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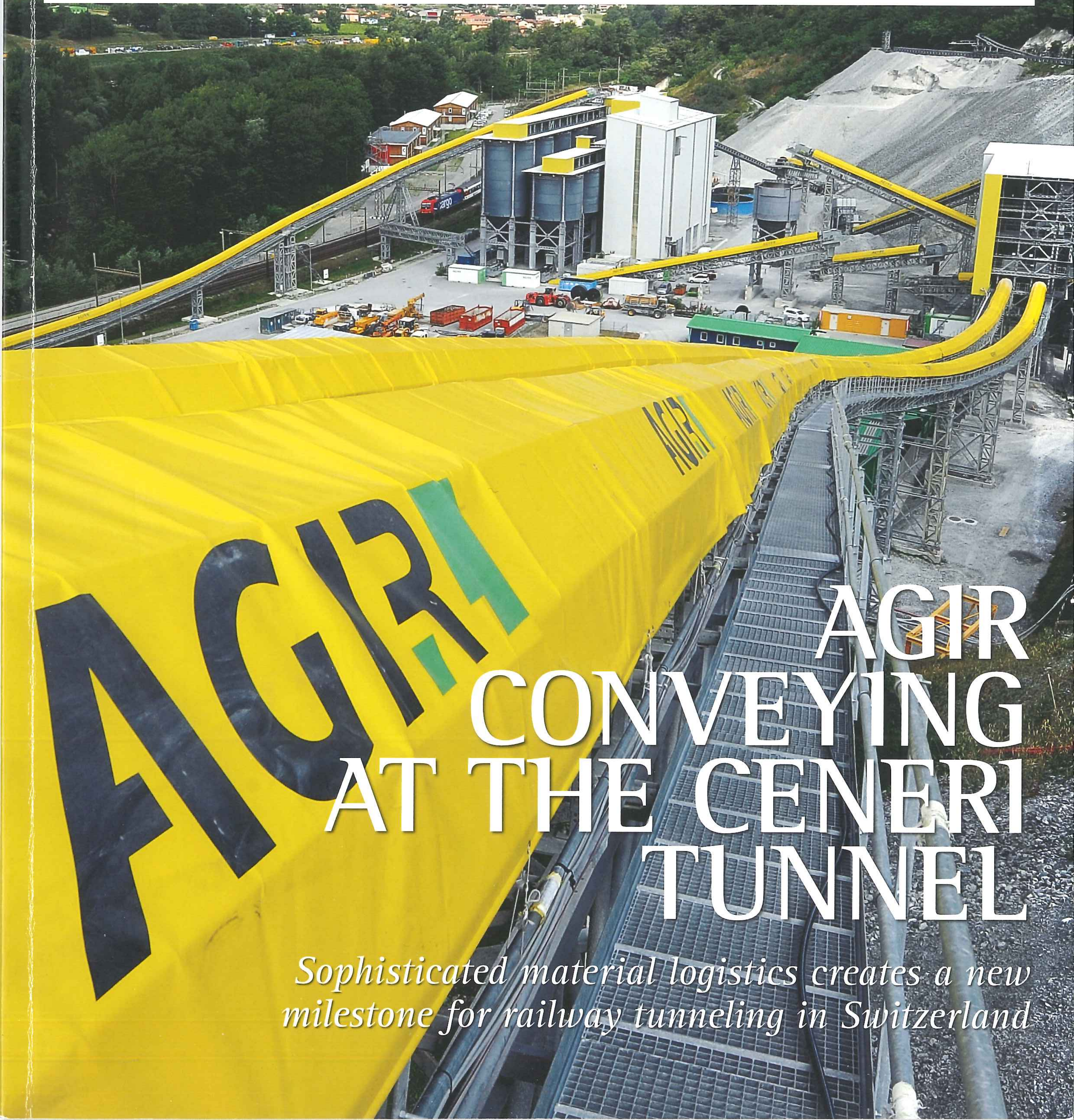


AGIR CONVEYING AT THE CENERI TUNNEL

Sophisticated material logistics creates a new milestone for railway tunneling in Switzerland

INTERNATIONAL EDITION
October 2015

Tunnels AND TUNNELLING

+ Middle East
+ Icing shields
+ Underground Utilities

HIGH PRESSURE

Extreme TBM tunnelling conditions

ANOTHER HURDLE

IN A trip to China, the UK's chancellor George Osborne has been trying to spark interest in High Speed Two (HS2) investment opportunities. Some GBP 24bn (USD 36.5bn) was laid out for the consideration of potential spenders at an event in Chengdu, the capital of Southwest China's Sichuan province. Osborne tweeted from the event: "Today we open bidding process for HS2 construction with contracts worth 11.8bn. A milestone in a project key to Britain's future."

