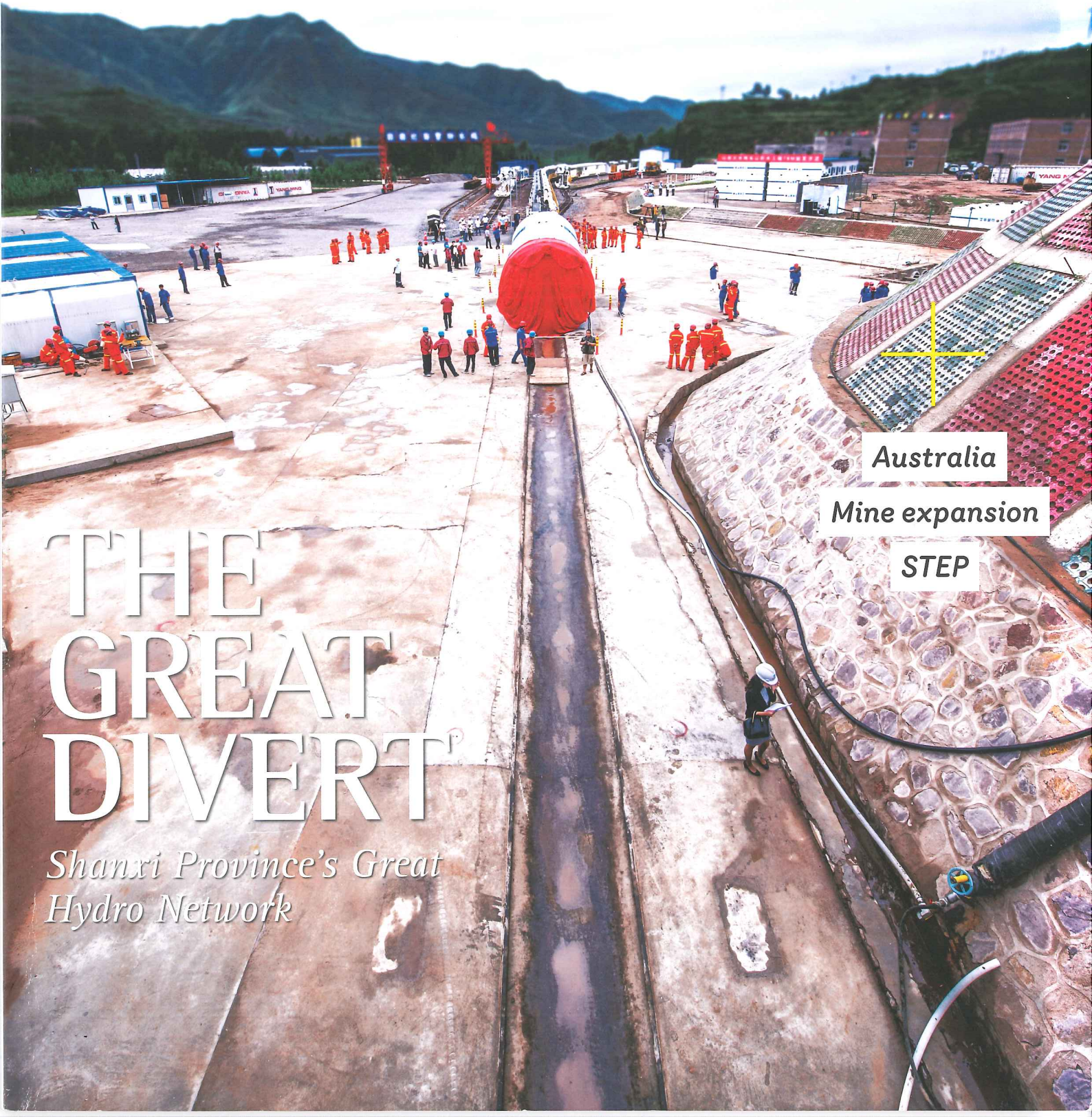
INTERNATIONAL EDITION
April 2016

Tunnels AND TUNNELLING



Australia

Mine expansion

STEP

THE GREAT DIVERT

Shanxi Province's Great Hydro Network

RISKS AHEAD

BAUMA IS RETURNING TO MUNICH this month. For those who have never been, Bauma is a construction and mining equipment trade fair held in the Bavarian capital once every three years. It is huge, with over 500,000m² of exhibition space, around 3,500 exhibitors and over 500,000 visitors from all over the world. It also enjoys a lot of public interest; local German parents can be seen showing their children around the equipment displays, having paid the USD 50 daily entrance fee.

Ahead of the event, the German Engineering Federation (VDMA), which represents German manufacturers, has assessed the industry based on its members' performance and market analysis. In summary, German manufacturers are doing well, but globally the market experienced a "double digit downturn".

Johann Sailer, chair of the Construction Equipment and Building Material Association within the VDMA said: "German companies were not as much affected by the severe downturns, e.g. in China, Latin America and Russia. Instead, we participated in the above-average positive developments of the European, Middle East, and North American markets."

Prospects for 2016, however, are mixed according to the association. Construction equipment manufacturers are "expecting positive stimuli for their business in Southern and Central Eastern Europe and believe that the high-volume markets of Germany, UK, Scandinavia and Benelux will remain robust. Internationally, it is particularly the Indian market that is giving rise to hopes".

The problems, according to VDMA, come from the risk present in the global market. Political conflicts and violence, excessively low prices for oil and raw materials, as well as several regional unresolved economic crises are worrying.

Every region is affected differently. Russia is expected to continue at a very low ebb, Latin America and China will not dazzle the world with growth, and North America and the Middle East are expected to become a little disappointing.

VDMA hopes that the industry as a whole will experience three per cent growth, but because of wildly varying regional circumstances, individual companies are also expected to have wildly different experiences of the coming year. Although Bauma is a positive, says Sailer.

The VDMA signs off its pre-Bauma analysis by taking aim at the ongoing European political debate on exhaust emissions.

"A major backlash can be expected," a spokesman stated. "According to the latest plans drawn up by Berlin's Senate Department for Urban Development and the Environment, all construction equipment will need to be colour-coded to indicate its emission level. This is already being done for cars. When applied to construction equipment, however, the new regulations are threatening to put a stop to any modernisation. Machinery equipped with extremely complex and expensive exhaust emission after-treatment will be but in a worse position than ancient, inefficient machines retrofitted with diesel particle filters (DPFs) which only achieve good values when it comes to particulate emissions.

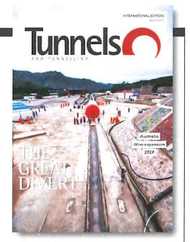
"Berlin is thus threatening to play an environmental prank, as the pollution caused by such outmoded machinery is several times higher. Moreover, it is twice as noisy, uses about 15 per cent more fuel and emits over 90 per cent more nitrogen oxides"

editor@tunnelsonline.info

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

Alex Conacher
Editor

Cover
This issue's front cover shows one of the TBMs lined up and ready to bore the Great Hydro Network in Shanxi, China



Next issue
In the next issue of Tunnels and Tunnelling we have a country spotlight on Turkey, which has a booming tunnelling industry and an industry society growing "like a bullet from a gun" as described by its chairman, Nuh Bilgin.

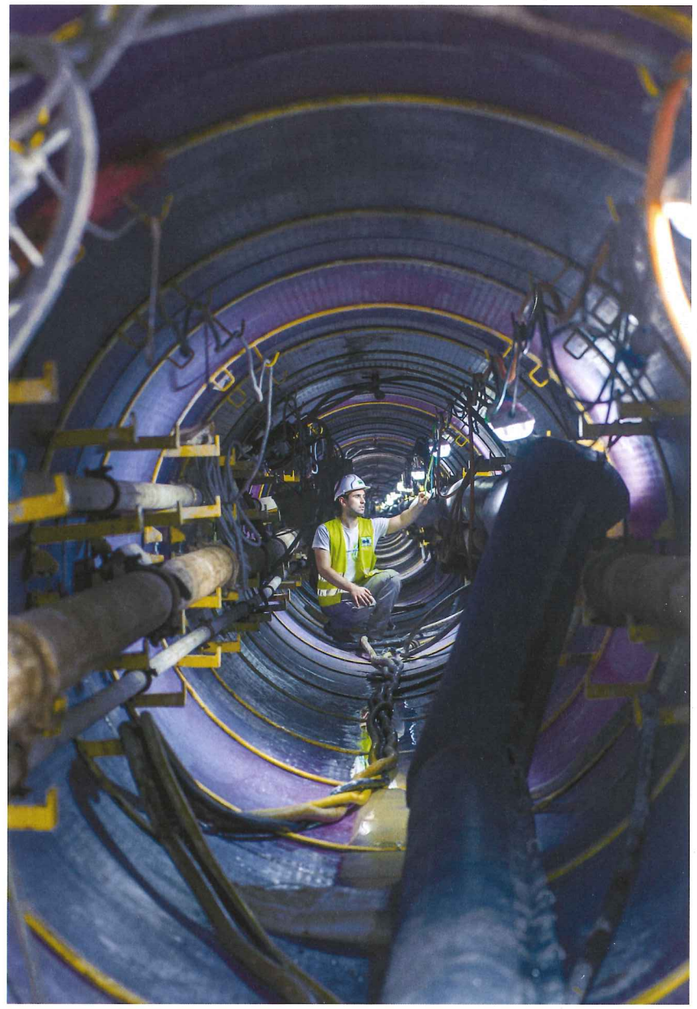
This month...

5 YEARS AGO

Excavation of the Gotthard Base Tunnel was completed earlier last month. Five months on from the final breakthrough of the eastern drive, workers finished excavating the last metres of the west tube between Faido and Sedrun. Breakthrough into the Sedrun section on 23 March by the Faido- launched TBM marked the end of excavations on the world's longest transport tunnel, a continuous bore of over 57km. Construction on this section of Gotthard began in 2001 in the south at Bodio. Pre-work began in 1996, and included access tunnels and 800m-deep shafts.
Tunnels and Tunnelling, April 2011, p.5

10 YEARS AGO

The world's largest operating TBM, a 15.2m-diameter Herrenknecht giant, should be joined by a second mammoth 15.2m diameter TBM to be used on Madrid's M-30 south bypass project in Spain. This second EPB machine, manufactured instead by MHI- Duro Felguera will be used by the FCC and Dragados JV to bore the 3.65km long south tunnel for the scheme. On 21 February, Madrid's mayor, Alberto Ruiz Gallardón, visited the site with representatives of the project's promoters, Madrid Calle 30, to view progress on the machine assembly, prior to commissioning in March. Mitsubishi Heavy Industries (MHI) and Duro Felguera formed MHI-Duro Felguera in 2003 to carry out "engineering, design and manufacture of TBMs.
Tunnels and Tunnelling, April 2006, p.6



Above: A report on Abu Dhabi's Strategic Tunnel Enhancement Programme (STEP). Page 56

Key people in this issue

SHAHZAD ORAKZAI
Shahzad Orakzai is the Programme Management Department Manager at Abu Dhabi Sewerage Services Company (ADSSC). He is a civil engineer with Masters in Business Administration and currently undergoing his doctoral studies in business administration.

CAROLA EDVARDSEN
Carola Edvardsen is responsible for Cowi's activities within concrete durability technology and service life design for new structures in general, and bridges, tunnels and marine structures in particular. She has concentrated on combining durability technology of concrete structures with the design of reliable new structures worldwide

MIRKO MARTINI
Mirko Martini works as Technical Manager for Salini Impregilo. He is a Chartered Member of the ICE. He has a MEng in Tunnels and TBMs. Mirko has been working in the Middle East for the last few years.

QATAR RAIL CELEBRATES DOHA RED LINE NORTHERN SECTION SUCCESS

QATAR — Excavation has been completed on the northern section of the Doha Red Line. The final TBM breakthrough was on a section of tunnel between Legtaifiya Station and Qatar University (QU) in late March. The location is a point at which the rail transfers from tunnel to an elevated section.

Qatar Rail reported that overall progress was moving ahead well, with over 85 per cent of tunneling for the Doha Metro project finished and overall project completion reaching 37 per cent. Some 37 stations are also under construction with 17 at the stage where the concrete roof slab is being cast.

Tunnelling on the Red Line began in July 2014. It stretches for 41km from Al Wakra in the south through to Lusail. The USD 2bn northern section was awarded to the ISG JV of Impregilo, SK, and Galfar Al Misnad. In addition to the tunnels, ISG is constructing the seven underground stations, but not the 11 other stations.

The first phase of the Doha Metro project is expected to be complete in the fourth quarter of 2019, while completion of the Lusail Tram is set for 2020.

By 2030, all the three networks – Doha Metro, Lusail Tram and the long-distance rail, which will link Qatar with the GCC Rail network – are expected to be complete. With the completion of the first phase of the Doha Metro and Lusail Tram, Qatar Rail expects to offer 600,000 passenger trips per day by 2021. By then, 37 metro stations are expected to be complete, with an average journey time of three minutes between adjacent stations.

Commenting on the breakthrough, Abdulla Al Subaie, managing director of Qatar Rail said: "We are particularly delighted by the progress on this section of the project as we and our colleagues in ISG have had to overcome some significant challenges. It is well know that one of our TBMs was flooded one year ago and the achievement today shows how effective our recovery operations were and that overall project progress was not affected.

"Across the project as a whole we are continuing to move to plan. Later this year we will be over halfway to delivering the whole project and tunneling, which is currently at 85%, is expected to finish in the Autumn. At that point, we move from construction into systems installation as track, power supply and signaling starts to be installed. We also start the architectural finishes of the stations."

Saad Al Muhannadi, Qatar Rail chief executive officer said, "Today is the first in a series of major milestones on the Doha Metro project over the next few months. Soon we will see the completion of tunneling on the Gold and Green Lines and later in the year our longest line – the Red Line will also finish its tunnels. All these events are opportunities to share our achievements with the public and we will be making the most of each occasion."

Barry Crouchman, project director for the ISG joint venture added, "We made our pledge to QRAIL to "Deliver Together" and "Right First Time" in February 2014. The combined efforts of the entire team, client, contractor and project manager, have resulted in the achievement which we celebrate today and is a shining example of what can be done when all parties unite in order to achieve a common goal. As we move into the second and final phase of the project, we are confident that the trust, professionalism and transparency that we have built between us will assist us in ensuring a similar success to the end of this immense project."

Salini Impregilo chief executive Pietro Salini offered his own take on the achievement: "We are the first group to finish excavation work on the Doha Metro and it's always a pleasure to be first, especially when it happens to be Italians who achieve it."

Officials inspect the Herrenknecht TBMs prior to the start of tunnelling

Bavarian Brewery pipeline installed by pipe ramming

GERMANY — Two 800mm steel pipes have been installed at a brewery in Bavaria, southern Germany. The project is intended to increase the production capacity of the Herzoglich Bayerisches Brauhaus Tegernsee brewery.

The pipes are to connect a new brewery site to the existing brewery production facility. The pipes will house beer pipes, nitrogen pipes, and also electric power lines.

Pipe ramming was selected to install the pipes underneath 11m of existing building, and a Koloss rig from German pipe installation specialist Tracto-Technik was supplied to the job.

Before ramming could begin, building foundations had to be chiselled out to a depth of 2 meters using a hydraulic hammer. Then the 6m long steel pipes were positioned and aligned.

Then the foundation area around the pipe was refilled with gravel concrete, securing the outer wall of the building and preventing the house walls from crumbling due to ground vibration during the pipe driving process. To make pipe jacking through the gravel concrete possible at all, the pipes were also bubble wrapped.

The geology was sandy and gravelly boulder clay, some 12m³ of which needed to be cleaned out of the pipes with a suction excavator after the job was complete.

BREAKTHROUGH ON CHENNAI METRO

INDIA — The second drive on Lot UAA-01 of the Chennai Metro was completed as the TBM reached daylight. The 1km-long twin tunnels formed part of the city's Line One, running from Washermanpet to Chennai International Airport.

Contractor Afcons Infrastructure had to contend with difficult ground conditions that included sections of 150MPa granite, as well as sand, silt, and clay with boulders up to 300mm in diameter. The 6.65m-diameter Robbins TBM was launched from a 28m-deep shaft for this second drive in February 2015.

The machine broke through into a reception shaft, emerging under water. Allegedly the first breakthrough in India under wet conditions. The reception shaft was filled with Bentonite slurry 10m from the base slab in order to prevent water entry from outside the diaphragm wall.

A spokesperson for the manufacturer said: "The design utilised a combination of 17-inch diameter disc cutters as well as soft ground tools. Small grippers located around the circumference of the machine's shield allowed for cutterhead stabilisation in harder ground, while additionally reacting the forces needed to pull the cutterhead back from the face in difficult conditions."

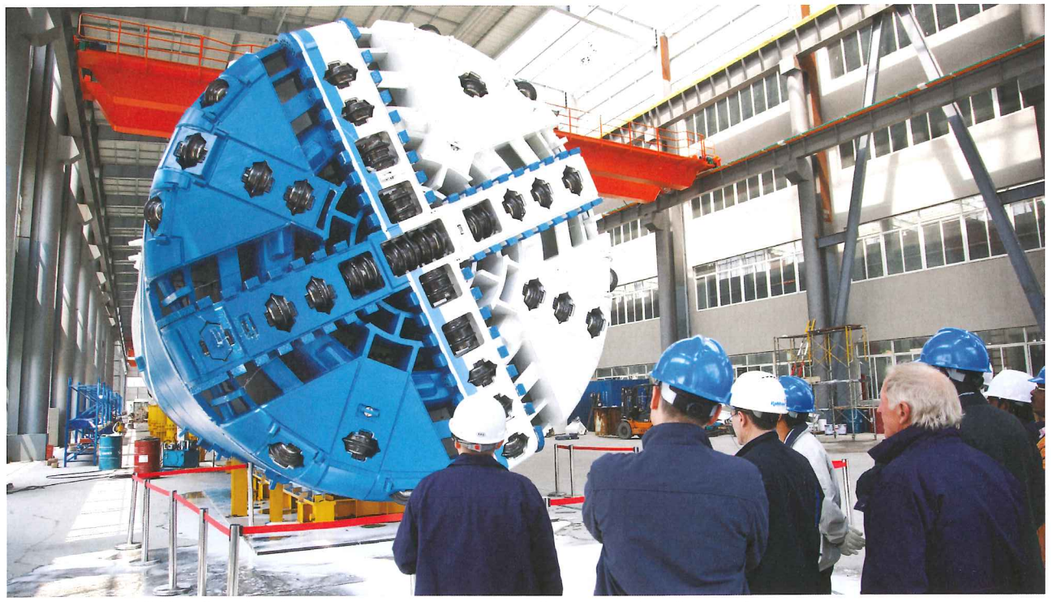
Unexpectedly hard rock conditions caused high cutter consumption rates and slowed the advance.

To contend with this a geologist was appointed to carry out face mapping for the entire first drive, in both hyperbaric and open mode conditions on a daily basis to calculate optimal operating parameters.

Gopal Dey, senior manager for Afcons said: "We are really proud of our executing team, who have maintained a high standard of quality.

"We didn't record any water leakage or settlement at the surface, and we have demonstrated a high standard of safety in the tunnel during construction."

Line One of the Chennai Metro is a 32.1km-long route with 14.3km underground and a total of 17 stations.



Chennai Metro TBM undergoing factory acceptance tests as well as inspections by the client

Singapore awards four in one integrated depot contract...

