation and coatings.	88/89
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Norberto Odebrecht A global organization of Brazilian origin, Odebrecht maintains an unwavering commitment to ensuring its Clients' satisfaction, generating value for Shareholders, developing the Communities where it is present, and ensuring its Members' personal and professional fulfillment.	96
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Geoconsult Holding 2T GmbH Geoconsult is an independent engineering & consultancy group serving private enterprises and governments around the world. The company provides services in the disciplines of civil, structural and geotechnical engineering, soil and rock mechanics, geology, hydrology, hydrogeology, geodesy, geo information, environmental and mining engineering.	63a
Geocontrol do Brasil Geocontrol, S.A. is an engineering company established in 1982 which has participated in more than 342 tunnels with a total length exceeding 1,000km	21
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Maccaferri do Brasil Maccaferri and its sister company Elas Geotecnica offer specialist technical solutions to the global tunnelling industry from excavation to final lining.	24
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Palmieri SPA Founded almost 40 years ago in Italy, Palmieri has grown to become a truly international supplier of highly specialized and tailormade products and solutions for civil engineering companies.	
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Promat Internacional NV Promat is a market driven solution provider, a recognized business leader in high performance fire protection and Insulation. Promat is a dynamic part of Etex, a Belgian industrial group manufacturing and marketing high quality building materials and insulation systems.	91
Propex do Brasil Ltda. Propex is a global provider of fibers for the reinforcement of concrete in the construction, roads, flooring, mining and tunneling industries.	37
Putzmeister Ibérica	67
Rascor RASCOR boasts a near-50-year track record as a globally operating manufacturer of special products for the waterproofing of tunnel, foundation and geotechnical engineering works.	70a
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Subterra Ingeniería Limitada Subterra is a Latin American leading tunnel-engineering company. Our staff has considerable overseas experience (21 countries, 4 continents).	57
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The Robbins Company Robbins TBMs are customized to meet each project's unique specifications, and proven in the most difficult conditions. Our Earth Pressure Balance Machines (EPBs) have been designed for durability and longevity with a heavy-duty cutterhead and an operational life of 10,000 hours for use in the world's toughest tunnels.	75
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Trelleborg Ridderkerk BV Trelleborg is a global industrial group whose leading positions are based on advanced polymer technology and in-depth applications know-how.	90
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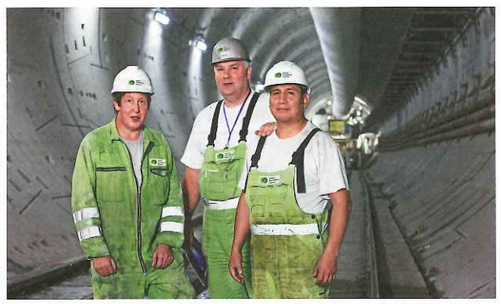

SURVEYING and MONITORING

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VENTILATION

What's on

2014

Samoter
8-11 May 2014
Verona, Italy
This trade show dedicated to earth moving, site and construction machinery is held every three years. In 2011, the exhibition attracted 98,000 visitors and more than 900 exhibitors (of which almost 30 per cent were international).
www.samoter.it

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

15th Australasian Tunnelling Conference
17-19 September 2014
Sydney, Australia
The 15th Australasian Tunnelling Society (ATS) Triennial Conference will be held in Australia's largest city, Sydney. This conference is the industry's opportunity to share in the knowledge, share project and application experiences and provide you the opportunity to hear what others have to say. Including case studies showing applications of new technologies in tunnelling.
www.atstunnellingconference2014.com

Intertunnel 2014
14-16 May 2014
Moscow, Russia
Intertunnel exhibitors come from all sectors of the tunnelling supply and services industries to present systems needed to construct, equip and operate tunnels and underground spaces. Topics covered will include: Tunnel construction equipment, materials and plant, microtunnelling and trenchless, fire protection, communications, security, pollution control and ventilation equipment, electrical and lighting.
www.intertunnelrussia.com

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

Tunnel Expo Turkey
28-31 August 2014
Istanbul, Turkey
The number of newly-excavated tunnels in Turkey is among the highest in the world, and in Istanbul, a great number of infrastructure tunnels are planned to be excavated soon, worth more than USD 10bn. Demos Faurcilik, in association with the Turkish Tunneling Society, is organising the third short course on tunnelling in Instabul, along with a tunnel technology fair.
www.demosfuar.com.tr

15th Australasian Tunnelling Conference
17-19 September 2014
Sydney, Australia
The Australasian Tunnelling Society's triennial conference, and registration is scheduled to open online this month.
www.atstunnellingconference2014.com

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

TAC 2014 Annual Conference
26-28 October 2014
Vancouver, British Columbia
The Tunnelling Association of Canada's Vancouver TAC 2014: Tunnelling in a Resource Driven World will include plenary presentations, technical sessions, and a trade exhibition all designed to highlight advancements in tunnelling research and practice from around the globe. This event will include TAC's Annual General Meeting and Awards at the Sheraton Wall Centre Hotel.
www.tac2014.ca

2015

Shotcrete conference and exhibition
29-30 January 2015
Tyrol, Austria
Wolfgang Kusterle and his team welcome you to the Conference and Exhibition Shotcrete 2015 at the Alpbach Conference Centre. Knowledge and experience do not help, if they remain hidden. This platform has gathered shotcrete specialists for 25 years, in a surrounding field where the exchange easily takes place.
www.spritzbeton-tagung.com

World Tunnel Congress 2015
22-28 May 2015
Dubrovnik, Croatia
The jewel of the tunnelling calendar heads to the Dalmatian Coast for the technical event of 2015 as WTC returns to Europe. Details to be confirmed.
www.wtc15.com

RETC
7-10 June 2015
New Orleans, Louisiana
The Underground Construction Association's biennel conferece.
www.smenet.org

British Tunnelling Society

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

C310 Thames Tunnel
15 May 2014
Riku Tauriainen, project director, Andreas Raedle, technical and risk manager, Andy Ingram, construction manager from the Hoctief Murphy JV discuss the geotechnical and tunnelling related specifics in urban tunnelling and river crossing with low overburden.

Harding Lecture
19 June 2014
The Harding Lecture is named after the founder Chairman of the Society, Sir Harold Harding and is given every second year. The lecture is given this year by Donald Lamont, with the title: 'Health and Safety in Tunnelling - Evolution and Revolution'

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