The visit by Osborne is timed to precede an October state visit to the UK by Chinese president Xi Jinping.

'Great Northern Leaders' (northern City Councilors) also joined Osborne on the trip to show their interest and enthusiasm for what they see as a vital project and potential boost to their regions. The visit also took in trips on the country's vast high-speed rail network for inspiration and a bit of symbolism.

The Chancellor was immediately and predictably criticised by anti-HS2 campaigners, as Parliament has yet to approve the scheme. Although at the time of writing, it looks like both major political parties will back the project.

The manager of the Stop HS2 campaign Joe Rukin said: "The Chinese way of doing things certainly seems to be rubbing off on George Osborne, as he has decided to start a GBP 12bn bidding process without any democratic mandate to do so, as Parliamentary approval of HS2 is still at least a year away."

Penny Gaines, chair of Stop HS2 added: "There are very real concerns over these plans to encourage Chinese firms to bid for such large HS2 construction contracts. What is really key is that HS2 does not have the go ahead now for construction and HS2 will never have the go ahead unless the HS2 Hybrid Bill, currently being scrutinised by Members of Parliament, passes the third reading and gets Royal Assent."

People have been speaking more and more about the change in public opinion towards infrastructure projects in general in this part of the world.

The BBC's three-part Crossrail documentary released the other year is often cited as a big part of that, and some of these lessons are being taken abroad.

Anecdotally, tunnelling in particular is becoming more popular. In a letter to Tunnels and Tunnelling (see August issue, page 7) consultant Bill Grose told the story of a exchange between rugby players and young tunnellers in a bar after a day of lectures during the BTS Design and Construction Course. The rugby players were fascinated to meet tunnel engineers, and Grose called it "a tipping point in the street cred of tunnellers".

I saw a later exchange, however. One of the rugby players asked an engineer which project she was working on. When he heard that it was HS2, he walked away in annoyance.

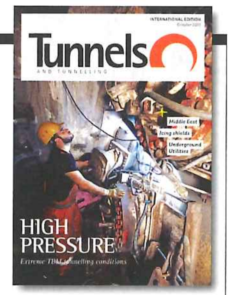
The industry should not get complacent with its recent public relations successes. The fact remains that a lot of the public do not want to see the start of work on HS2, and are not afraid to make themselves heard

editor@tunnelsonline.info

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

Alex Conacher
Editor

Cover
Challenging conditions for TBMs are explored by Herrenknecht in the cover story, see page 36



Next issue
In the next issue of Tunnels and Tunnelling we will cover the Asian market, as well as road tunnel operations, including articles from PIARC regarding the sustainability of tunnel ventilation, and a piece by Mouchel on ease of emergency egress