SINGAPORE — GS Engineering and Construction Corporation will build the world's first 'four-in-one depot'. The Land Transport Authority (LTA) awarded the SGD 1.99bn (USD 1.45bn) contract for the depot and its reception tunnels to the Korean contractor in late March.

The East Coast Integrated Depot will stack the train depots for the East-West Line, the Downtown Line and the Thomson – East Coast Line, and a bus depot, within a 36ha (360,000sq.m) site. The structure will be capable of housing 220 trains and 550 buses. The integration saves Singapore, a state where space is limited, some 44ha (440,000sq.m).

Construction of the depot is expected to begin in Q2 2016 and complete in 2024.

...and three new station construction contracts

SINGAPORE — In addition to the integrated depot, the LTA awarded contracts for the Siglap and Bayshore Thomson-East Coast Line stations, and Xilin station on the Downtown Line Three Extension. The three station contracts were valued at SGD 1.31bn (USD 960M) in total.

Siglap station was awarded to a John Holland – Zhen Hua joint venture for SGD 176M (USD 128.3M). Both companies are subsidiaries of the China Communication Construction Company (CCCC).

A joint venture of Who Hup and Shanghai Tunnel Engineering Co will construct Bayshore station and its associated tunnels. The contract value was SGD 296M (USD 215.71M).

Both stations will additionally serve as civil defence shelters. They are scheduled to start construction in Q2 2016 and are scheduled to complete in 2023.

Xilin station and its associated tunnels, as well as tunnels to the integrated depot were awarded to Samsung C&T Corporation for SGD 834M (USD 607.8M) Construction is due to start in Q2 2016 and finish in 2024.

UNIVERSITY LINK PROJECT OPENS

USA — Sound Transit opened its University Link light rail extension on 19 March, adding mobility to some of Washington state's most congested areas. The University Link project is in operation six months ahead of schedule and about USD 200M on under its USD 1.9bn budget, Sound Transit announced. University Link connects with the existing light rail line between SeaTac and downtown Seattle

"Today, we celebrate an historic achievement – delivering new high-capacity light rail that will transform transportation in our region for the next century," said Sound Transit Board Chair and King County Executive Dow Constantine.

The University Link extension is estimated to nearly double weekday ridership on the existing light rail line to more than 70,000 riders on weekdays by 2020.

Building the LRT project included about 4.6km of tunnels, bid as two contracts for twin bore tunnels of 6.4m excavated diameter: U-220, awarded to a joint venture of Traylor Brothers/ Frontier-Kemper (TFK), and U-230 awarded to a joint venture of Jay Dee/Coluccio/Michels (JCM).

Consultants on the project included construction management by firms CH2M and Jacobs Engineering (START); final design by MacMillen Jacobs, Aecom and HNTB (Northlink Transit Partners); as well as Hatch Mott MacDonald and LTK Consulting Services.

TBM prepared for factory acceptance prior to the successful project. The University Link opened on 19 March six months ahead of schedule and USD 200M under budget

Sika opens new plant in Canada

CANADA — Sika has opened a mortars and concrete admixtures plant in Vancouver. It will serve the Pacific Northwest including major cities such as Vancouver, Seattle and Portland.

Christoph Ganz, Sika regional manager for North America said: "Local production will be very beneficial to customers in the region by providing improved product availability, reduced lead times and faster deliveries. Moreover, eliminating the cost of shipping products from our Edmonton and Montreal plants and using locally sourced raw materials will enable us to optimise our cost structure."

The new facility in Vancouver includes a modular mortar plant and blending equipment for the production of a wide range of concrete admixtures.

In addition to the production area, the new building also houses a quality control laboratory, a warehouse and office space for administrative and sales personnel.

Ribbon-cutting ceremony at Sika's new plant

Chris Dulake joins Mott MacDonald

GREAT BRITAIN — Mott MacDonald has appointed Chris Dulake as major projects portfolio director. Dulake is due to join the company in May and will be involved with customer engagement and "positioning Mott MacDonald for major United Kingdom and international infrastructure projects".

A spokesperson for Mott MacDonald said: "Chris has nearly 30 years' experience as a civil engineer and has worked on major infrastructure projects around the world. He joins Mott MacDonald from HS2, where he was engineering director for Phase One. Prior to this he spent seven years as chief engineer on the Crossrail project. During this time he was the single point of engineering technical authority for the programme, providing technical leadership to deliver a world-class level of performance."

Mike Haigh, Mott MacDonald board director, said: "Chris is a fantastic appointment for us as he has great insight into the priorities for clients undertaking major infrastructure projects. He will be a hugely valuable resource for our staff due to his vast experience and our clients can only benefit from his knowledge to help realise their project ambitions."

Mott MacDonald stated that it had told HS2 that Chris would not be involved in HS2's current procurement processes.

The spokesperson added: "Mott MacDonald is involved in some of the world's most recognised major infrastructure projects, such as Crossrail, HS2, London Power Tunnels and Thames Tideway in the UK, Alaskan Way Viaduct [replacement] and East Side Access in the United States, Hong Kong International Airport third runway, HKZM link, Africa's giant 7,000km Mwambani Rail Corridor and the Tarbela Dam hydropower expansion in Pakistan. Chris will be engaged across all of the sectors and regions Mott MacDonald operates and will significantly strengthen the company's service offering on major projects."

EGLINTON LRT STATION GROUNDBREAKING

CANADA — The Eglinton Crosstown light rail project broke ground on its first of 25 stations, Keelesdale Station, on 10 March, the Province of Ontario announced.

"We are making considerable progress on the Eglinton Crosstown LRT line," said Steven Del Duca, minister of transportation.

"The start of construction of the Keelesdale station is an important milestone and further proof of our government's commitment to provide accessible, modern transit infrastructure that will reduce commute times, create jobs and improve the quality of life for Ontarians."

Keelesdale Station is one of the underground stations on the 19km line, and located at the intersection of Keele Street, Trethewey Drive, and Eglinton Avenue West.

A total of four TBMs are employed on the project, which requires 5.75m diameter tunnels.

Crosstown Transit Constructors, a joint venture of Obayashi Canada, Kenny Construction, Kenaidan Contracting and Technicore Underground, won the contract to build the 6.2km tunnel in 2012. A second contract, awarded to an Aecon-Dragados Joint Venture, are constructing approximately 3.25km of twin tunnels using the other two TBMs.

The Eglinton Crosstown LRT is the largest public transit project currently under construction in Canada and represents the single biggest expansion of urban rapid transit in the Greater Toronto and Hamilton Area in more than half a century, according to the Province.

Premier Kathleen Wynne attended the ground-breaking ceremony to celebrate the station groundbreaking.

The province has invested CAD 5.3bn (USD 4.25bn) toward the capital costs of the LRT line, which is expected to begin service in 2021.

Metrolinx and Infrastructure Ontario are working together to deliver the Crosstown, which will remain publicly owned and controlled.

The new LRT line will have 25 stations and stops along Eglinton Avenue between Weston Road and Kennedy Station, and will also link to 54 bus routes, three TTC interchange subway stations and GO Transit. The Crosstown project costs approximately CAD 5.3bn (USD 4.25bn) in 2010 dollars.

"We are excited to move into this next phase of the Eglinton Crosstown LRT project - building the stations and stops, track and signal infrastructure and maintenance and storage facility to support the line," said Bruce McCuaig, president and CEO of Metrolinx.

"The Crosstown is one of Metrolinx's key projects that will transform the way Toronto and the region moves with a fast, convenient and integrated transit network."

The first of the Eglinton Crosstown stations broke ground in March

Closure joint formwork installed on Coatzacoalcos tunnel

MEXICO — The closure joint formwork for the Coatzacoalcos immersed tube tunnel has been successfully installed.

The tunnel is the first immersed tube in Latin America and connects the city of Coatzacoalcos and the petrochemical industry town of Allende across a river in the state of Vera Cruz.

The closure joint was emptied and bulkheads were opened in a 45-minute operation by the Marine Joint Venture which comprises Volker Construction International and Dragamex (Boskalis).

The road tunnel runs for a total length of 1,200m with a 690m stretch below the riverbed.

The submarine section is formed of five precast concrete elements that measure 138m-long, 25m-wide and 9.2m-high. Casting took place in specially constructed basin in a dry dock positioned adjacent to the alignment.

The elements were then floated out of the dock on a specially constructed Volker modular catamaran.

The company said the advantage of this was that it could easily expand or reduce its capacity, and was very stable when lowering the pieces to the prepared gravel bed.

Locking fill was applied to anchor the elements in place, and then rock protection was provided.

After this a six-month period to allow for initial settlement of the elements took place before construction of the closure joint.

Tender and detailed design was provided by TEC.

The delivery consortium responsible for the project was Constructora Tunel de Coatzacoalcos (CTC).

Gaskets supplier expands offering

GREAT BRITAIN — Seals and gaskets supplier VIP has taken delivery of two new "C Frame" LWB Steinl presses which the company said would increase gasket jointing capacity and also facilitate the production of angled joints, which VIP notes are increasingly being required by gaskets for tunnel segments.

High Speed Two phase one delivery partner confirmed

GREAT BRITAIN — High Speed Two (HS2) confirmed the delivery partner for its first phase between London and Birmingham. The rail link will be delivered by a joint venture of CH2M, Atkins and Sener.

Engineers from the companies will be integrated within HS2 to provide engineering and construction management support, as well as assistance with preparations for the procurement of the main civil engineering contracts.

The ten-year contract covers the whole of Phase One construction, with the team focusing on a number of key functions, including:

- Supporting preparation for, and procurement of, the main civils contracts and subsequent work packages, including stations and railway systems
- Managing support of the design stage and construction stages of the works
- Providing project engineering and construction management
- Providing technical assurance of design

Jim Crawford, HS2 managing director for construction said: "Today's contract award marks an important milestone as we continue to move towards the start of construction in 2017.

It is vital that we constantly challenge our suppliers to ensure we deliver long-term value for money for the taxpayer as well as a world-class railway for all our passengers, stakeholders and communities along the line."

Dywidag sets out corporate structure

INTERNATIONAL — Effective from 1 March Dywidag Systems International (DSI)'s construction and underground businesses have been reorganised into two separate divisions on the market. DSI said Construction will continue to trade under "Dywidag Systems International" or "DSI" and keep its current company logo, the Underground business will use DSI Underground as a name.

Both divisions will be led by two fully dedicated CEOs: Patrik Nolåker, current CEO of DSI, will lead DSI Construction, whereas Michael Reich, current Chairman of DSI, will be the new CEO of DSI Underground. Nick Moses, current CFO of DSI, continues to act as CFO for the group and both divisions in a shared role. Central functions such as Legal, Finance, Treasury, Internal Audit and Marketing/Communication will be shared between the two divisions.The current DSI board of directors will not change and govern both DSI Underground and DSI Construction. A new Chairman of the board will be announced in due course, according to the company.

The split of DSI Group into two divisions follows the acquisition of Jennmar businesses in Europe, Latin America, Australia and China (50% of the shares). This acquisition is the largest in DSI's history and involves several countries and business locations.

A successful merger of Jennmar businesses into local DSI Underground businesses is a sensitive process and requires focus of the entire DSI Underground leadership team, including full dedication of the CEO.

DSI Construction will continue growing its Geotechnical, Post Tensioning and Concrete Accessories business in its current markets and beyond, led by a fully dedicated CEO and committed management team.

CRENSHAW/LAX TBM GOES UNDERGROUND

USA — The Los Angeles County Metropolitan Transportation Authority announced on 3 March a significant milestone occurred on the USD 2.058bn Crenshaw/LAX light rail line. The TBM, a 21.5ft Herrenknecht machine named after Harriet Tubman, an African-American abolitionist, humanitarian and reportedly a spy for the Union north during the American Civil War, was lowered in pieces to the bottom of the future Expo/Crenshaw Station.

Excavation of the southbound tunnel is expected to begin in late April or early May, moving south under Crenshaw Boulevard from Exposition Boulevard toward Leimert Park. This stretch of track will include three underground stations: Expo/Crenshaw, Martin Luther King, Jr. and Leimert Park.

Walsh-Shea Corridor Constructors is comprised of Walsh, Shea, HNTB, Comstock and Arup, and is using a 21.5ft (6.5m) diameter TBM for the project's twin 1-mile (1.6km) tunnels.

At Leimert Park the TBM will turn around to mine the northbound tunnel. In total the Crenshaw/LAX Line alignment is 8.5-miles (13.7km) long.

The TBM due to bore the Crenshaw/LAX light rail line was lowered in early March

FEHMARNBELT CLIENT ANNOUNCES PREFERRED BIDDERS

DENMARK/GERMANY — The preferred bidders for the Fehmarnbelt Fixed Link have been named. Client Femern said it had chosen a joint venture consisting of Vinci Construction Grands Projets, Per Aarsleff, Wayss & Freytag, Max Bögl, CFE, Bachy Solétance, BAM Infra, BAM International, Dredging International, and Cowi.

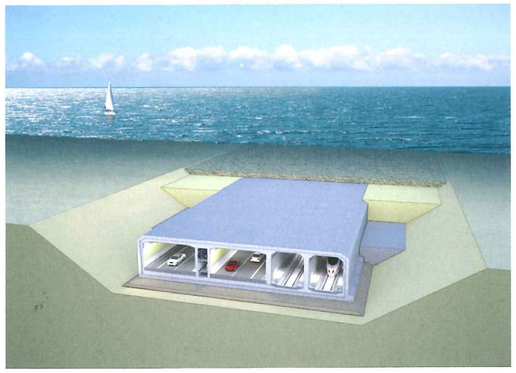
The aim is to sign conditional contracts in mid-May, on the understanding that binding contracts will be signed when the German construction permit is in place.

In Germany, even though the political decision for the project was taken in 2009, the process to give formal approval by the authorities in Schleswig-Holstein is still in progress.

The Danish Parliament approved the proposed Construction Act for the Fehmarn Belt fixed link road and railway tunnel in early summer 2015.

The Fehmarnbelt project aims to construct an 18km-long immersed tunnel between Denmark and Germany. Past estimates have put the project at USD 7.3bn. It will have two rail tubes and dual two-track road tubes separated by a service and escape corridor.

The Fehmarnbelt link is expected to minimise the travel time between Copenhagen and Hamburg by approximately 2.5 hours. Both the projects will be financed by users of the fixed link, Femern stated. The tunnel is expected to be open in 2021.



Early concept art from the Fehmarnbelt project

Repair work wraps up on Spirit Lake tunnel

USA — The U.S. Forest Service confirmed in early March repair work on the Spirit Lake Outlet Tunnel is complete.
Along with the U.S. Army Corps of Engineers, the agency awarded a contract repair the tunnel near Mount St. Helens on the Gifford Pinchot National Forest for USD 3M to Cat Works, LLC, last October. The Forest Service said "the repairs will address critical short-term needs while more sustainable long-term solutions are explored."

During the repair work contractors installed additional structural supports, restored the outlet tunnel's diameter and excavated the material that had seeped into the outlet tunnel's interior.

"Protecting downstream communities is our number one priority," said Jim Peña, regional forester. "These important repairs will reinforce the outlet tunnel's integrity and give us time to work with our partners to find a more viable solution for this geologically active area."

According the public affairs office of the Army Corps of Engineers, when Mount St. Helens erupted on 18 May 1980, a massive avalanche of rock and debris completely blocked the natural outlet where Spirit Lake flowed into the North Fork Toutle River and on into the Toutle, Cowlitz and Columbia rivers.

The avalanche created a dam of sediment, ash and fragmented rock, with heavier, less porous materials below and more erodible pumice and ash from pyroclastic flows above it. Snow and rain continued to feed Spirit Lake, but without an outlet, the water level rose closer to the more easily erodible material.

Concerns for floods lead to the construction of the Spirit Lake Outlet Tunnel, which was completed in 1985, and comprises a 40ft (12m) deep intake shaft connecting to an 8,465ft (2.6km) long, 11ft (3.4m) diameter tunnel. The Corps said since project completion, it has repaired the tunnel many times, mostly small repairs to "restore tunnel integrity."

In October 2014 a routine inspection revealed damage to the outlet tunnel lining, deposits of clay in the outlet tunnel's interior, and a 2.5ft (0.78m) reduction in outlet tunnel diameter due to the encroachment of surrounding rock. A subsequent inspection this spring revealed further damage and an additional half-foot reduction in outlet tunnel diameter.

CREG to supply Wuhan Metro slurry machine

CHINA — CTE has announced that the China Railway Engineering Group (CREG) has been awarded a contract to manufacture a slurry TBM for Lot Ten of Wuhan Metro's Line 6. The 6.5m-diameter TBM will excavate the Qinwu Running Tunnels with lengths of 1,732m and 1,691m.
The tunnels pass under the Han River for approximately 350m. The tunnels will have a finished internal diameter of 5,500mm.

CTE was established in 2013 solely to market TBMs manufactured by CREG (formally CREC-TBM) and to provide support to users of CREG TBMs in terms of field service and after sales activities.

A CTE spokesman added: "With the recent acquisition of Aker Wirth tunnel-boring and shaft-boring technology CTE are now in a position to offer the full range of EPB, Slurry and Hard Rock TBMs."

Sandvik Mining and Rock Technology formed

SWEDEN — Sandvik Mining and Sandvik Construction are set to merge into one business: Sandvik Mining and Rock Technology. The new structure will be effective as from 1 July 2016 and Lars Engström, currently president of Sandvik Mining has been appointed president of the new business area, Sandvik Mining and Rock Technology. Dinggui Gao, president of Sandvik Construction will leave the company on 1 July.

Björn Rosengren, Sandvik president and CEO added: "Products developed for the customer segments mining and construction are based on common technologies with a similar aftermarket offering. In addition, manufacturing units are already largely shared with [...] shared front line resources. By joining the operations into one business we achieve a leaner and more efficient structure."

Tunnelling Association of Canada sees rapid membership growth

CANADA — The Tunnelling Association of Canada's (TAC) ongoing effort to increase membership is showing excellent results with more than 400 individuals and firms expected to renew or join for the first time in 2016.

At the end of December 2015, the TAC active membership count was stated as 391, which included 50 corporate members, 293 private members, nine retired members and 39 student members. This reflects a year over year increase of 10.5 per cent from December 2014's member count of 354.

Brokk marks 40th anniversary this year

SWEDEN — Brokk, manufacturer of remote-controlled demolition machines, is celebrating 40 years in 2016. Brokk said it introduced its first demolition machine in 1976 to demolish a furnace at a lead smelting plant.

"It all started in 1976 when two entrepreneurs in Skelleftea, Sweden, faced a confined space demolition challenge that led them to develop the world's first demolition robot," the company said in a release.

For the past 40 years, Brokk has, by its own count, delivered about 7,000 demolition machines to more than 100 countries across the world.

"We are proud and excited to be celebrating 40 years of innovation in the remote-controlled demolition industry," said Peter Bigwood, vice president for sales and marketing for Brokk in North America.

"Our products have not only changed the nature of the demolition business, but they also improved the environmental and safety factors for contractors and operators worldwide."

Brokk said it will be celebrating the anniversary with a range of events and a preview of the new Brokk 120 Diesel, its smallest diesel-powered model offering.

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

editor@tunnelsonline.info

WASHINGTON DC METRO SHUT AFTER FIRE

USA — The Washington DC metro was shut down for 29 hours last month to perform emergency safety checks after an electrical tunnel fire. Workers inspected 600 jumper cables along all tunnel segments in the system following a tunnel fire yesterday. No one was injured.

The shutdown, which the operator called unprecedented, impacted all six lines and 91 stations. Inspections revealed 26 areas where damaged jumper cables and connector boots needed to be replaced.

Crews worked through the night to ensure repairs were made by the following morning.

The system's general manager and CEO Paul Wiedefeld said at the time of the shutdown: "While the risk to the public is very low, I cannot rule out a potential life safety issue here, and that is why we must take this action immediately. When I say safety is our highest priority, I mean it.

"That sometimes means making tough, unpopular decisions, and this is one of those times. I fully recognise the hardship this will cause.

"As a preliminary matter, the conditions appear disturbingly similar to those in the L'Enfant incident of a year ago, and our focus is squarely on mitigating any risk of a fire elsewhere on the system."

Illustrative photo of a Washington DC Metro station

Last year one person died and 83 people were hospitalised after a Washington metro tunnel filled with smoke.

After the shutdown, Metro released a statement on the works: "Metrorail service will resume [...] on a normal weekday schedule. However, if additional track repairs are needed, Metro will announce the areas that are in need of repair as soon as they are known.

"Beginning at midnight a team of electricians and cable construction crews walked through 100 miles of tunnel inspecting for defects in jumper cables, connecting boots that were damaged or improperly positioned, water infiltration, and debris that could burn near cables.

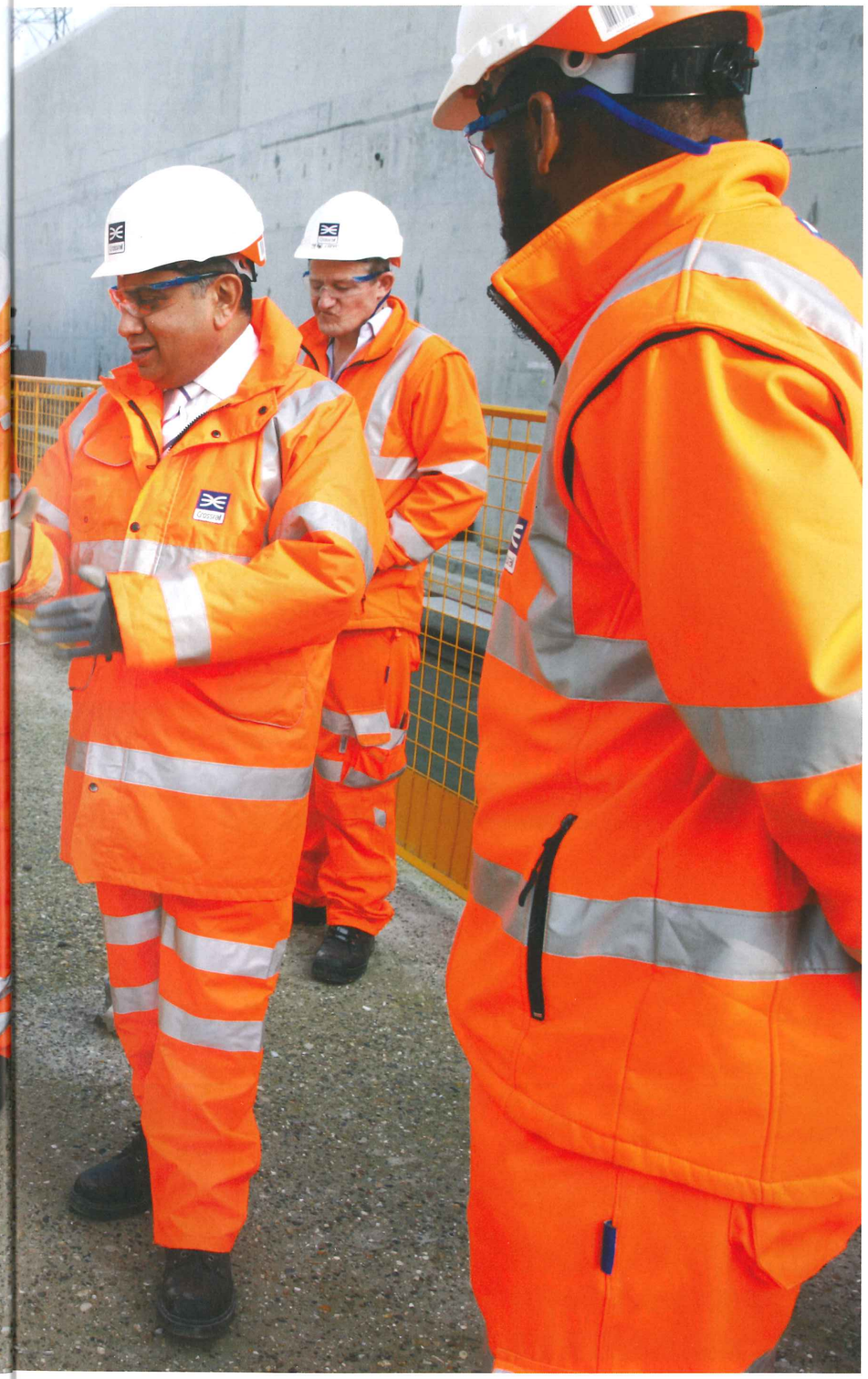
"Repairs that do not require immediate action will be scheduled after normal service hours.

"While these findings do not indicate that cable fires were imminent, these conditions are hazardous and increase the risk of fires on the tracks.

"Metro's Safety investigators are reviewing the history of the damaged boots and cables, and all findings will be shared with Federal Transit Administration (FTA) and National Transportation Safety Board (NTSB). Investigators will then review inspection records, age of materials and maintenance records to identify any procedures that were not followed or standards that were not met."

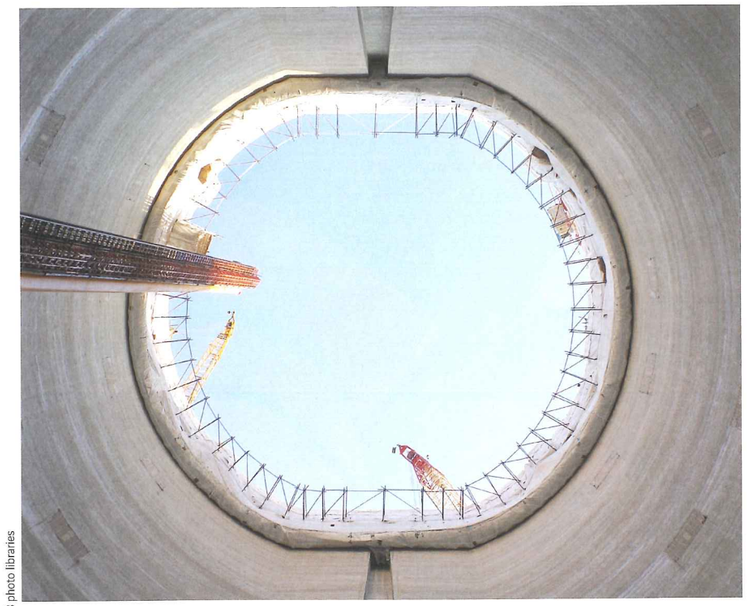
Prior to the resumption of services, Wiedefeld issued another statement: "I know that today presented a hardship for many throughout the region, but I want to emphasise that this shutdown was indeed necessary. I want to thank everyone for their patience and support in putting safety first."

"Throughout this intense inspection deployment, our focus has been on effectively mitigating fire risks," said Wiedefeld. "We are being as clear as we can about what actions we have taken so that customers and employees feel safe as they ride Metro."



Left: Transport Minister Lord Ahmad has visited the Crossrail project to see the progress that has been made to install the permanent track in the new rail tunnels.

Over 10km of track has been laid so far for the new railway which will be known as the Elizabeth line when services through central London commence in December 2018. The Transport Minister visited the new Custom House station site and the eastbound tunnel where he saw the recently laid track



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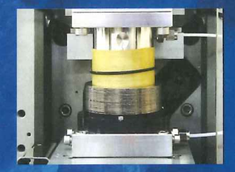

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WTC 2016

Registration is open for the worldwide tunnelling event of the year as it returns to North America. The Underground Construction Association of SME (UCA of SME) is hosting the 2016 World Tunnelling Congress (WTC) in San Francisco. Expect as many as 600 unique technical presentations, short courses and breakout sessions, and more than 200 exhibitors from around the world. Be sure to visit *Tunnels & Tunnelling* at Booth 1215

When and where

April 22-28
San Francisco
www.wtc2016.us

Exhibitors list

Exhibitor	*Booth*
ABC Industries, Inc	315
ABC Ventilation Systems	1207
Advanced Concrete Technologies	1115
Aecom	314
Aecom delivers integrated solutions to major tunnel projects, totaling more than 1,000 miles worldwide. Our experts are well versed in all methods of tunneling in every type of ground condition. Aecom connects knowledge and experience across our global network of experts to help clients solve their most complex challenges.	
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Arup	406
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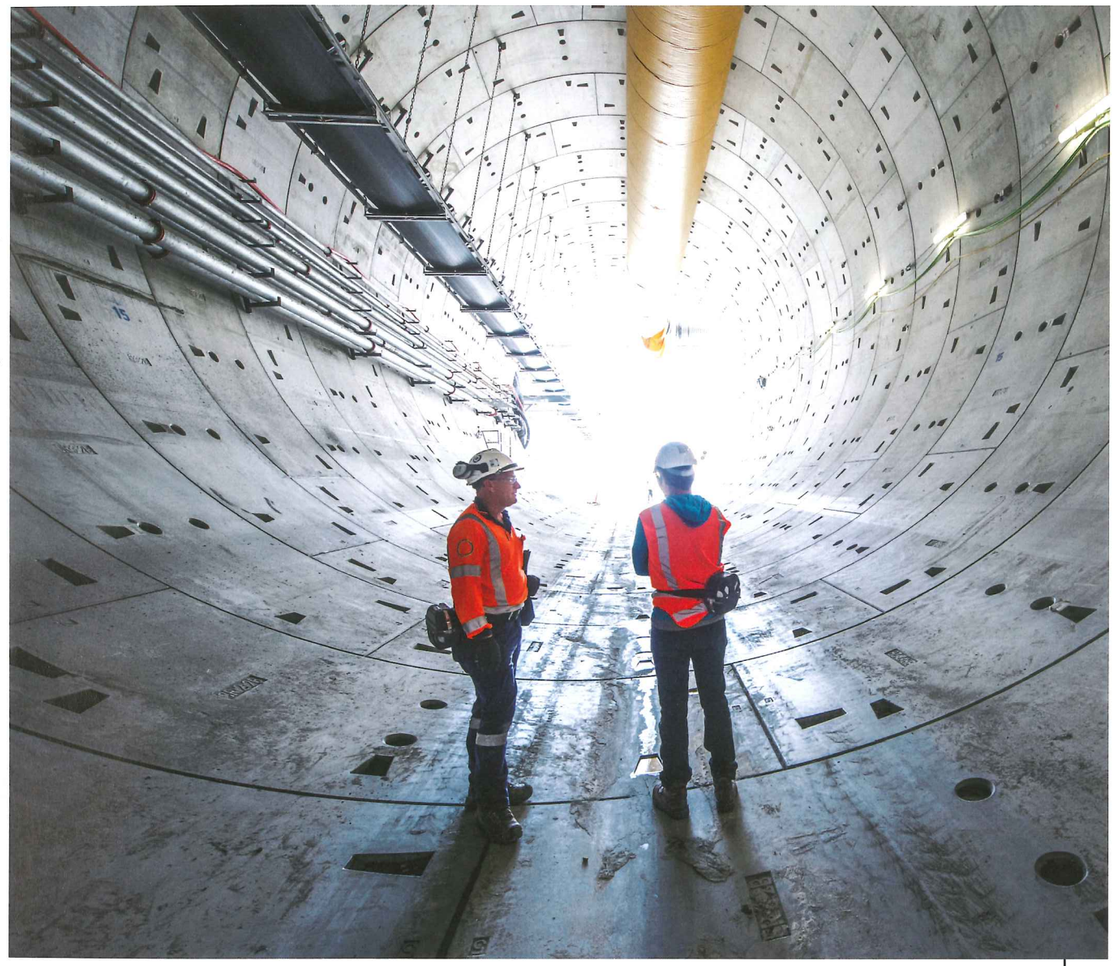


TUNNELLING DOWN UNDER

Transport infrastructure is providing ample opportunity for Australia's tunnelling industry. **Keren Fallwell** reports

TUNNELLING IN AUSTRALIA was given a real boost in 1997 when the Warren Centre published its Study on Underground Space.

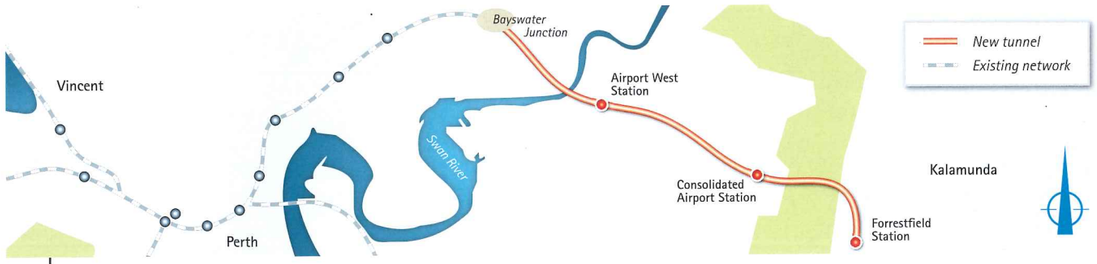
The thought leadership organisation outlined the benefits of the greater use of underground space for transport, utilities, warehouses, and even sports facilities. It also detailed the necessary planning, finance and geotechnical considerations, as well as the need for more research and development to improve the technology.

According to Malcolm Dixon, GHD's principal engineer – tunnelling, over the past five to 10 years there has been a steadier stream of major projects as the popularity and awareness of possible underground solutions for urban areas has increased.

***Above:** The Waterview Connection project. New Zealand and Australia share a tunnelling society*

"Client organisations are far more aware of available tunnelling techniques to provide underground solutions on their projects," he says, adding that representatives of client organisations are often seen at international tunnel

Keren Fallwell
Keren has joined the *Tunnels and Tunnelling* team as a contributing editor



conferences.

Many international construction and design companies are looking to establish an Australian branch to their business and more young practitioners are interested in a career in tunnelling.

"The Australasian Tunnelling Society (ATS) Tunnelling Short Course in Brisbane in 2015 demonstrates this growing interest among young professionals," says Dixon.

When James Garnier of CH2M moved from the UK to Australia 11 years ago the tunnelling industry was starting to take off and, fuelled largely by the booming mining industry, that progress continued for a decade. Now, however, with that investment phase completed tunnelling work has turned largely to transport schemes.

"We have a large projected population growth, centred around the main capitals. There's also a push to link up the major areas of population," says Garnier.

There's also a need to alleviate traffic congestion. The NSW government estimates that traffic congestion is currently costing Sydney AUD 6bn (USD 4.6bn) a year, a burden that is set to grow to AUD 28bn (USD 21.3bn) by 2031 unless solutions are found.

And providing and improving transport systems in densely populated urban areas means tunnelling is an obvious solution.

David Lees, Australasian Tunnelling Society editor, says this is good news for the tunnelling industry. "The future for tunnelling seems bright, particularly for large infrastructure projects as the government tries to get public transport working but still needs to reduce congestion of road traffic," he says, adding that trenchless technology for utilities is also busy.

Some of these projects are funded by the state or federal government while others are PPP or unsolicited proposals.

Work is under way on Sydney's metro and the Victorian government recently announced that the Melbourne metro will go ahead. There is also likely to be investment in separating passenger and freight networks to remove the latter from city centres to unlock capacity from passenger lines.

***Above:** Forrestfield-Airport Link route. It is the first real metro work in the city*

***Opposite:** A Herrenknecht TBM working on the Legacy Tunnel in Brisbane several years ago*

***Below:** Investment in Australasian tunnelling has seen some impressively large-scal eprojects in recent years*

Another big rail project is an inland rail route linking Brisbane and Melbourne, via Sydney. It has been "discussed for years and years", says Garnier, and the federal government has just released AUD 300M (USD 228.9M) for a further study. There is still no schedule for the new line but Garnier is confident it will happen "perhaps in the next five or 10 years".

Despite the revolving door of prime ministers in recent years, the Australian government's focus on infrastructure has remained consistent, according to Dixon, with significant federal funding devoted to road and rail freight projects. Now Prime Minister Malcolm Turnbull has indicated there may be greater federation involvement in public transport, which may also include tunnelling components.

Often, however, projects fall victim to the rough and tumble of Australian politics and the short political cycle. A change in state government can change the appetite for infrastructure or the approach to funding.

"Changes in government are always interesting because each one says that the previous government's decisions were wrong," says Lees. "In Brisbane we have seen decisions going backward and forward between the Cross River Rail and the BAT Tunnel; in Melbourne decisions on the Melbourne Metro and east-west link road tunnels have also changed with changing governments."

In Queensland, Labor, which replaced a Liberal government, has stopped the leasing of assets to fund infrastructure, while in New South Wales the Liberal government was re-elected on the back of a promise to do just that.

"They managed to get their message over well as to their plan for the future and the benefit to the population and how it's going to be funded," says Garnier.

The NSW government recently started the leasing of the electricity network, boosting the state's coffers to provide the funding for infrastructure projects.

The Victorian government has a reputation for successful PPP projects but a recent change in government demonstrated projects' vulnerability to political changes. When Labor came to power it stopped the east-west tunnelling link which had already been awarded to Lend Lease and Bougyues.

"It was quite a major tunnelling project and everything had been signed and the financing had been dealt with," Garnier explains.

Although the Sydney metro is starting, about six years ago a change of government led to the project in another guise being cancelled despite tenders having been submitted. This type of situation has created some caution in the tunnelling industry.

"Construction consortia invest around AUD 20 to 30M (USD 15.3 to 22.9M) in tendering so there is always concern when a major project comes up near the end of a political cycle or there is significant resistance from one party or within the existing government," says Garnier. "It's all down to the short political cycles where rather than getting stuff done, people worry about re-election."

The conservative approach of government clients also impacts on companies' decision to tender.

"One of the big gripes here is the cost of tendering and the sheer volume of documents that's required to be analysed

at the time of tender. That in itself tends to stifle a lot of new thought because there's concern over who's reviewing it," says Garnier. "It also pushes up the cost so people are less willing to come up with new ways of thinking because of the volume of documentation that goes with it and then it will be a non-compliant tender."

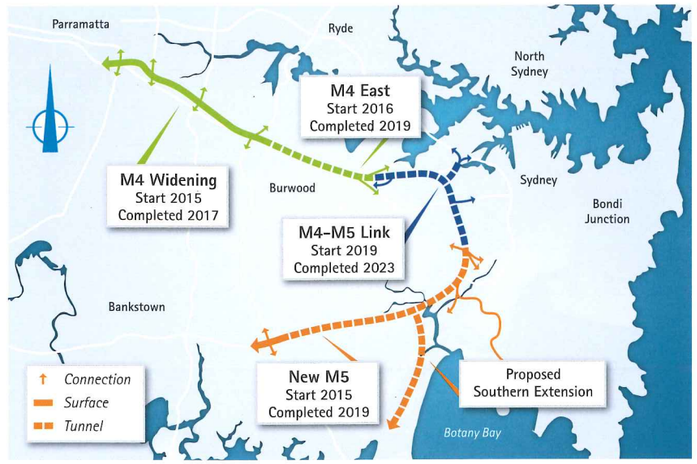
This means there can be a slower uptake of what might be established technology in Europe.