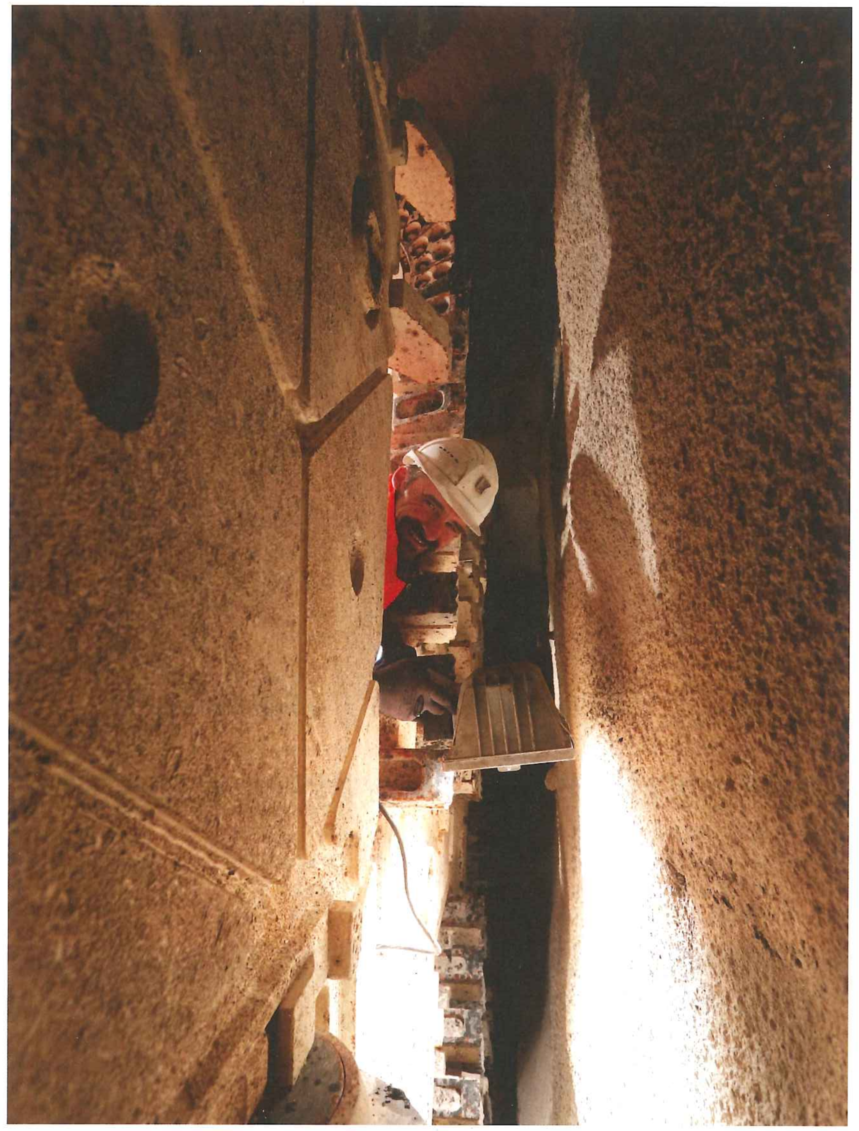
This month...

20 YEARS AGO

Detailed design plans for the Preveza-Aktio immersed tube tunnel in western Greece have just been submitted to the Greek Ministry of the Environment. The joint venture of Christiani & Nielsen with Greek partner Technical Company of General Constructors, has been working since December 1994 on a design and build contract for the USD 61M scheme, which will provide a road crossing under the strait between Preveza and Aktio. Running a total length of 2,366m, the project consists of a 1,000m-long underground section.
Tunnels and Tunnelling, October 1995, p.10

40 YEARS AGO

Five giant tunnels will be built to connect the West Bank of the Suez Canal to Sinai as part of a USD 9bn redevelopment of the free trade zones, states a report on the Middle East by the Henley Centre for forecasting. It is understood that Saudi Arabia will contribute a substantial loan towards the redevelopment project. It has been reported that Iran will provide USD 100M dollars to finance a tunnel at El Shatt, 7km north of Suez. Austria has agreed to contribute technical assistance and a small goodwill contribution towards the finance for the El Shatt tunnel following a political meeting in June. The El Shatt tunnel is believed to be of the reinforced concrete box type with single carriageway, dual lane accommodation for traffic.
Tunnels and Tunnelling, September/October 1975, p.11



Above: A worker at the face of the Filder Tunnel, page 41

Key people in this issue

NEEL GOORVADOO
Neel Goorvadoo worked as Lead Tunnel Engineer for Tube Lines, part of Transport for London at the time of his interview in this issue of Tunnels and Tunnelling. He led a small dedicated team of tunnel and civil engineers responsible for maintaining and enhancing existing tunnel assets on the LU deep tube tunnels, namely Jubilee, Northern & Piccadily Lines. Now working at CH2M as associate director for tunnels, he is still based in London. He is interviewed in this issue regarding the re-lining of a problematic section of tunnel on the Jubilee Line between Baker Street and Bond Street. Read about his work on page 30.

WERNER BURGER
Werner Burger is the head of engineering and member of the Traffic Tunnelling Executive Board at Herrenknecht. Burger is one of the world's foremost experts in mechanised tunnelling technology and has been responsible for the development of TBMs at Herrenknecht for some 25 years. He studied mechanical engineering from 1978 to 1982 at the Offenburg University of Applied Sciences in Germany and joined Herrenknecht in 1985 from the automotive industry. In this issue he looks at some challenging cases of TBM use in the modern tunnelling industry. See page 36.