"One example is segmentally lined shafts which are standard use in Europe. No-one had done it in Australia until six or seven years ago and because of that it's difficult to get it through the approvals process," says Garnier.

There could be similar challenges ahead as plans for three-lane motorways will require larger TBMs. "Some of the technology that's been used elsewhere to generate the size of those TBMs will be a new thing in Australia and we will have to bring the clients along on the journey," he says.

Dixon says Australia's steady development of tunnelling over the past decade has already encouraged the use of some new technologies.

"We've seen the rapid adoption of international technologies like steel and synthetic fibre-reinforced concrete, precast construction, sprayed waterproof membranes and various types of TBMs," he says.



As clients' understanding of tunnelling techniques and potential increases so too does their appetite for bigger and longer excavations, which can bring benefits for the client and project team.

"The fewer intermediate launch and retrieval points along a proposed tunnel represent significant stakeholder, interfacing and risk minimisation advantages," says Dixon.

However, he too warns that the high cost of tunnelling projects is potentially a limiting factor.

"We need to ensure that we're not gold plating our tunnels with systems and complexity that may not be required. There will be a continuing need for innovative tunnelling solutions to drive value for money for inner urban underground transport projects and maximise net benefits and productivity gains for the broader economy," he says.

The mining industry's interest in civil engineering techniques is another trend in the Australian market.

"In particular both Robbins and Atlas Copco have been working with the big mining companies to develop special equipment for underground excavation," says Lees, adding that a Robbins TBM has just completed the decline at Grosvenor Mine.

Dixon agrees that the Grosvenor Mine could be a marker for Australia's tunnelling industry. "Pioneering projects like this demonstrate the potential for extending innovative tunnelling techniques into new industry sectors," he says.

Just as state politics can affect infrastructure projects, so too can interstate rivalry and the development of metro schemes in some of Australia's largest cities has invigorated the historical competition between the east coast states. "We saw it with the desalination plants eight years ago where one started building one and all the others decided they wanted one too, so all the programmes overlapped. We're starting to see that now with the major metros," says Garnier.

This flurry of activity means that, aside from what is already under way, three major tunnelling projects – the Sydney metro's City and West section; Melbourne metro; and Melbourne's Western Distributor road project – will all come to market around the third quarter this year.

"In terms of tendering that will soak up all the capacity in Australia," says Garnier.

Dixon agrees that there is potential for skilled labour shortages but says that both Australia and New Zealand have significant home-grown skills and experience in designing and delivering tunnelling projects of all sizes.

"We also anticipate continued interest from international companies looking to take part in local projects. The growing influence of Chinese construction contractors and design institutes is also a key factor," he says.

TRANSPORT DOMINANCE

There are now many rail or road schemes on the drawing board or under way in Australia, many of them vying for the title of the country's largest transport infrastructure project.

In March last year, the first sod was turned on WestConnex, a three-stage motorway project to expand capacity and improve traffic flows on the existing M4 and M5 roads – the latter considered to be the worst motorway traffic bottleneck in Sydney – and improve links to the city's airport and the Port Botany area. In order to keep property purchases and disruption to a minimum two-thirds of the scheme – around 22km – will be tunnels.

Stage one involves widening the M4 and extending it via the 5.5km M4 East twin tunnels (cut and cover); stage two is a new M5 running from the existing M5 East corridor at Beverly Hills via twin tunnels to St Peters, more than doubling capacity of the corridor and substantially improving east to west corridor access between the Sydney CBD, Port Botany and Sydney Airport precincts and the south-west growth areas; and stage three will join the first two stages with 5.5km twin tunnels with three lanes in each direction.

Leighton Contractors has been selected to design and construct stages one and two. For the AUD 2.7bn (USD 2.1bn) stage one contract the company is in a joint venture with John Holland and Samsung C&T, and for the AUD 4.3bn (USD 3.3bn) stage two it has teamed up with Dragados and Samsung C&T.

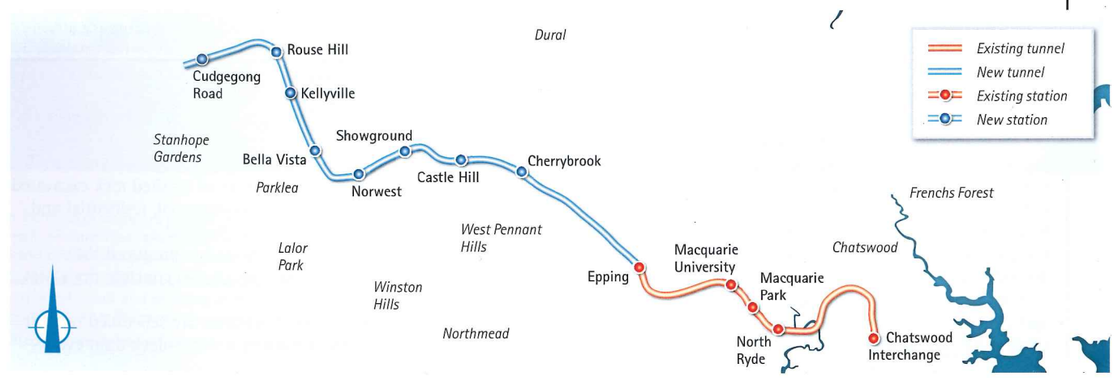
Stages one and two are due to open in 2019 and the final stage is scheduled to open to traffic in 2023.

In the north of Sydney, work has also started on the 9km NorthConnex motorway tunnel. The AUD 3bn (USD 2.3bn) toll road will alleviate traffic on Pennant Hills Road, said to be Australia's most congested urban road, by linking the M1 Pacific motorway at Wahroonga to the Hills M2 at West Pennant Hills via twin tunnels. When complete in 2019 it will link Sydney's north to the orbital network and enable the 1,000km journey from Newcastle, north of Sydney, to Melbourne to be made without encountering a single set of traffic lights. Excavation of the first tunnel shaft started last September.

***Opposite, top:** The Westconnex project route, located in Sydney*

***Opposite, bottom:** April 2013 saw breakthrough on the Legacy Tunnel*

***Bottom:** Sydney Northwest Metro route map*



Above: Road surface preparatory works

Tunnel shafts will be excavated to a depth of up to 93m, providing the launch point for roadheaders to tunnel to the north and south.

The tunnels in both North and WestConnex will have complex interchanges with the existing motorway, says Lees.

In January tunnelling was completed on the AUD 8.5bn (USD 6.5bn) Sydney Metro Northwest, Australia's first fully automated metro rail system and the first stage of Sydney Metro.

This first route will deliver a fast public transport system to Sydney's north west, an area which has the highest car ownership levels per household in Australia and where the population is forecast to grow by 200,000 over the coming decades.

Stretching west from Epping to Bella Vista, the new line comprises twin 15km tunnels – Australia's longest rail tunnels – with connecting cross passages about every 240m.

The contract has also notched up another milestone as the first transport infrastructure project in Australia to use four TBMs. Each 120m-long machine has a diameter of 7m and the finished tunnels will be 6m in diameter.

Roadheader machines are being used to build the short sections linking the new tunnels to existing tunnels, as well as the cavern to allow trains to cross from one track to another.

The Thiess John Holland Dragados joint venture is carrying out the AUD 1.15bn (USD 880M) tunnelling contract, which also includes the excavation and civil works for five new stations along the route.

On average, the tunnels are 29m deep, with the deepest point at 58m.

Sixty per cent of boring is through Sydney sandstone, and the rest shale. The 2.8 million tonnes of crushed rock excavated by the TBMs is being recycled on commercial, residential and environmental projects elsewhere in Sydney.

A factory established at Bella Vista has produced the 100,000 concrete segments for the 16,000 concrete rings that line the twin tunnels.

Services on Sydney Metro Northwest are scheduled to start in the first half of 2019, delivering a single-deck train every four minutes during peak hours.

Kiwi connections

Across the Tasman in New Zealand, work is progressing on the Waterview Connection in Auckland, currently the largest transport project in the country.

The 14m-diameter Herrenknecht TBM broke through in October last year, completing excavation of the two 2.4km-long road tunnels.

The NZD 1.4bn (USD 960M) project is the last segment of Auckland's south-western motorway and the final key link for the 48km Western Ring Route.

The Well-Connected Alliance, a joint venture comprising Fletcher Construction, MacDow, Obayashi Corporation, Beca, Parsons Brinckerhoff and Tonkin and Taylor, has led the design and delivery of the project, which is scheduled for completion by mid-2017.

Two other major projects on the drawing board for Auckland are City Rail Link (CRL) and Central Interceptor.

Part of Auckland Council's investment in renewing and improving the sprawling city's water and wastewater infrastructure, Central Interceptor is a new wastewater tunnel proposed to run between Western Springs, west of the CBD, and a wastewater treatment plant in Mangere, near Auckland Airport. The tunnel will be approximately 13km long and lie between 22 and 100m below the surface. It will cross Manukau Harbour at a depth of about 30m below the seabed.

In January the New Zealand government confirmed it would provide its share of funding for CRL two years earlier than originally promised. Bringing forward the finance for the NZD 2.5bn (USD 1.71bn) project will allow Auckland Council, which is jointly funding the project, to achieve its construction start date of 2018 and completion by 2022.

The 3.4km underground line will run from Britomart station in downtown Auckland through the CBD to connect with the existing western line at Mt Eden station. The scheme will include two new stations near Aotea Square and Karangahape Rd.

Enabling works for the CRL – a pair of cut and cover tunnels – will start in May this year.

A new harbour crossing is also being considered.

Just 10 years after the Auckland Harbour Bridge opened in 1959 it was struggling to accommodate rising traffic levels and so two-lane box girder clip-ons were added to each side. Maintaining the clip-ons is costly and a second Waitemata Harbour crossing has been on the drawing board since the 1980s. The current proposal is for twin two-deck tunnels for rail and three lanes of traffic.

GHD's Malcolm Dixon points out that while tunnelling has finished on Waterview, New Zealand has a "solid pipeline" of major sewer and drainage tunnels in the near future.

CH2M's James Garnier agrees there is "massive opportunity" for tunnelling in New Zealand but there is room for only a limited number of players.

"It's quite a small market and it's difficult to break into; couple that with labour costs and that makes it quite difficult for Australians to work there efficiently because they're comparatively expensive," he said.

Under the next phase of Sydney's Rail Future, the NSW government's rail plan, the rapid transit network will be extended under the harbour and into the central business district.

In Sydney, ventilation can be a challenge for long tunnels, says Lees.

"The M4 East will be heavily used by large trucks and there have been many concerns about the quality of air in the tunnel," he says.

A few years ago the NSW government built a filtering system, at large cost, for trial but concluded it didn't assist in the tunnel ventilation. "Certainly every time a new tunnel is planned the biggest hurdle is over where the ventilation stacks will be located," says Lees.

In Brisbane the on-again-off-again cross-river project has been another casualty of political changes but it's still on the state's agenda and the Queensland government plans to make a funding submission to Infrastructure Australia and the federal government. The crossing was originally proposed as a bridge but subsequent revisions have included a twin-tunnel and a single tunnel concept.

In Perth steady progress is being made on the Forrestfield-Airport link and recently the Salini Impregilo - NRW joint venture was named as the preferred bidder for the main design and construct contract. When it opens in 2020, the AUD 2bn (USD 1.53bn) state government-funded train line will connect Forrestfield to the city, opening up Perth's eastern suburbs to the rail network and improving connections to Perth Airport. The 8.5km route is largely underground, with two 8km tunnels which will be bored beneath the airport runway and the Swan River. Last year geotechnical studies were completed, including the creation of 150 boreholes, 25 monitoring wells and five pumping test wells. Construction will start later this year.

The area's complex geology has led Perth Transport Authority to specify an EPB and slurry mixshield TBM.

Generally Australia's geology is quite straightforward for tunnelling, especially in Sydney which is built on sandstone.

"In Sydney there is great experience now in excavating tunnels in Sydney sandstone, both with TBMs and roadheaders," says Lees. "One tragedy on the Cross City Tunnel in 2004 where the roadheader operator was killed has enhanced our understanding and respect for the bedding in the Sydney sandstone."

Melbourne sits on a basalt cap but in some areas the Coode Island silt, an alluvial deposit of the Yarra River, has to be managed. "The moment you start dewatering it you get a massive amount of settlement," says Garnier. "In Melbourne any tunnel you put in generally interfaces with this silt at some point so you have to be careful with dewatering and the way you work with it, or any hydraulic operations."

Lessons were learnt, says Lees, during construction of the CityLink motorway network in the late 1990s. "The problems associated with Melbourne CityLink and the draining of the surface sediments causing settlement to some important buildings will certainly ensure that the permeability of the Melbourne mudstone will be taken well into consideration in future projects," he says

MITIGATION NOT LITIGATION

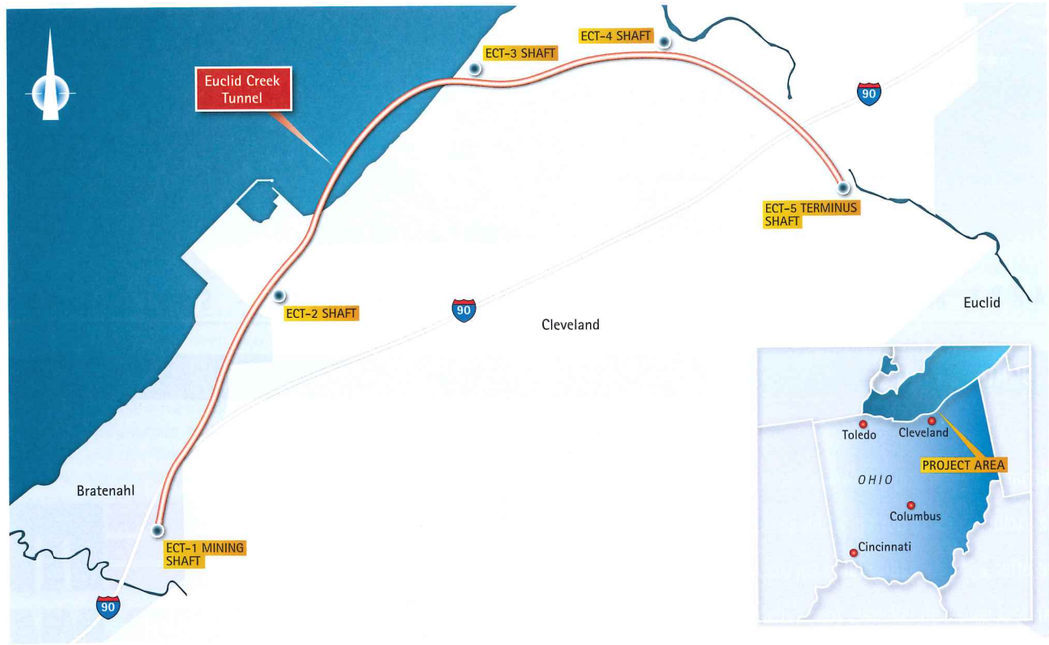
Michael Vitale
Michael is senior vice president and regional US practice leader for Hatch Mott MacDonald

Doug Gabriel
Doug is the construction program manager for the Northeast Ohio Regional Sewer District

On August 21, 2013, amidst a crowd of proud team members, "Mackenzie", the 1,500-ton (1,361 metric tons) Herrenknecht TBM completed its journey and broke into Shaft 5 of the Northeast Ohio Regional Sewer District's Euclid Creek Tunnel. Two years later the project is now in site-restoration and the NEORSD can reflect on what has become known as one of the most successful projects in their storied 43-year history. **Michael Vitale** of *Hatch Mott MacDonald* and **Doug Gabriel** of *NEORSD* report

THE EUCLID CREEK TUNNEL (ECT) is the first of seven planned storage tunnels under "Project Clean Lake" that will relieve overflows in the Cleveland-area sewer system. This 18,000ft-long (5.5km) 24ft-diameter (7.3m) tunnel is roughly 200ft (61m) beneath Cleveland's streets, with 3,000ft (914m) traversing beneath Lake Erie. When operational, the tunnel will hold approximately 60 million gallons (228 million liters) of combined stormwater and wastewater. After heavy rainfall, the combined sewage will be pumped via the adjacent Tunnel Dewatering Pump Station to the Easterly Wastewater Treatment Plant, protecting the valuable freshwater resource of Lake Erie and its tributaries. The annual one

Below: Euclid Creek Tunnel project overview



billion gallons of storage is enough to fill more than 1,515 Olympic-sized swimming pools. In American Football terms, it would overflow the Cleveland Browns Stadium every year.

Hatch Mott MacDonald (HMM) was appointed lead consultant for ECT back in 2006. The firm was responsible for overall design of the project, geotechnical oversight including the geotechnical baseline report preparation, cost estimation, risk analysis and preparation of the plans and specifications (tender package). The McNally-Kiewit Joint Venture (MKJV) secured the USD 198.6M contract to build the project in December 2010, with notice to proceed given in April 2011. This highly successful project has experienced no significant claims or delays and is now completed and ready to accept flow later this year.

PROJECT GEOLOGY AND ALIGNMENT

The ECT traverses through predominantly residential neighbourhoods from Bratenahl south of Interstate 90, northeast through Cleveland to the NEORSD's Easterly Wastewater Treatment Plant. There the tunnel swings under Lake Erie for nearly 3,000ft (914m), and terminates near Euclid, Ohio, at the intersection of Saint Clair Avenue and 185th Street.

The TBM had a 27ft (8.2m) diameter cutter head that was affixed with 44 single-cutter discs and eight dual-cutter discs. The TBM was rotated by nine hydraulically-operated torque hubs, and had 32 thrust cylinders as well as 16 thrust pads (two cylinders per pad). Each pad had a bearing area of 159,952sq.mm (approximately 0.16m² or 247.9in²).

*Top: **Main tunnelling shield at work on the project***

*Below: **View of Curve 1 of the tunnel***

Like most of the NEORSD tunnels before it, the ECT mined through the Chagrin Shale formation. This formation is massive and relatively stable, so earlier tunnels in the NEORSD's program, especially of smaller, 8 to 13ft (2.4 to 4m) diameter, were typically successful. However as the NEORSD required larger and larger tunnels to meet their Consent-Decree-mandated storage volumes, some of the Chagrin Shale challenges and risks became more apparent, leading to past project delays and ultimately litigation. The two main risks included excessive H2S and methane infiltration, and deterioration of the crown and invert. This deterioration was caused by thin bedding coupled with relatively high stress, and was exacerbated in the crown by gravity and in the invert by water and train traffic. The traditional method of

support had been a two-pass system using steel ribs and timber lagging, followed by cast-in-place concrete. Control of the rock overbreak proved difficult with large-diameter two-pass operations, and invert degradation led to train derailments. The NEORSD and HMM set out to mitigate these risks so that there would not be a repeat during the Euclid Creek Project.

*Above: **Precast fiber reinforced concrete fiber distribution across a broken segment***

TUNNEL INNOVATIONS

During the course of the design, HMM introduced several key innovations. For the first time, a NEORSD tunnel would use one-pass, precast, bolted, gasketed concrete segments reinforced with steel fiber alone (no rebar) to line the tunnel. This improved the overall quality of the tunnel and saved several months from the construction schedule, while mitigating scores of potential risks such as overbreak, gas, derailments, and work stoppages. However, several residual risks were created by the use of segments in conjunction with an open-faced TBM in the shale bedrock.

First and foremost, the TBM would cut a void that would need to be filled immediately behind the TBM shield to provide segment support. This would be difficult to do with an open-faced TBM, but no one wanted to specify a closed-face TBM just for this eventuality since the rock was generally excellent and little to no groundwater was expected. In addition, the one-pass system meant that overbreak above the TBM or lining could not be easily seen, and more importantly, any overbreak ingested at the TBM face would result in voids behind the lining. Such voids could lead to lining instability in general and operational requirements also dictated that these voids be filled so that the lining could resist internal surge pressures during tunnel filling in a storm event.

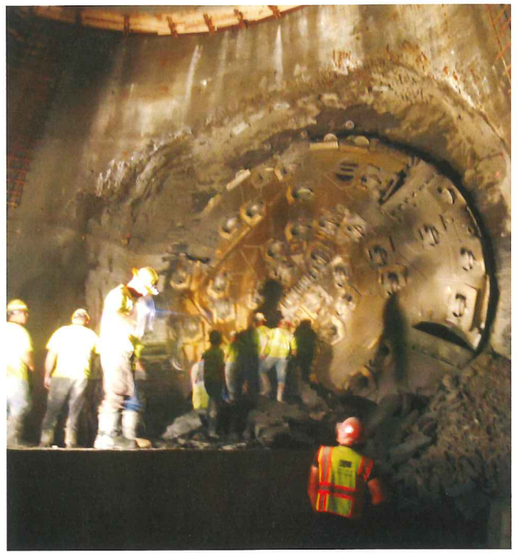
To fill the tail void behind the segments, HMM specified a two-part sodium-silicate-accelerated grout system, injected through the tail of the TBM. However, this met resistance as many in the industry were quick to point out that nowhere in the world had this been attempted in conjunction with an open-faced TBM. While this was true, the design team felt that the risks mentioned above, and additional residual risks from the tail void injection, could be mitigated in the design and construction. The required residual risk mitigation included: keeping grout from flowing forward around the shield, potentially locking the TBM in place and or flowing into the open TBM face; avoiding 'ring squat' into the annulus overcut void around the lining while the grout flowed and set; detecting and grouting overhead voids as the TBM progressed.

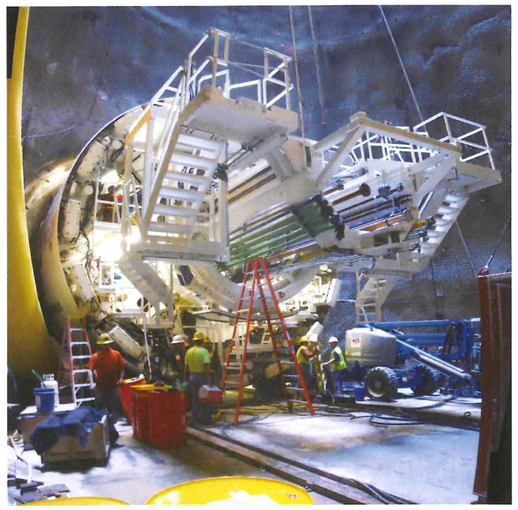
To provide immediate support to the segments, the two-part sodium-silicate-accelerated grout was designed to gel in 30 seconds or less to limit forward flow and provide resistance to segment movement. Additionally, the gel strength was specified to be sufficient to provide a firm foundation for the TBM trailing gear and other loads. During construction, the MKJV developed and tested more than 60 mix designs until a working annular grout mix was created and proven through full-scale field trials. It is believed that this system of tail void grouting behind an open TBM in rock was indeed a world first and an innovation that provided great benefit to the NEORSD and their rate-payers.

Although this annular grout may have been the most critical project risk-mitigation element, probing through the lining (and 3ft into the rock above) was also required to check for overbreak in the rock and resulting voids. Contact grouting was required to extend into any overbreak areas or voids to function both as consolidation grout as well as contact grout.

Several other innovations were introduced on the ECT project, including:

- The successful fabrication, transport and testing of full-scale plastic-fiber-reinforced concrete segments. This exercise, which to our knowledge had not been done before, will pave the way for potential use of plastic fiber on future segmentally-lined tunnels.
- Physical modeling of baffle drop structures. While these had been used successfully in Cleveland for 100 years, the design was strictly empirical – old working designs were copied and there were no reliable design algorithms to upsize the flow beyond what had been shown to work in existing structures. The solution, which was approved and funded by NEORSD, was to partner with the Iowa Institute of Hydraulics Research to build a scale model of the baffle structure. The data was evaluated and the results were fed back into the design process. This allowed the design of larger, higher-capacity baffle structures and the data from this project is now being used all over the world, on projects from the United Kingdom to New Zealand.
- While it does not qualify as an innovation as such, the starter





and tail tunnel final linings used plastic fiber as the sole reinforcement. According to the fiber manufacturer, no one had ever used plastic fiber as the sole reinforcement for a cast-in-place tunnel lining prior to the ECT project.

PROJECT RESULTS

After some early learning curve issues with accelerators and other modifications, the MKJV ultimately averaged 17 rings per day with best days in excess of 30 rings per day (150ft or 46m) using three shifts. The vast majority of the tunnel was installed with insignificant stepping, lipping or other offsets in the segments. Where segments had squatted or moved prior to grout gelling or other reasons, hydrophyllic polyurethane grout was injected behind the segment gaskets. However, this was only required if the movement exceeded the tolerance on required gasket pressure resistance, and very few such instances occurred.

Gas was mitigated effectively via a combination of the segmental lining and a robust ventilation system. Slightly elevated levels were noted occasionally, yet there were no shutdowns of note. Invert degradation was mitigated by the concrete segments, and the MKJV was able to build the tunnel under factory-like conditions rather than fight overbreak and other risks for past tunnel projects in the area.

Check-hole drilling was routinely performed several feet through and behind the lining at the crown, using dedicated drilling equipment on the trailing gear that was located five rings behind the TBM shield. Contact grouting was immediately injected as necessary through these same check holes.

Very little overbreak was observed using a bore scope through the check-holes, and typically a fully grouted void was present. This was confirmed when the horizontal adits were excavated at the connection points to the tunnel. The shale was hand-mined revealing the annulus grout in nearly perfect encapsulation of the segmental ring. The two-part accelerated grout method has proven to be very successful, and the NEORSD is using the same system on the Dugway Storage Tunnel (DST), which will connect directly to the ECT tunnel at Shaft 1 near the Pump Station (see page 24). The Salini Impregilo/Healy JV recently started construction on the DST project, (approximate USD 153M Contract Value).

This tunnel, designed by the HMM/MWH Americas joint venture, is of the exact same diameter as the ECT project, albeit significantly shorter. However future designers should remain cautious, especially if using this method in rock with potential for large groundwater inflows. The evaluation of the plastic fibers was promising, particularly for the concrete segments, and the NEORSD is evaluating the use of plastic-fiber-reinforced segments in an upcoming tunnel to further prove the viability of these fibers.

The physical baffle-structure modeling allowed efficient design of structures many times larger than what has been done in the past. In fact, additional physical modeling on subsequent projects has yet to indicate a size limit. Furthermore, by offsetting the dividing wall from the center of the shaft into the area traditionally reserved for worker access, the flow capacity can increase without increasing the shaft diameter.

CONCLUSIONS

By any metric, the ECT project was extremely successful, and has won the International Project of the Year Award from the Tunnelling Association of Canada and a High Commendation from the NEC/ITA. However, it must be mentioned that the project's success could only have been achieved via a constant and open collaboration between the NEORSD, HMM, MKJV, Herrenknecht, segment supplier CSI/Hansen, grouting specialists at BASF, and others. The staff and expertise provided by all parties was top-notch and all knew that if proper attention was not given to key, critical issues such as the grout make up and injection, this project could have had a very different ending

Top: ***Final hole through***

Above: ***TBM as viewed from tail tunnel***

Acknowledgements and notes

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THE WAY AHEAD

Excavation of the tunnel access to the new Grosvenor longwall coal mine in Queensland, Australia was achieved via TBM methodology – a first for the state's mining industry. **Sally Spencer** reports

Sally Spencer
Sally has joined the *Tunnels and Tunnelling* team as a contributing editor

ANGLO AMERICAN'S GROSVENOR MINE, in Australia's Bowen Basin, is groundbreaking in more ways than just the literal sense.

Thanks to changes in the methodology of excavating the access tunnels to the longwall coalface, the Grosvenor mine is being hailed as "industry leading" and "the future of underground mining".

The AUD 1.95bn (USD 1.48bn), greenfield underground coal project in Moranbah, central Queensland, is one of the few new longwall coal mines to come on stream in Australia. Work began in 2012 and, once operational later this year, the mine will produce around seven million tonnes of metallurgical coal annually, which will be processed into five million tonnes of coking coal for export each year for the next 26 years.

The longwall panels will be 300m in width with lengths up to 6,200m and access to the coal seam at the shallowest depth of 160m is achieved via two decline tunnels.

The first – the conveyor drift – will transport the coal from the longwall to stockpile areas on the surface, while the second – the transport drift – will allow access for personnel and equipment once the mine is operational.

METHODOLOGY

Grosvenor targets the same Gonyella Middle coal seam as Anglo American's Moranbah North coal mine, just to the north. The company's experience of the geology – and a costly coal production -halting roof collapse in the Moranbah North

Below:
Contractor Redpath prepares for TBM walk-down
PHOTO: REDPATH

H+E solutions for spatial challenges

TORONTO/CANADA. The Toronto-York Spadina Tunnel is an 8.6 km subway extension that includes six new stations. It will connect the city of Toronto to the regional municipality of York and offers a transit alternative to the burgeoning communities in northwest Toronto and to the north of Toronto.

Two vertical conveyors and vertical storage units by H+E Logistik GmbH, installed in 2013, ensure a reliable overburden removal capacity of 500 t/h. They transport material vertically out of the shaft and provide an optimum conveying solution even in projects that are characterized by spatial restrictions, like the Spadina Tunnel.

PROJECT DATA/VERTICAL CONVEYOR:

- Belt Width: 1,200 mm
- Height of Lift: 23 m
- Capacity: 500 t/h
- Installed Power: 1 x 160 kW
- Installation: 2013

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H+E Logistik GmbH
Josef-Baumann-Str. 18
44805 Bochum
Germany
Tel. +49 (0)234 | 950 23 60
Fax +49 (0)234 | 950 23 89
info@helogistik.de
www.helogistik.de

conveyor drift in 2011 – fed into the decision to excavate Grosvenor's tunnels via TBM methodology, rather than roadheaders, which are the Australian coal mining industry's usual modus operandi.

Conventional excavation by roadheaders did feature in original plans for the conveyor drift but engineering and design consultancy GHD's initial detailed design of the conveyor drift (geotechnical investigations; risk assessments; ground support classification and models; design of SCL; design of rock support; portal design, including canopy tubes; and finite element analysis of tunnel support) led to Anglo American's decision to adopt the TBM methodology.

This marks the first time TBM technology has been used in the Queensland coal industry and, according to Adam Foulstone, Anglo American's general manager and site senior executive at Grosvenor, it's the first time an EPBM has been used in a mine in the whole of Australia.

GEOLOGY

The geology along both drifts' alignments consists of varying soil and rock conditions. The soft ground portion consists of sand, sandy clay, clay and conglomerate. The mixed face/rock portions consist of siltstone, coal, sandstone and basalt.

The conveyor drift is about 900m and declines at a gradient of 1:6, while the transport drift is about 1,100m and is at a gradient of 1:8. Each drift has an internal diameter of 7m and consists of steel fibre reinforced concrete segmental lining.

With the exception of a vertical curve at the top of the tunnel, where the TBM was assembled, there are no curves along either drift. The tunnels are about 120 degrees offset to each other and end underground around 150m apart (the portals above ground are about 2.5km apart).

Both drifts feature man refuges at 200m intervals, allowing pedestrians to take cover when mobile equipment goes past and ventilation is via a 5.5m diameter, 170m-deep shaft and three 1,000kW exhaust fans on the surface. The fans create low pressure in the underground environment, which then turns both tunnels into intake airways.

The geology along both alignments changes from soft clays and soil in the first 300m, to stone and basalt as the tunnels extend down the decline.

"We had very mixed ground in a range from about 0.5MPa to about 90MPa, which would have been very hard going for a roadheader," said Foulstone. "We had also had the drift fall in our system line about 7km away [at Moranbah North mine] and these were the main reasons for going with a segmental tunnel.

"Another reason was that the TBM method was much faster, allowing us to access the coal seams 10 times quicker than if we'd used a roadheader. And, excavating through all the coal seams before we hit our predominant seam meant we had to deal with the presence of methane. That would have been very hard to manage with a roadheader."

TBM SPECIFICATION

Contractor Redpath Mining was in agreement that using a TBM as the primary excavation tool was the way forward in providing an extremely safe working environment and "certainty" regarding the development programme, hence Robbins was duly introduced into the process providing TBM and backup equipment.

Robbins project manager Martino Scialpi recalls that the company participated in the multi-stage risk assessment required for Grosvenor even before any manufacturing decisions were taken.

"We made ourselves completely available to interpret new and stringent Queensland legislation relating to the tunnel design and the TBM design with the client, the contractor and the consultants," he said.

"We spent more than 35,000 engineering hours on Grosvenor, which is about three times what we would usually spend on a standard TBM for a civil project of around the same size. We regularly had meetings with 30 people from 30 different companies around the table."

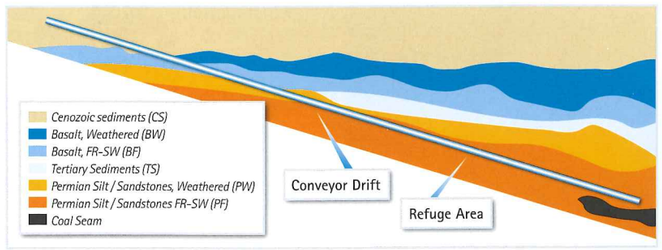
The Robbins 'Crossover' TBM used at Grosvenor – Lucia – is an 8m, high-performance rock/mixed face convertible shield TBM.

"It's capable of conversion between a pressurised EPB mode and a non-pressurized single shield mode," said Scialpi. "Because of the requirement to build two blind tunnels quickly, while maintaining full ground support, the machine was also designed for quick disassembly so it could be relaunched on the second tunnel."

The TBM is fitted with a back-loading cutterhead powered by 12, 330kW explosion proof electric motors, providing a total installed cutterhead power of 3,960kW.

"The cutterhead is designed to operate in different modes depending on the type of ground," said Scialpi. "It can be used in EPB mode with cutting bits, a relatively open mixing chamber and a screw conveyor for muck pick-up. Or it can be operated in rock mode by exchanging the knife bits with disc cutters, the scrapers with bucket lips, adding modular radial loading plates into the mixing chamber, sliding forward the hopper built into the centre bulkhead and extending the screw conveyor forward into the mixing chamber, underneath the

*Below: **Geological section of the Grosvenor project***



hopper."

He added that the screw conveyor is designed to operate in changing ground conditions and in gassy conditions.

"The mixing chamber and the screw conveyor form a sealed chamber. Methane gas may be contained within the excavated material flowing through the screw conveyor, which will escape and be removed at the conveyor discharge by the snuffing box (a steel frame bolted to the discharge gate). The suction created at the screw conveyor discharge draws the methane inside the main duct and out of the tunnel."

TRAINING REQUIREMENT

Part of Redpath's scope was to operate and maintain the TBM and it engaged in-house TBM expertise and sourced experienced tunnelling operators and miners.

With no pre-existing experience of operating a TBM among Queensland's mining community, extensive training was vital. In fact, as Scialpi admitted, the Crossover design was so new that even the company's own field engineers had to undergo internal training.

"A programme of formal training and competencies were developed – as far as we understand, this is a first in the tunnelling and mining industry – to ensure proof of training and compliance with the mine training guidelines were met," said Rob Nichols, CEO of Redpath's Australian operations. "The engineering and supervision was by experienced tunnelling personnel with a mix of coal mining engineers and other professionals to ensure understanding of both industry requirements were combined and integrated."

The project did have a lucky break, however, because while there may have been limited or no TBM experience among the miners, there was a pool of knowledge within the civils industry.

"We were pretty fortunate in that the Brisbane airport link tunnel was demobilised just as we were beginning to ramp up, so we got some experienced operators from that project," said Foulstone.

"The only real challenge we had was that their experience was with a Herrenknecht machine, so we had to retrain them on the Robbins equipment. It took around two to three months to gain that understanding during the ramp up period but then the second drive was nearly twice as fast as the first one."

Assembly at the jobsite started in July 2013, the TBM was ready to be walked down into the first launching tunnel in November and boring operations on the conveyor drift started on December 20.

This first drive was completed in 20 weeks, on 13 May 2014, reaching the coal seam at a depth of approximately 160m. The total length was 798.41m, with an average production of about 40m per week and an average advance rate of 1.32m per hour.

The first four weeks were relatively slow due to the carrying out of final load tests, fine-tuning of equipment and the learning curve of the operators, while progress in weeks six and seven was hindered by the need for a replacement gearbox for the screw conveyor drive.

After that the pace picked up, reaching about 65m per week, with a best day on 28 March of 13.9m and an impressive 85m in week 20. The last six weeks were characterised by the presence of gas, with routine implementation of the procedures for mitigation and management of the detected gas concentration levels.

MIXED GROUND OPERATION

As mentioned, although the TBM was designed for dual mode, Redpath took the decision to use it in its mixed ground configuration (disc cutters and scrapers) for the conveyor drift, rather than in either of its 'extreme' hard rock or soft ground modes. This, said Scialpi, resulted in a lower performance in the areas of soft ground but avoided the 7-10 day downtime that would have been needed to switch from soft ground to hard rock modes.

"The project did operate in open, hard rock mode for a short

Below: After completion of the conveyor drift the TBM was retracted and transported to the next site where new machine shields awaited assembly

period on the first drift, however, due to the lower strength of rock encountered, the type of muck developed by the softer mixed soils and the control of methane gas, the TBM operated mostly in closed EPB mode," said Redpath's Nichols.

"This allowed the soil conditioning to be optimised and the cutting chamber to handle and remove the muck efficiently through the centrally located double screw. The screw accommodated a plug that assisted with the continuity flow of muck and in the management of the methane gas encountered nearer the coal seams."

Once excavating the conveyor drift was complete, the TBM was backed out in order that it could be used for the second tunnel, the transport drift. This was, said Redpath, a major challenge given the 1:6 decline – and a challenge to be repeated, of course, when the transport drift was completed.

The TBM design incorporated special features to allow the quick demobilisation in a blind heading without the need for a large disassembly chamber and without any hot work.

The cutterhead was designed with an inner/outer bolted construction and the TBM was backed up 600mm to provide access in front of the head so that these bolts could be removed. Roof support consisting of rock bolts and shotcrete was applied from within the safety of the cutterhead before personnel entered this area.

The outer cutterhead segments, consisting of two 180-degree sections were then 'parked' in the invert and rock bolted to the face – they were then recovered from this position once the core of the TBM had been removed.

"The TBM core (the cutterhead core, cutterhead support, main drives, screw conveyor, segment erector and bridge) and back-up were retracted as a self-propelled single unit up the 1:6 slope on a special 'walking dolly' system," said Scialpi.

He added that, while the concept was simple, the walking system was complicated by the limited space beneath the TBM core and the need to distribute the 1,000 tonne weight over seven precast segments in order to prevent damage to the tunnel liner.

"The system consisted of three dolly units working in unison to distribute the load," he said. "The back-up gantries were fitted with lift jacks to provide anti-slide."