OARS BREAKTHROUGH

USA — The City of Columbus Public Utilities department celebrated the hole-through of the TBM mining the 7.25km-long Olentangy Scioto Interceptor Sewer (OSIS) Augmentation Relief Sewer (OARS) sewer tunnel on September 10.

A joint venture of Kenny/Obayashi received notice to proceed on the phase 1 September 2010. The USD 264.5M contract included the entire 20ft-diameter tunnel; Shafts 1, 2 and 6; OSIS Relief Structure at Shaft 6, Screen Building over Shaft 2, West Gate Chamber. Phase 2 began in August 2011 and involves construction of three more shafts, a pump station, pump electrical building, river overflow structure and other infrastructure. The overall project is currently scheduled to be completed in late summer 2017.

The OARS tunnel will include three relief structures that will divert wet weather combined sewer flow from the OSIS to the OARS tunnel.

The OARS project will control all of the relief structures where the sewers currently overflow to the river in the downtown riverfront area.

The tunnel is being built approximately 170ft below ground, reducing risks associated with construction at more shallow levels.

New M5 tunnel project awarded

AUSTRALIA — A Leighton Contractors, Dragados and Samsung C&T joint venture has been selected as the preferred contractor to design and construct Sydney's AUD 5bn (USD 3.51bn) New M5 Motorway.

The New M5 tunnel, Stage 2 of WestConnex, Australia's largest integrated transport and urban revitalisation project, is being delivered by Sydney Motorway Corporation (SMC), on behalf of the NSW Government.

The New M5 will run via tunnel from the existing M5 East at Kingsgrove to a new interchange at St Peters, substantially improving east-west corridor access between the Sydney CBD, Port Botany and Sydney Airport precincts and the South West growth areas.

The project will deliver approximately nine kilometres of two-lane twin tunnels with capacity to operate three lanes in the future, motorway to motorway connections to the King Georges Road Interchange Upgrade at Beverly Hills, and a new interchange at St Peters.

Subject to completion of the project's approval process, major works are expected to commence in mid-2016 and the New M5 tunnel is scheduled to open to traffic in late 2019.

WestConnex is being delivered in three stages, with final completion scheduled for 2023.

Leighton Contractors Managing Director Román Garrido said: "Delivery of the New M5 tunnel will provide a high quality link in Sydney's road network operations, which will double the capacity of the M5 East corridor. Working closely with SMC our experienced team is contributing innovative design solutions and construction methodologies to enhance the motorway's efficient construction and operations as well as community and environmental outcomes."

Stillwater Mining gets go-ahead for new tunnel

USA — The US Forest Service and Montana Department of Environmental Quality signed off on September 1 on construction of the Benbow Exploration Portal and Support facilities for Stillwater Mining Co. (SMC), at Custer National Forest, near Dean, Montana.
The Benbow Exploration Portal is part of SMC's Blitz project at the Stillwater Mine. A TBM will be used to mine an approximately 20ft (6m) diameter tunnel for exploring ground and rock characterization, and evaluating mine feasibility. Following the drive, if feasible the approximately 7km-long tunnel will be used long-term for underground ventilation, secondary underground egress, and limited mine resupply.
Under existing approved operations, SMC is currently developing underground mine workings from the Stillwater Mine (i.e. west to east) using a refurbished 5.5m-diameter main beam TBM from The Robbins Company, which had previously been used on New York's East Side Access project. SMC's intent is to drive mine workings approximately 7.6km to the eastern extent of the J-M Reef. As of June the TBM has progressed 2,400m.
The Benbow tunnel will be developed from the north and would eventually link into these mine workings.
SMC operates two underground mines along the J-M Reef, the world's richest known deposit of platinum group metals, located in the Beartooth Mountains in south-central Montana.

Former ITA president highlights Crossrail technical and PR successes

POLAND — Speaking at a conference in Krawkow, former International Tunnelling Association (ITA) president and CH2M tunnelling MD Martin Knights saluted the achievements of London's Crossrail project, and made particular mention of the importance of public awareness of tunnelling activities.

The event was a knowledge sharing activity to discuss the importance and challenges of transportation infrastructure in big cities.

Tunnel engineers in Britain have spoken of a change in public attitude (see Letter, Tunnels and Tunnelling International August 2015, page 7) to underground construction projects, particularly in the wake of a BBC documentary on the Crossrail project, a second series of which is planned for the future.