TBM MOVE AND RECOMMISSIONING

The TBM was walked out between July and August, loaded onto two "super-trucks" and taken to the transport drift portal 2.5km away.

"An advantage from the first use of the machine was that it provided lessons that allowed upgrading and modifications to the machine during reassembly phase, thus increasing productivity and introducing further confidence in applying stretch advance rate targets," said Nichols.

The machine was made ready between September and October and relaunched on 11 November 2014.

Based on the experience gained on the conveyor drift and the almost identical geology, Anglo American and Redpath reconsidered the most efficient way to approach the second drive.

As a result, the cutterhead was completely redressed with soft ground tools (scrapers and knives), as these were deemed more appropriate for the initial soft ground conditions.

Recommissioning the TBM for the second drive was a much smoother process and that, along with the now experienced operators meant that production was much improved from the outset.

After about 540m (between weeks nine and 10) the changing geological conditions necessitated a four-day stoppage while soft ground tools were exchanged for disc cutters. However, despite this delay, plus 100 hours of downtime to manage high concentrations of methane, completion of the 988.4m transport drift was achieved after just 13.5 weeks on 9 February 2015, almost three weeks ahead of schedule.

Average weekly production was 70.6m, the average advance rate was 1.83m per hour and the best day's production was 25.2m.

Extracting the TBM from the second tunnel was also a much quicker process than the first. "It took 10-11 days and we achieved a walk back speed of more than 100m per day," said Scialpi. "To achieve that speed with 1,000 tonnes of steel on a steep decline is quite remarkable."

EXPLOSION PREVENTION

Methane gas

Looking back, the real challenge of the excavation of both tunnels was in predicting where methane would be encountered (when the machine approached and excavated through the coal seams) and at what levels, said Nichols. It estimates that methane was an issue in approximately 15 per cent of the length of each drift.

"The TBM was designed to the Queensland Coal Mine regulations for equipment to operate in an explosive atmosphere," said the spokesperson. "Gas detection devices and associated interlock systems were designed and integrated into the machine and this, essentially, provided the confidence that, should methane gas escape the system and into the underground atmosphere, the TBM and related equipment would trip and shut down any potential ignition sources. Normal coal mining practices would then be introduced and carried out, including the evacuation of the environment, purging the drift of gas, increasing ventilation and the like.

"The fundamental system of managing the methane was through diluting the gas into the muck and providing an inert atmosphere within the cutting chamber. Soil conditioning was also used to arrest the potential for sparks during the cutting phase.

"Conveyor belts and hosing were flame resistant and anti-static (FRAS) and, as such, were compliant with coal mine regulations. The ventilation system for the TBM extracted gas through steel ventilation tubing via a surface fan and into the

general atmosphere. The drift lining installation and seal was fundamental during the period the TBM was excavating through the coal seams to prevent gas pressures escaping into the lined drift."

Explosive risk zone (ERZ) controllers were present at all times in the underground environment and the system was managed using a trigger action response plan (TARP), which ensured that personnel understood and complied with safety protocols.

Queensland Coal Mine regulations require that extensive preliminary risk assessments are carried out to establish the potential zones of accumulation and flow of methane gas. These zones are classified as NERZ (negligible explosion risk zone), with a methane concentration of <0.5 per cent; ERZ1 (explosion risk zone), with methane concentration between 0.5 and 2 per cent; and ERZ 0, with a methane of >2 per cent.

"When we have methane concentrations ranging from 0.5-2 per cent all our electronic gear has to be flame proof, so this TBM is probably the only one in the world that is adapted to manage methane in this way," said Foulstone. He added that, under the Queensland regulations, mining and excavation is not permitted where methane concentrations exceed 2 per cent. "We had methane concentrations of up to 45 per cent so to resolve this we removed the bentonite and used the bentonite lines to introduce nitrogen into the cutter chamber. This removed the oxygen and gave us an inert atmosphere. Then it didn't matter what level of methane we had in the cutter chamber because we knew it wasn't going to ignite."

Hydrocarbon products

Another potentially explosive challenge that had to be overcome, said Foulstone, was the presence of hydrocarbons.

"It was a by-product of the greases that were inside the cutter chamber," he said. "The cutters were creating a lot of heat and combined with the muck and the grease it resulted in high concentrations of hydrocarbons. This again created an explosive atmosphere within that chamber but by injecting nitrogen we were able to create an inert atmosphere. This enabled us to keep on going, irrespective of the mixture we had inside the cutter chamber."

Nichols added that TBM operating temperature was managed through a semi-closed water-cooling system on the surface, together with a bulk air cooler delivering chilled air into the drift.

Contractor and designer's works summary

- Tunnel design provided by Robbins; GHD provided advice and approval; Redpath reviewed and provided comment for the constructability of the tunnel; spatial elements were nominated by Anglo American to suit coal mining machinery and transport equipment.
- Design, manufacture and delivery of the TBM by Robbins; Redpath provided constructability reviews and advice on legislation compliance; technical review by GHD.
- Segment lining design by Robbins; design review and refuge area openings by GHD.
- Detailed redesign of refuge bay openings and support by GHD.
- Design, supply and installation of portal structures by Redpath; Design verification provided by Anglo American.
- Design, supply and installation of TBM assembly foundations by Redpath; Design verification provided by Anglo American.
- Design, supply and installation of TBM launch structures by Redpath; Design verification provided by Anglo American.
- Supply and installation of segment lining by Redpath.
- First drift assembly and commissioning of TBM by Robbins (supervision) and Redpath (personnel and equipment).
- Excavation and support of drifts by Redpath; Robbins supplied product specialists and advice.
- Disassembly and removal of TBM from drift and reassembly on second drift by Redpath; Robbins supplied product specialists and advice.

THINKING AHEAD

The TBM is now in storage, ready for Anglo American's next project – and the potential remains for it to be used in its full dual mode capacity.

"The ground conditions at Grosvenor were more thoroughly investigated than is usual for some civil work," said Scialpi. "For a short tunnel we had 10 times the data we usually have and this is an advantage because you can design the machine to satisfy the geology. Of course, an abundance of information means you add features onto the machine that probably won't be used but Anglo American wanted us to consider all the aspects and, wherever possible, to 'over-design' the machine because it was intended for use not just at Grosvenor but for other projects."

Business perspective

Foulstone is convinced that, notwithstanding the current slump in Australia's coal mining sector, those projects will come and the TBM will be redeployed.

"There is no way you would ever develop a mine any other way now," he said. "You only need to look at how much safer excavation is for the workers – they are not exposed to unsupported rock or fumes at any stage of the tunnel construction. And the speed. The rate is 10 times faster than a roadheader, which means we can access coal 10 times faster and get a return on the investment a lot quicker.

"The capital expenditure up front is a lot greater but the return at the back end of the project and the quicker access to the ore body makes it worth it," said Foulstone.

"And the final product is superior to what would be achieved using drill and blast or a roadheader. With those methods you are forever going back to do remedial work and the bolts and mesh systems only have a life span of 10-15 years, but the tunnel lining [from the TBM method] means that, from a maintenance perspective, you don't have to worry about it.

"It's definitely the way of the future, not only for coal but for any other commodity where ore bodies have to be accessed from the surface through a drift. It's something we definitely need to look at"

STEP UP

The November 2015 meeting of the *British Tunnelling Society* was treated to a presentation on Abu Dhabi's super sewer, the *Strategic Tunnel Enhancement Project* (STEP). The speakers were **Shahzad H Orakzai**, programme manager for the *Abu Dhabi Sewerage Services Company* (ADSSC); **Mirko Martini**, technical manager for *Salini-Impregilo*; **Carola Edvardsen**, technical director for *Cowi*

Shahzad H Orakzai
Shahzad is the Programme Manager at the Abu Dhabi Sewerage Services Company

Mirko Martini
Mirko works as Technical Manager for Salini Impregilo

Carola Edvardsen
Carola is responsible for Cowi's activities in concrete durability and service life design

THE STRATEGIC TUNNEL ENHANCEMENT PROGRAMME (STEP) consists of 41km of deep gravity tunnel sewer and 45km of link sewers taking sewerage flows out of the city of Abu Dhabi to a major new treatment plant outside Abu Dhabi.. The talk focused on the challenges of designing and constructing the deep tunnels and shafts, which start at a depth of 24m in the city and end at a depth of 80m with a diameter of 6m at the new treatment works.
A total of eight modern EPB TBMS were used for the tunnel construction with groundwater pressures of up to 8 bar. The tunnel was lined with a Corrosion Protection (CPL) secondary lining.
The success of designing such a sewer tunnel to have a long service life in the severe exposure conditions of the Gulf illustrates how modern developments in service life design and tunnel design can be applied to such projects and the experience gained will be of relevance to upcoming major tunnel projects in the UK.

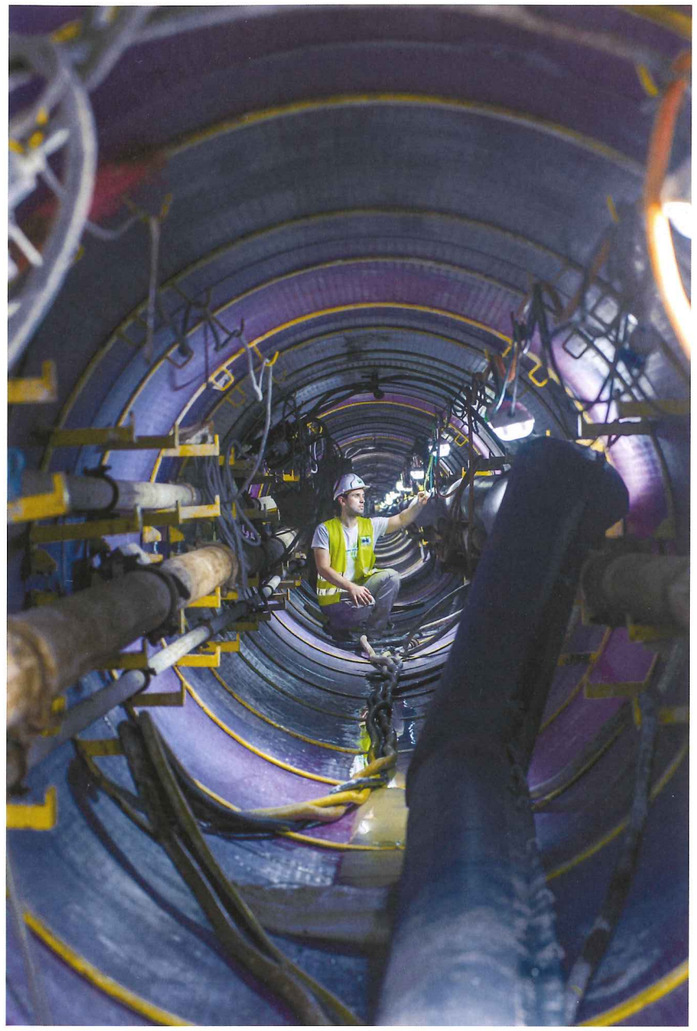
The project is based in the small most populated part of the Emirate of Abu Dhabi – primarily covering the main Island, the surrounding islands and the populated parts of the Mainland.

ADSSC has three licenced activities; Collection & conveyance (with a large asset base); Wastewater treatment (significant by its volume) and; Recycled water & bio solids. The presentation was based on the collection and conveyance activities.

Over the past decades Abu Dhabi has sustained tremendous growth from a population of about 100,000 in 1970s to over

Below, left: ***Tunnel before application of corrosion protection***

Below, right: ***Satellite photo of Abu Dhabi with project alignment overlaid***



1.6 million in 2014. The massive expansion of the green areas together with lots of new catchment basins has turned out to be a real challenge for ADSSC. In 2007 a hydraulic modelling exercise presented in fact a scary picture with high risk of flooding and a need for a massive investment.

The on-time delivery of Capital investment projects has been a challenge for ADSSC. Generally delayed Capital Expenditure (CAPEX) projects end up requiring additional budget, increased O&M costs (due to delayed improvements) and reputational damage. To overcome such a scenario ADSSC took a look at their own organisation and then came up with an innovative delivery approach by engaging with the private sector in a tripartite setup to include consultants and contractors. ADSSC young staff members were seconded to the Programme consultants, who were co-located with the client under one roof. Two new forms of contracts were used: Open-book consultancy contracts and Design & Build construction contracts - a first in UAE. Apart from targeting successful investment delivery, ADSSC also had the strategic objective of building internal capacity through knowledge and skill transfer while delivering the Programme and to works towards a partnership-type approach within the tripartite set up. Three leaning frameworks were used; Organisational learning (Rashman et al, 2009); Internal Stickiness (Szulanski, 1996) and Tacit Knowledge (Nonaka et al. 1991).

Above: ***A worker inspects a cable in a smaller tunnel on the project***

In the initial stage of the Programme, ADSSC undertook an optioneering exercise where four technical options were considered; Do nothing; Upgrade critical infrastructure; Construct an offshore pipeline; Construct a tunnel sewer. Options were assessed using both quantitative and qualitative criteria. The deep gravity sewer tunnel option emerged as the best option and was subsequently developed further. The selected deep gravity sewer option had a number of benefits including; reduced potential for overflows, reduced capital and O&M costs, reduced odour potential, improved health and safety and improved aesthetics.

The deep gravity sewer tunnel was planned to be connected to a series of link sewers to gravitate strategic parts of the existing system to the deep tunnel system terminating at a new large pumping station. In parallel, 35 number of existing pumping stations were planned for decommissioning and gravitation through the Programme.

STEP is a deep gravity system to collect the used water in Abu Dhabi Island and the mainland. It includes 41km of deep bored tunnel (4m to 5.5m in diameter), 45km of link sewers (0.2m to 3.1m diameter) and 1 large pumping station (ultimate capacity 39m³/s). The used water will flow under gravity to a new treatments works at Al Wathba. The new system will accommodate an average used water flow of 1.7Mm³/day by 2030. The first construction contract was awarded 2009 and the entire Programme is scheduled to be finished in 2016.

DESIGN CHALLENGES OF THE STEP T-02 AND T-03 LOTS

One of the critical aspects of the project was designing and constructing tunnels to have a long service life in the very aggressive environment of the Gulf. This could only be possible if all the parties acted as a team. The designer had to be on the site permanently.

The overall solution was defined by ADSSC and their Engineer CH2M. The design was a 40-80m deep segmental bored tunnel, T-02 280mm thick segments and T-03 350mm thick segments (due to deeper alignment). The

secondary lining was a cast-in-situ lining with cast HDPE lining (2.5mm) inside to avoid microbiologically induced concrete corrosion (sulphuric acid attack) to take place. The HDPE worked in conjunction with the un-reinforced concrete sacrificial lining. The tunnels had a design life of 80 years – this presented the designer with a major challenge.

The Gulf has some of the most aggressive soil / groundwater conditions in the world. Groundwater contains 10-12 per cent chlorides 4 to 5 times that of seawater, extremely high suphate contents (up to 5000 mg/l) are present that are not found in Europe. Not forgetting the temperature of about 30 degrees Centigrade throughout the year.

A lot of construction in the Gulf has learnt the hard way – that unless durability aspects are taken seriously into consideration concrete will not last very long (no more than 5-10 years). Taking account of the high risk of corrosion - new ground was broken. If the segments were designed in the conventional manner with black steel rebar cages then cover of 80mm and more would have been required to meet durability requirements assuming a normal quality concrete. This large cover is practically not possible for a bored tunnel due to high risk of spalling during transportation, installation and erection within the tunnel. There was a possibility to use stainless steel mainly at the joints where there is the highest risk of chloride concentration. This would be too costly and a new solution was sought. The solution was the use of Steel Fibre Reinforced Concrete (SFRC).

Even in aggressive environments with high temperatures SFRC is much less sensitive to corrosion compared to traditional steel reinforcement. It can be argued that there are no concerns with SFRC it is only an aesthetical issue – and what does that matter in a sewage tunnel?

Table 1. TBM main features

Feature	T-02 TBM	T-03 TBM
No / diameter / type	3nr x Ø6340mm EPBMs	2nr x Ø6980mm EPBMs
Weight (excluding back-up)	360t	440t
Thrust Force	42575kN	50668kN
Torque (nominal)	4463kNm	5940kNm
Design groundwater pressure	5 bars	8 bars
Ability to probe and grout ahead.	Yes	Yes

Source: Presenters

Table 2. Achieved performances

	T-02 TBM	T-03 TBM
Best Day	33rings (46.2m)	33rings (46.2m)
Best Week	156rings (218.4m)	178rings (249.2m)
Best Month	555rings (777m)	653rings (914.2m)

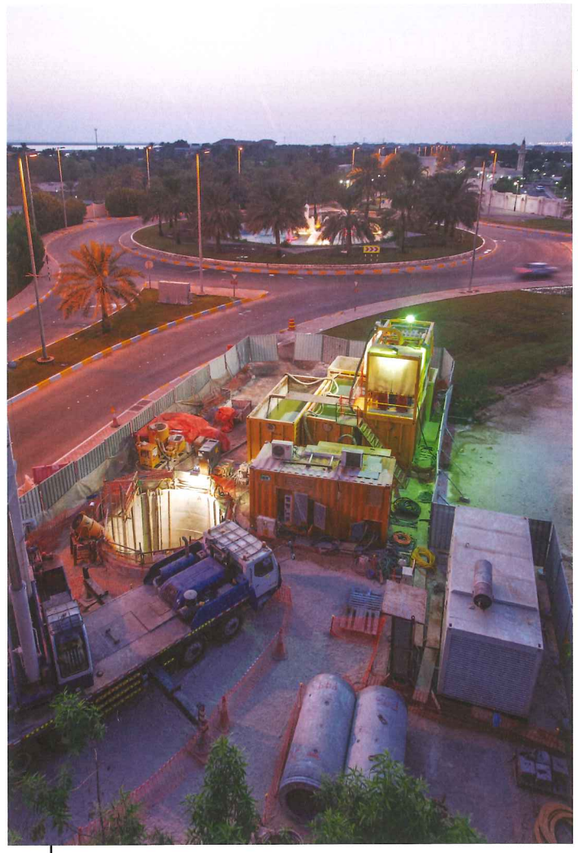
Source: Presenters

Below: TBM control cabin with operator

One of the reasons SFRC is more durable is that the fibres are "swimming" or "floating" in the concrete which means that they get an excellent interface between the fibres and the concrete with reduced voids in the contact zone between the steel fibre and concrete. With conventional reinforcement there is always a small void between rebar and concrete as the concrete shrinks during curing and this is where reinforcement corrosion starts. Hence SFRC can tolerate much higher chloride threshold values – 5-10 times more than conventional reinforcement. In addition, electrochemically the formation of anodes and cathodes is impeded as the fibres are minute. Only the fibres that poke out of the concrete surface will corrode with no deeper corrosion as the fibres are discontinuous. If internal fibres do corrode, the volume (rust) of a single fibre would be so small such that no tension in the concrete would be created - so no risk of spalling and cracking of concrete. So SFRC is the obvious choice for a long lasting sewage tunnel in the Middle East.

However, the structural design was not so easy – high bursting stresses were determined at the segment radial joints, up to 2 MPa which forced the use of some traditional rebar at such locations. . It was decided to place a limited amount of rebar along the radial joints. Four single bars connected with stirrups. . In addition these bars were difficult to hold in place with the traditional cage.

The durability design approach for traditional reinforced concrete (RC) was based on the service life approach as given in the fib Bulletin 34 "Model Code for Service Life Design", 2010. The same approach has nowadays been incorporated in the fib Model Code 2010 and ISO16204. The key tool of the fib-34 approach is a mathematical tool to determine the concrete cover and the quality of the concrete to make sure the concrete will last for 80 years. In case of chloride ingress the chloride migration coefficient determines the concrete quality. The chloride migration coefficient tells how fast the chlorides penetrate from the outside of the concrete to the rebar. The lower the value the denser the concrete and the slower the chloride migration happens. The coefficient is very much dependent on the binder content which needs to include OPC + FA + MS or GGBS if working in the Middle East.



Above: *Aerial shot of one of the worksites in Abu Dhabi*

Below: *Project timeline*

and followed the NT Build 492 method, was carried out in the laboratories in Abu Dhabi.

Cross checking was carried out in a laboratory in Denmark which gave comparable results. This test methodology was done in preference to the ASTM C 1202 method as it is a direct measure of chloride ingress and gives the input parameter for the fib Bulletin 34 modelling.

The concrete mix was also judged to be sustainable. A C02 reduction of more than 60 per cent was achieved compared to OPC concrete and traditional reinforcement as used in other bored tunnel projects such as the Copenhagen Metro or the Channel Tunnel between England and France.

For once sustainability and durability are going in the same direction.

In summary; SFRC is an obvious choice for segmental linings in the Middle East which need a long service life, with the following advantages; More durable than traditional reinforcement, Avoid a mix of steel fibre and traditional rebar, damage to segments is reduced with less repair and minor rejection of segments, linings can be thinner and sustainability advantages. For shafts improved constructability, reduced time and materials and reduced maintenance.

THE MAIN CONSTRUCTION ASPECTS OF STEP CONTRACTS T-02 AND T-03

Contract T-02 runs outside the Abu Dhabi Island (i.e. outside the main city centre) and passes underneath a low density urbanized area. It comprises the following scope of works:

- Main gravity sewage 5m ID tunnel, 15.5km length with depth varying from 35m to 59m;
- Three 16m ID work shafts (WS5, WS6, WS7) with depths varying from 45m to 64m;
- One vortex structure at WS6;
- Three 6m ID access shafts (AS4, AS5, AS6) with depths varying from 38m to 51m;
- Three adits from access shafts to main tunnel.

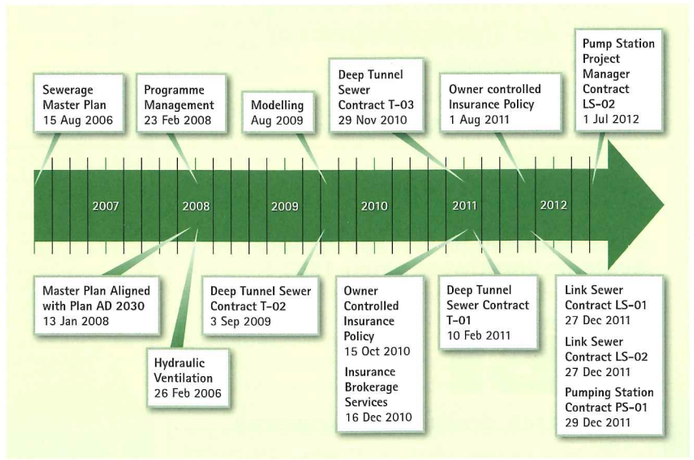
Contract T-03 comprises the following scope of works;

- Main gravity sewage 5.5m ID tunnel, 9.7km length with depth varying from 59m to 81m;
- Two 17m ID work shafts (WS8, WS9) with depth varying from 74m to 86m to be converted into access shafts at later stage;

Portland cement alone is not durable enough. Concrete with OPC + GGBS has a coefficient five times less than OPC concrete.

For a concrete cover of 65mm, the maximum limit the designers could tolerate, a maximum chloride migration coefficient of 2.4 x 10-12m²/s was determined. Only a high-performance concrete of grade C50/60 with a triple blend of 50 per cent OPC + 20 per cent FA + 30 per cent GGBS could comply with that low value. The fibre class was F1.4/0.6 (following the German approach for steel fibre design) and 40kg/m³ was used. It was not easy to develop the right quality of the concrete mix and the "fine tuning" of the concrete mix took 1 year to complete.

Mechanical testing of the concrete mix was also undertaken. This was done using the four-point bending test to verify the specified F1.4/0.6 fibre class. Actual segments were broken to verify that the fibres could be evenly distributed throughout the segment thickness. The durability testing for chloride migration, developed in Sweden



- Two 6m ID access shafts (AS7, AS8), with depths varying from 70m to 81m;
- Two adits from access shafts to main tunnel.

The main challenge to be faced by the contractor right from the project start was the tight construction programme:

- 3 Work Shafts to be excavated concurrently during the first year of the project;
- 4 out of 5 TBMs running at the same time (total of 25km bored over 21 months);
- 14 tunnel secondary lining fronts to advance concurrently during the finishing work stage (total of 25km over 19 months).

The considerable shafts depths rendered all the above more demanding. It was in fact the first time that depths up to 86m and water heads up to 84m were reached in Abu Dhabi, with a lack of case histories that could be used for guidance. This impacted on the selection of the construction methods, design of plant and equipment and logistics in general.

The overall ambient conditions represented another key construction challenge. The Abu Dhabi geology consists of a liner coastline with an alternation of sedimentary beds prone to karst phenomena. In addition, the hyper salinity of groundwater (Cl- up to 120,000mgl/l and S04 up to 5000mg/l on T-03) combined with the regional hot climate (temperatures regularly in excess of 40°C during summer months with humidity above 70 per cent) produces an extremely aggressive environment.

Efficient and effective logistics was a critical aspect for meeting the construction programme, in particular the planned TBM production rates. Key site installations at each Work Shaft included amongst others:

- one electrical generation substation (electric power network not available);
- daily storage of 240m³ of sweet water (water network not available for the expected consumption rates);
- one chiller station to cool water/ air from ambient (in excess of 40°C during summer) to TBM (26°C);
- a tandem of gantry cranes delivering the construction materials to and mucking out from shaft bottom; one vertical conveyor belt magazine at surface.

*Above: **Corrosion protection lining on the main tunnel***

SHAFTS

The temporary lining of the Work and Access Shafts was typically formed from diaphragm walls in the upper portion of the shaft and sprayed concrete lining in the lower. The continuous and watertight diaphragm wall lining was installed from ground level down to a typical depth of 45m with panels excavated in primary and secondary sequence, using bentonite slurry as a stabilising fluid. A hydromill capable of operating in any soft or hard material with accurate verticality (1:800 circumferential, 1:400 radial) was used for such works.

TBM LAUNCH CHAMBERS

The TBM launch chambers at each Work Shaft consisted of a 60m long headshunt plus a 40m backshunt. The chambers were designed following a review of the available S.I. (permeability data in particular) and the actual geology encountered during the shaft excavation.

The excavation clear inner section was sized based on the TBM cut diameter. Ground support was provided by wet

shotcrete reinforced with steel fibres in combination with steel arches. Advancements were maintained shorter than 1m.

The tunnel headwalls were reinforced with fibre glass dowels.

TBM TUNNELS

T02 tunnels presented a 5.50m ID lining formed from 5+1 280mm thick PCC trapezoidal segments sealed with EPDM gaskets. T03 tunnels had a 6.00m ID lining formed from 5+1 350mm thick PCC trapezoidal segments also sealed with EPDM gaskets. On both contracts the ring, of universal type, was 1.4m long and used guide rods. The segments were reinforced with a combination of steel fibres and traditional cages installed in correspondence of the radial joints.

EPBMs were chosen on the basis of the following criteria:

- Machine capable of operating in close mode as per Client's requirements;
- Clay content in the majority of the rock formations, which would be very difficult to handle in the separation treatment plant required by a Slurry Shield;
- EPBM capability to cope with the expected ground conditions maintaining face stability;
- Salini - Impregilo's extensive experience in driving EPB machines.

CORROSION PROTECTION

The Corrosion Protection Lining (CPL) for the main tunnel comprises a 2.5mm primary lining of HDPE Anchor Knob Sheet embedded into a 250mm secondary lining of un-reinforced cast in situ concrete. The same concept was previously used on the Singapore DTSS Project. The finished sewer presents an inner diameter of 5m (T-02) and 5.5m (T-03) with the primary lining covering 320° of the upper internal circumference. The HDPE liner of each tunnel section presents different colours for traceability in case of repair. The CPL for each bored tunnel was constructed from two independent work faces, one travelling upstream and the other downstream. Both fronts started from the centre of the main tunnel, each of them using two shutters of 12m length for forming the vault. Similarly to the TBM drives, this phase of the project required lot of planning and logistics design with also considerable investments in plants and equipment. Typical weekly productions for a work front were in the range of 120m of tunnel lined.

Questions from the floor

Charles Allen, OTB Concrete: Did the team consider coating the extrados and joints of the segments with an epoxy emulsion?

Carola Edvardsen: Several epoxy coatings were tried and underwent exposure testing – but they did not last therefore they were not allowed.

Martin Knights, CH2M: What were the benefits and dis-benefits of adopting a programmatic approach?

Shahzad H Orakzai: This was one of the key challenges. Project management in general and programme management typically was totally misunderstood not just within own organisation but in area as a whole. Generally speaking within the market the element of trust was missing, through this Programme we have been able to improve on that. We knew that the Programme was extremely challenging from all aspects. We were able to disassociate this particular investment from the rest of our CAPEX. We had about GBP 1.2bn to deliver in about 6 years, a lot in terms of market capacity. A programme approach allowed us to disassociate the STEP scheme from existing policies and procedures of the company which were sometimes quite constraining in terms of contract form etc. It also helped us integrate consultants as part of the Client organisation.

On the IDRIS project in Doha, the contractor is considering using precast concrete segments with an integral synthetic lining and in-situ sealing of the joints by vulcanisation. Has this been looked at here?

Carola Edvardsen: yes we looked at this; not all projects at IDRIS are using this approach.

Peter Jackson, Cowi: We did look at this approach but with time constraints it wasn't possible to change the solution. You do end up with welded joints which we weren't too excited about.

Richard Southerton, Aecom: What bolts were used in the segmental lining joints?

Mirko Martini: We used guide rods and no radial bolts between segments. Temporary bolts were used on T-03 during the TBM drive but were removed later on.

Neil Moss, London Underground: How did you determine the thickness of the concrete behind CPL?

Carola Edvardsen: The 250mm thickness was determined based on multiple factors, such as the horizontal curves along the tunnel alignment, the length of the formworks used to cast the CPL and their positioning accuracy. The lining is designed to take the external groundwater pressure.

Rapporteur: Nicholas Tucker, Mott MacDonald

CONCLUSIONS

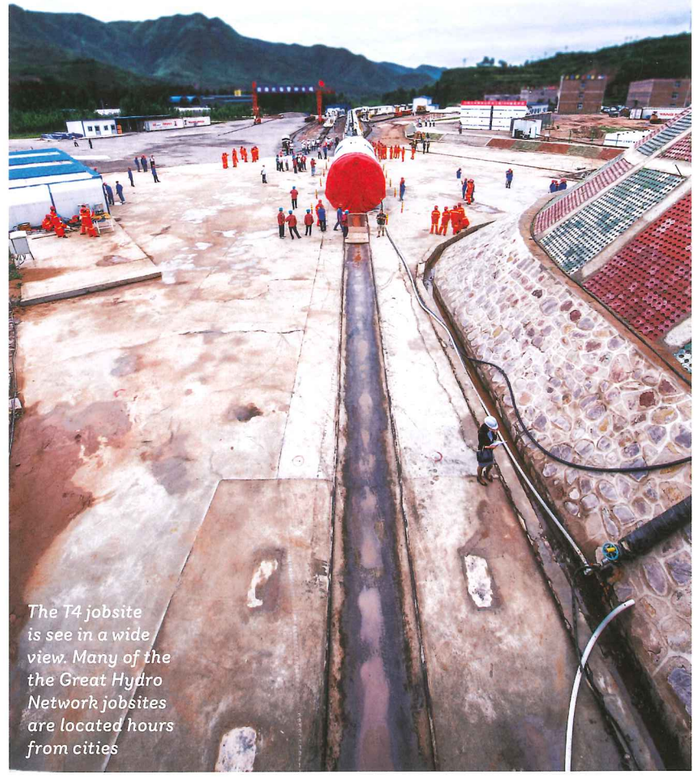
The STEP deep gravity Tunnels project was deemed a major success. The new gravity sewer system will meet the Plan Abu Dhabi 2030 demand.

The tunnel was completed with savings and with an amicable closure – no disputes and with highly successful branding results.

The new initiatives of staff secondment, co-location with consultants, open-book consultancy contracts and design-build construction contracts were all deemed successful. Apart from facilitating knowledge transfer from the private sector to the seconded staff, the local market and construction industry skill base has also been enhanced because of successful delivery of massive construction projects.

Key enablers have been; proactive risk management (packaging of works, form of contract and contract administration), risk appointment (unforeseen physical conditions) and a partnership approach to contract administration

CHINESE DIVERSIONS


The T4 jobsite is see in a wide view. Many of the the Great Hydro Network jobsites are located hours from cities

Desiree Willis, technical writer for TBM manufacturer *Robbins* gives a run down of some of the design and operational requirements for machinery supplied to the tunnel projects making up Shanxi Province's Great Hydro Network (GHN)

AT 5,464KM LONG, the Yellow River is the second longest in China and provides water to over 12 per cent of the country's 1.4 billion people. Its reach falls short, however, in chronically dry Shanxi Province – a region that only receives about 473mm of rainfall annually, and has in recent years experienced severe droughts coupled with rapid economic growth.

Sprawling equally long at thousands of kilometres, the province's Great Hydro Network (GHN) is a mind-boggling feat of human engineering in the making. The network of tunnels will source water from the Yellow River to benefit up to 24 million people in the drought-ridden region. Once complete the tunnels will supply 2.3 billion cubic metres of water per year, improving both capacity and reliability of water supply.

"Shanxi Province has rich coal resources, but the economic and social development is mainly restricted by the shortage of water resources. The GHN project will reallocate the mainstream configuration of stored water as well as the water from the Yellow River to where it is needed most. It will greatly improve the water resource usage and help economic growth, so people in China look forward to the project's success very eagerly," said Weihao Li, project manager for Robbins China.

The project is a continuation of efforts in the region to transfer water – the Shanxi Wanjiazhai Yellow River Water Diversion Project, initiated in 2001, spanned over 10 years and 300km of tunnel. The network transports water from Wanjiazhai Dam to far-reaching industrial areas in Taiyuan, Pingsuo and Datong.

On that project, multiple Double Shield TBMs excavated long reaches of tunnel and erected a honeycomb segmental lining in all of the tunnels. In that sense, the Great Hydro Network takes a cue from past projects in the region, but aspects of TBM design and treatment of the difficult ground on the vast project are all new.

A NEW GENERATION OF WATER TUNNELS

Tunnels throughout the GHN project are being excavated mostly by drill and blast, with four designated TBM-driven tunnels. "About half of all the tunnels under construction are very deep underground. The terrain and geological structure in the area is complex; some tunnels cross coal seams and below protected areas, underground springs and other unique geological structures. The tunnels carry construction risks including methane gas, groundwater and rock bursting," said Lijuan Xu, production control planner for Robbins China. She continued: "The construction area is about 115,000km². The coordination required for land acquisition for construction sites, demolition,

Desiree Willis
The Robbins technical writer has covered a range of topics for *Tunnels and Tunnelling*

compensation and resettlement has been a huge task."

Robbins has supplied three Double Shield machines on various lots. Contractor China Railway 18 Bureau Group Co. Ltd. is responsible for Tunnel 1 (T1), a 26km long drive through limestone, dolomite, mudstone, amphibolite, and gneiss. Tunnels 2 and 4 (T2 and T4) are using 5m and 4.2m Double Shields, respectively, on 25 km and 15.6km long drives. Both sites are operated by Shanxi Hydraulic Construction Engineering Bureau. Tunnel 3 (T3) is using a TBM from another manufacturer.

All three Robbins TBM-driven tunnels are located in Class III to Class V rock, and excavation was expected to be challenging from the outset. In particular the rock at T4 tested as over 27 per cent Class V and nearly 23 per cent softer soils, with just 36 per cent of the tunnel in Class III rock.

The jobsites are located in mountainous areas and logistics of site preparation ahead of the TBMs was another challenging task. "The T4 jobsite is quite remote, about 1.5 hours from the nearest town," explained Robbins project manager Mark Belli. "The contractor had to finish an access road to get to the site before we could prepare the portal."

The other sites, T1 and T2, are located about 45 minutes from towns, but even those required major jobsite preparation work.

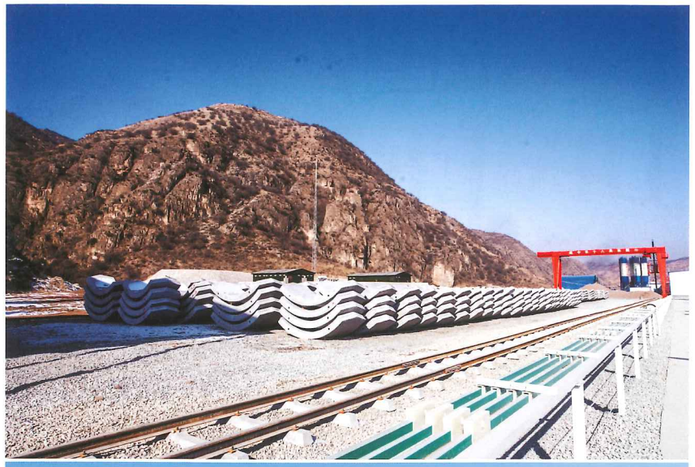
"On T2 they had to reconstruct the access road to go around the camp, because the original road would have gone right through the portal." All three of the sites required onsite work camps that were built in greenfield-type areas. Structures including segment plants, spares inventory, and even convenience stores for the workers were all built from the ground up.

Workshops were built near each portal to repair and maintain equipment, such as cutter discs, allowing for quicker access to supplies in what will become very long tunnels.

TBM DESIGN

The trio of TBMs have been designed to meet the geological challenges and long tunnel lengths. All three machines were assembled in Shanghai, then reassembled at the jobsites. The TBMs were built with components from Italy, Germany, Switzerland, China, and the U.S.

The tunnel is lined with precast concrete segmental rings. The segments are of hexagonal type and built in rings of four, each 1.2m long. No steel reinforcement is included in the design, but gaskets between each segment help to seal them. Afterwards pea gravel is pumped into the annulus through a port in the segments to backfill voids, while a layer of grout seals them into place.



Top: Hexagonal segments are manufactured and stored at the large T1 jobsite

Above: Officials unveil the TBM at T1 before a crowd of onlookers

"The TBMs have some redundant supporting equipment systems that have caused us to lengthen the back-up on each machine to between 45 and 50 decks. Each deck is 6 to 10m long. We have two different grout systems and at least one additional pea gravel system," said Belli. Additional extras include redundant air compressors, as well as a rescue chamber, cafeteria, and toilet.

A specialised car mover on the back-up allows two empty muck cars to be brought in with each supply train. The cars can be slid into place without needing a locomotive so that downtime in the long tunnel is minimised. The two extra muck cars have enough capacity for about two machine pushes or five rings, and can be pulled out with the next muck train.

The different diameters of the machines also necessitated unique design features, continued Belli. On all of the machines, squeezing the internal elements, particularly the hydraulics, into a small diameter was a challenge. The T1 and T2 machines, at 5.06m in diameter, were able to use conventional torque cylinders in their design. The T4 machine, however, at just 4.16m in diameter, required a redux of an old design—the

lattice cylinder arrangement. The design is reminiscent of earlier Double Shield designs and offers a space advantage for machines less than 6m in diameter. Torque arms normally occupy a large amount of space on Double Shield TBMs, and the design opens up more area to position the motors on smaller machines. It also leaves the invert open, which can aid in maintenance such as cutter changes.

"The lattice cylinder design allows for greater control of steering in a smaller machine. However the drawback is that it gives so much steering freedom and there are so many features, the operator has a larger learning curve when steering the machine," says Belli.

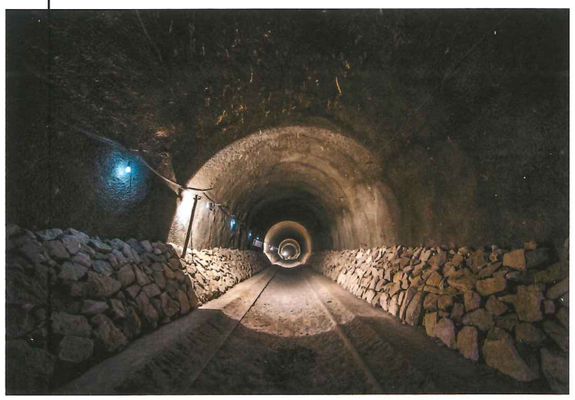
In the early startup and boring phase, Robbins drove the TBMs with the customer, providing special training to speed up the learning curve. Modifications were later added to the hydraulics of the lattice cylinders and the skew ring, which corrects roll on the TBM. The modifications allow for easier steering control on the T4 TBM.

CHALLENGING GROUND CONDITIONS

The small Double Shield for T4 was the first to launch in summer 2014. The machine began boring in two eight-hour shifts, with a third eight-hour shift dedicated for maintenance. The vast jobsite covers an area of 133 square kilometres and employs an army of workers. "We have 180 people all living at the T4 jobsite. We have a good environment here, with people working hard at muck removal, TBM operation, and segment casting," said Jinping Li, Onsite Director for T4, Shanxi Hydraulic Construction Engineering Bureau.

Obstacles presented themselves nearly from the outset, as ground changed quickly between soft, weak rock and hard, abrasive rock—a condition that caused frequent cutter changes. Clay clogged the cutterhead, while water inflows occurred from a lake overhead. Despite the challenges, the contractor is hopeful that the 15.6km tunnel will be completed in 2017.

Below: The T1 starter tunnel



The machine at T1 was the next to launch in early 2015—the assembly of which was a challenge due to timing. "It was winter and the temperatures reached -25ºC while we were assembling, testing and launching the TBM.

"It brought great difficulties to the normal operation of the TBM, so we had to use heating equipment and a greenhouse was installed to keep the whole TBM warm. With those strategies the TBM testing and launching ran smoothly," said Xingkun Yang, Project Manager for T1, China Railway 18 Bureau Group Co.

Nearly 300 people work and live onsite in a schedule that begins with a four-hour maintenance shift at 7:00 AM, followed by an eight-hour day shift and 12-hour night shift. Since its launch the TBM has bored over 2km.

Design changes were made due to the tunnel being bored on a decline. Yang added: "As this lot is a decline boring tunnel, all the construction wastewater is discharged by a pump. We worked with the manufacturer's field service and design teams to come up with a better solution. We decided to reuse some of the TBM equipment cooling water for equipment cleaning, belt washing and grout making for cement grouting, which reduces the needed water supply and drainage for energy saving."

As the TBM progresses further into the tunnel drive, logistics will be of increasing concern. "There is only one adit (for ventilation and drainage) in the middle of the 26km tunnel. Therefore, we require the highest standards for the water supply, power supply, ventilation, materials supply, water discharge and muck removal. It is a great challenge for us," said Yang. The contractor expects the long tunnel to be completed in 2019.

The last of the machines, for T2, was launched in spring 2015. About 320 people work and live on the jobsite that covers 20sq.km. The T2 machine experienced similar varying ground conditions to those at T4, vacillating between soft rock and hard, abrasive rock.

"There are still some problems. Currently, we have water bursting in the tunnel, so we need to use probe drilling to detect the geology ahead of us," said Zhimin Li, deputy project manager of T2 for Shanxi Hydraulic Construction Engineering Bureau. Other challenges include the decline nature of the tunnel—the jobsite opted for rubber-tired vehicles to haul muck as the gradient exceeded the limit of rail cars. The 25km long tunnel is expected to be completed in 2017.

A LOOK AHEAD

As the project continues to advance, the benefits of the water tunnels remain clear. About two-thirds of all surface rainwater that the arid province receives annually are not captured, but flow out of Shanxi. The GHN will improve water storage capabilities as well as improve the reliability of the water supply. The vast network of tunnels will increase the province's total water supply by 2.3 billion cubic meters, and its scope of supply applies to an area roughly 76,600sq.km, about the same size as the Czech Republic.

Roughly 72 per cent of the province's population, or about 24 million people, will see a benefit from the tunnels, including 11 large cities and 70 counties.

To put it simply, GHN is tunneling on a grand scale, and it will be a project to follow over the next years as work progresses

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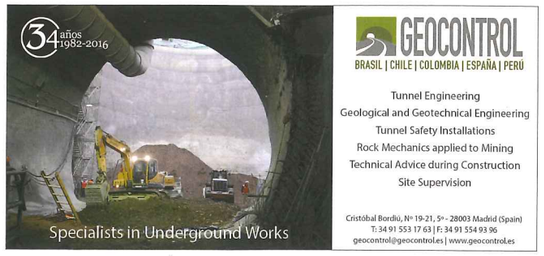

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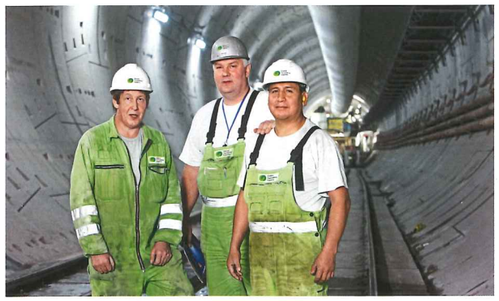

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What's on

2016

Bauma Munich
11-17 April 2016
Munich, Germany
The 31st meeting of the world's largest trade fair for construction machinery, building material machines, mining machines, construction vehicles and construction equipment returns to its traditional home: the Neue Messe Munchen exhibition centre in eastern Munich.
www.bauma.de/en

Infrarail
12-14 April 2016
London, UK
The UK's definitive railway infrastrcture exhibit. Infrarail 2016 takes place against a background of high levels of investment in Britain's main line and urban rail infrastructure.
www.infrarail.com

International Symposium on Submerged Floating Tunnels and Underwater Structures
20-22 April 2016
Chongqing, China
This event, organised by the National Engineering Laboratory for Highway Tunnel Construction Technology, the China Institute of Mechanics, the Chinese Academy of Sciences, and the University of Naples will cover all topics from design to operations.
www.cmct.cn

World Tunnel Congress and NAT
22-28 April 2016
San Francisco, California
The 2016 World Tunnel Congress (WTC) and the 39th General Assembly of the International Tunnelling and Underground Space Association (ITA) will be held in conjunction with NAT.
www.wtc2016.us

Conference and Exhibition on Mass Mining
9-11 May 2016
Sydney, Australia
The MassMin series of conferences remains the pre-eminent global bulk mining event, attracting hundreds of delegates from all major mining companies and countries.
www.ausimm.com.au

Underground Construction Prague and EETC
23-25 May 2016
Prague, Czech Republic
Delegates are cordially invited to the thirteenth Underground Construction (UC) Prague Conference.
www.ucprague.com

Swiss Tunnel Congress 2016
15-17 June 2016
Lucerne, Switzerland
The annual Swiss Tunnel Congress (STS) is organised by the Swiss Tunnelling Society and is the premier event for tunnelling in Switzerland. Approximately 800 delegates attend from around 15 nations to take in the high quality presentations.
www.swisstunnel.ch/en

GeoChina International Conference
25-27 July 2016
Shandong, China
This conference will provide a showcase for recent developments and advancements in design, construction, and safety Inspections of transportation Infrastructures and offer a forum to discuss and debate future directions for the 21st century. Conference topics will cover a broad array of technical issues.
www.geochina2016.geoconf.org

Urban Underground Space & Tunnelling Summit
6-9 September 2016
Singapore
Asia's Leading Urban Underground Space & Tunneling Summit will return to discuss leading practices, innovative techniques and sustainable solutions for Design, Engineering & Construction of Underground Space and Tunneling Projects
www.equip-global.com

No Dig Live UK
20-22 September 2016
Peterborough, UK
Following the success of No Dig Live UK held in September 2014, the 13th biennial trenchless technology exhibition, outdoor demonstrations and seminars will return to Peterborough. Visitors to thie show were offered a wide ranging programme of educational opportunities.
www.nodiglive.co.uk

Innotrans
20-23 September 2016
Berlin, Germany
InnoTrans is the leading international trade fair for transportation technology, and takes places every two years in Berlin, Germany. The event is sub-divided into the five segments Railway Technology, Railway Infrastructure, Public Transport, Interiors and Tunnel Construction.
www.innotrans.com

Nordic Grouting Symposium
26-27 September 2016
Oslo, Norway
The Norwegian Group of Rock Mechanics (NBG) and the Norwegian Tunnelling Society (NFF) have the pleasure to announce that the 8th Nordic Grouting Symposium will take place 26-27th of September 2016. Nordic colleagues are invited to present papers and exchange experiences.
www.nordicgrouting.com

BTS Conference and Exhibition
11-12 October 2016
London, UK
The British Tunnelling Society is pleased to announce the highlight of its 2016 events calendar, held at the QE2 Conference Centre in Westminster. Presentation synopses of 250 words are now being accepted for consideration with a deadline of 26 February. For more details please visit the society website.
www.britishtunnelling.org.uk

Expo Tunnel
19-21 October 2016
Bologna, Italy
ExpoTunnel is an exhibition dedicated to the world of tunnelling, drilling, mining, underground construction and research. It is an opportunity to meet in a global framework of supply and demand of high technology and its field applications, with the chance to learn new methods and harness new techniques.
www.expotunnel.it

Bauma China
22-25 November 2016
Shanghai, China
Bauma China is Asia's largest and most important event for the construction industry. It attracts international buyers—a fact that guarantees a high return on your investment as well as sustainable success. The show is a platform for product presentations and a grand industry party for communication.
www.bauma-china.com

TBM Digs
16-18 November 2016
Istanbul, Turkey
Turkey has a great potential for tunnelling work, and in the near future the country is expecting to see upwards of USD 35bn of investment in the underground. The Turkish Tunnelling Society is also rapidly expanding its membership. This looks to be an impressive event.
www.tbmdigsturkey.org

Bauma Conexpo India
12-15 December 2016
Delhi, India
The International Trade Fair for Construction Machinery, Building Material Machines, Mining Machines and Construction Vehicles—provides the construction industry in India with a professional platform for networking, investment and the exchange of ideas and information. The show launched in 2011 and did an impressive job of putting this quality standard to the test.
www.bc-india.com

2017

World Tunnel Congress
9-16 June 2017
Bergen, Norway
The theme of the 2017 WTC is 'surface problems - underground solutions'. The Norwegian tunnelling industry produces tens of kilometres of drill and blast tunnel every year and is keen to share its expertise with attendees. *www.wtc2017.no*

GeoMEast2017
15-19 July 2017
Sharm El-Sheik, Egypt
Recent rapid construction in Egypt has provided great opportunities for tunnel engineers to use their knowledge and talents to solve many challenging problems with innovative solutions and cutting-edge technologies.
www.geomeast2017.org

2018

World Tunnel Congress
20-26 April 2018
Dubai, UAE
The World Tunnel Congress heads to the United Arab Emirastes in 2018, and demonstrates the rise of the Middle East to the centre stage of the global tunnelling market. The region boasts a number of impressive megaprojects.
www.uaesocietyofengineers.com

The British Tunnelling Society

The BTS has a membership of over 814 individual and 266 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. Regular BTS monthly meetings are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month. In recent years, the BTS Young Members (BTSYM) group has also begun hosting its own events.

Harding Prize Presentations
21 April 2016
The annual competition is named in honour of Sir Harold Harding, founder chairman of the BTS and is open to engineers aged 33 or under. Entrants must submit an original paper relating to any aspect of tunnelling which they consider of interest to the industry. The winning paper is selected by members of the BTS Committee. Further details can be found on the society website under 'The BTS' tab, 'Awards' section. The winner of the Harding Prize receives two tickets to the BTS Annual Dinner, a copy of Sir Harold's book 'Tunnelling History and My Own Involvement', and a cheque for GBP 500.
Speakers: Harding Prize finalists

BTS Annual Dinner
6 May 2016
The BTS holds an Annual Dinner each year in May. The 28th Annual Dinner will be held at the Brewery on Friday 6 May 2016. Further details will be available shortly before booking opens in early February. Last year's event drew 848 attendees, the largest number since the BTS began keeping records in 1996.
Tickets for this event will become available from the BTS website

AGM followed by presentation on Singapore's Thomson Line
19 May 2016
Singapore's 30km all-underground Thomson Line (TSL) involves the operation of 30 TBMs to complete the twin running tunnels and the construction of 22 underground stations including 6 interchange stations. This involves a number of challenges in complex urban areas and partially reclaimed land. The presentation will concentrate on TSL-A and TSL-D with project features such as varying geotechnical conditions, SFRC and RC segment design, design of bored tunnels in consolidating marine clay, under- and overcrossing of existing railway lines, tunnelling beneath operational stations, as well as three-way Interchange Stations.
Speakers: Andreas Raedle, Leo Suhaendi and Rob Harding of Arup, and a yet to be confirmed representative of the LTA

Harding Memorial Lecture
16 June 2016
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 by an eminent speaker who presents a lecture on their specialist, tunnelling related subject.
The speaker has yet to be confirmed

The Emscher Interceptor
22 September 2016
A presentation on the construction of the Emscher wastewater interceptor tunnel which runs 35km from Dortmund to Bottrop. Pipe jacking ranged from 1.6 to 2.8m internal diameter with interlinking conduit sections in excess of 1,100m in length.
Klaus Rieker, Wayss & Freytag

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Greg James: greg.james@ice.co.uk
Paul Perry: paul.perry@ch2m.com

Contact us

Alex Conacher

Editorial

Editor
Alex Conacher
Tel: +44 7429 156 753
alex.conacher@tunnelsandtunnelling.com

Nicole Robinson

North America Editor
Nicole Robinson
Tel: +1 612 940 2780
nicole.robinson@tunnelsandtunnelling.com

Contributing Editor
Sally Spencer
sspencer@progressivemediagroup.com

Sally Spencer

Contributing Editor
Keren Fallwell
kfallwell@progressivemediagroup.com

Associate Publisher
Jon Young
Tel: +44 20 7406 6622
jon.young@worldmarketintelligence.com

Keren Fallwell

Sales

Group Sales Manager
Tom Willard
Tel: +44 20 3096 2608
twillard@tunnelsonline.info

Tom Willard

European Sales
Randolf Krings
Tel: +49 611 5324 416
Fax: +49 611 5324 519
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North American Sales
Clive Bullard
Tel: +1 845 231 0846
Mob: +1 845 309 0892
cbullard@cs.com

Italian Sales
Davide Ferrati
Tel: +39 331 521 8050
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Production

Production Controller
Loraine Lee
Tel: +44 20 8269 7799
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Head Office

World Market Intelligence
John Carpenter House
7 Carmelite Street
London EC4Y 0BS
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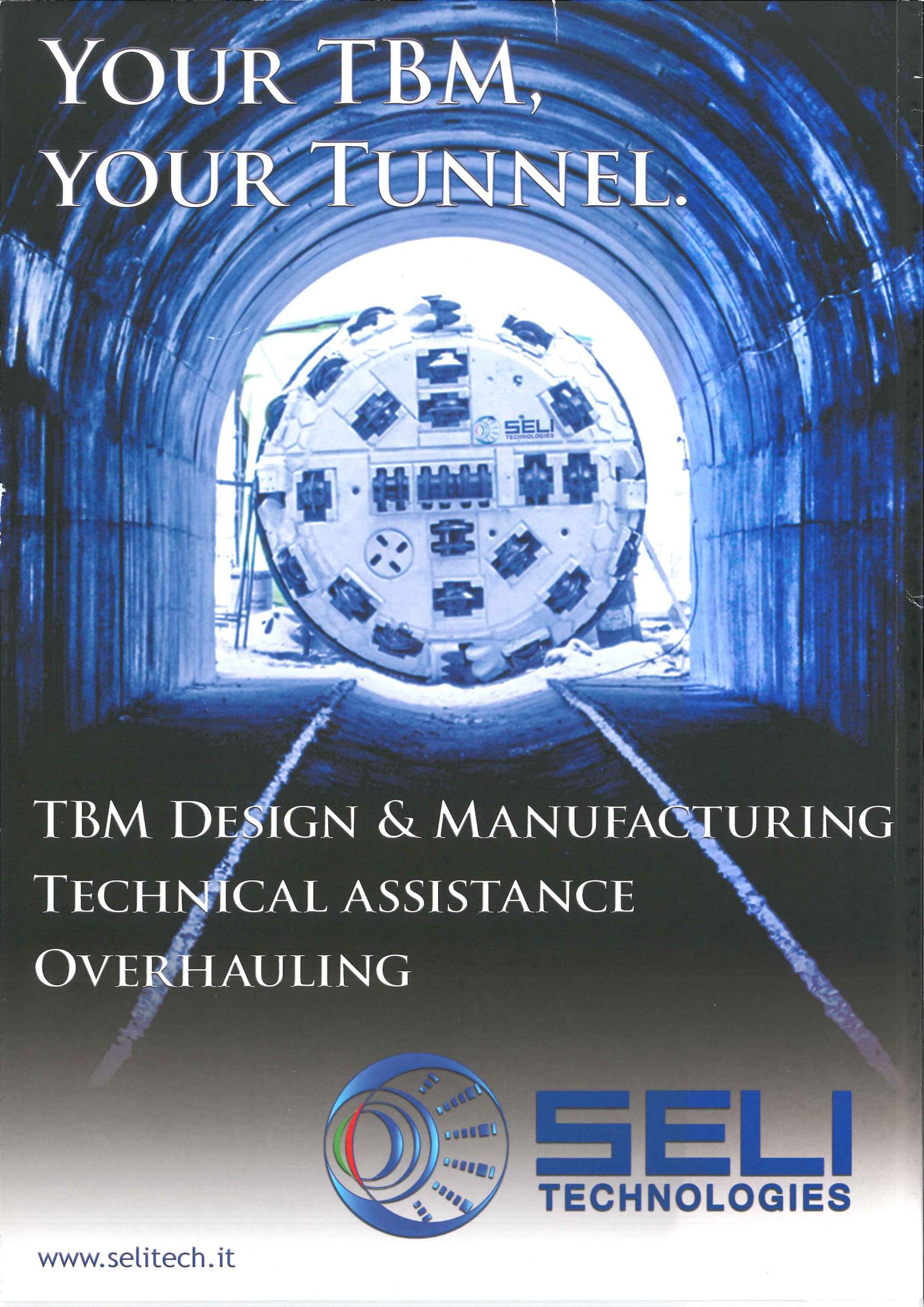

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