Martin Knights hailed the Polish conference, and said: "CH2M is excited to see Poland growing so rapidly and partnering with international companies to tackle its challenges. Our tunnels and earth engineering team from Krakow is already involved in global projects being delivered in the UK and US. This way we are contributing to building strategic skills for Poland.
I believe our experience is invaluable source of information, so helpful in further progress and strengthening its economy."

New York's Number 7 Subway Line Extension opens

USA — The No. 7 Subway Line Extension has opened in New York. The project has extended the metro line into the vicinity of 25th Street and 11th Avenue.

This project included twin running tunnels with five cross passages, a 34th Street station cavern, three shafts, and numerous ancillary structures.

The 7 Line Extension was built by a JV of Skanska/Shea/Schiavone known as S3. Gall Zeidler was involved with construction management as well as assessing the impact of the underground structures. The project cost approximately USD 2bn.

EUCLID CREEK TUNNEL COMPLETED UNDER BUDGET

USA — The Northeast Ohio Regional Sewer District (NEORSD) announced 17 September the Euclid Creek Tunnel completed USD 3.6M under budget.

The 5.5km-long Euclid Creek Tunnel is located 60 to 70m below ground, with a finished diameter of 7.3m. It will have the capacity to hold 61 million gallons of combined stormwater and wastewater. Construction began in 2011 and finished in 2013.

Originally a USD198M project, is the first in a series of storage tunnels constructed as a part of Project Clean Lake, the sewer district's 25-year, USD 3bn program reduce CSO discharge in local bodies of water.

"Our engineering and construction team worked diligently to complete this project under budget," said Kellie Rotunno, Chief Operating Officer, "The Euclid Creek Tunnel sets a new financial benchmark as we continue to identify cost-savings and save our customers money."

The tunnel will be fully operational upon completion of the Tunnel Dewatering Pump Station in 2016.

According to NEORSD the project garnered several firsts for the sewer district and the tunnelling industry:

First in World records:

- One-pass tunnel excavation/lining process in rock
- Utilisation of plastic fibers for concrete reinforcement
- U.S. Record: Deepest secant piles with excavation extended beyond tip

Follo Line ceremony kicks off works

NORWAY — A ceremony to start the main works on the Follo Line was headed by the Norwegian Minister of Transport and Communications. The ceremony took place at the Follo Line Project's construction site at Sydhavna in Oslo, where the construction of a new tunnel for the inbound Østfold rail line now has begun.

The Norwegian National Rail Administration also chose to highlight one contract that calls for the first use of drill and split in Norway. One of five EPC contracts for the line, the drill and split works will be used to cross existing sensitive infrastructure including the Ekeberg Oil Depot and also existing tunnels. Works on this section will be carried out by Italian construction company Società per Condotte d' Acqua, which was awarded the contract in February.

The Follo Line Project is currently Norway's largest transport project. The project includes a 22 kilometer long new double track line between Oslo Central Station and the public transport hub at Ski, a 20km-long railway tunnel (twin bore), extensive works at Oslo Central Station, construction of a new station at Ski and necessary realignment of the existing inbound Østfold line. The Follo Line is scheduled for completion in the end of 2021, and forms the core part of the InterCity development southwards from Oslo.

TBM launch on TEP II wastewater project

MEXICO — The TBM was launched on the Túnel Emisor Poniente II (TEP II) Project in Mexico City in August. The wastewater project will be undertaken by a joint venture of Aldesa, Proacon and Recsa.

The 5.9km will be excavated through variable ground conditions consisting of sections ranging from fairly competent to weathered volcanic rock, soft sands and clays. The TBM was manufactured by Robbins and is an 8.7m-diameter dual mode Robbins Crossover machine.

Túnel Emisor Poniente II will relieve overtaxed wastewater lines in three key municipalities home to 2.1 million people. The areas are prone to wastewater overflows of 2m or more during the region's rainy season.

A Robbins spokesperson said: "The design of the TEP II machine was based largely on experience from past Robbins projects, in particular the Kargi Kizilirmak Hydroelectric Project in Central Turkey. At Kargi, Robbins supplied a 9.84m diameter Double Shield TBM, based on initial geologic reporting of fractured hard rock. Within 80m of launch, the geology became substantially more difficult than expected, consisting of blocky rock, sand, clays and water-bearing zones. The machine required multiple bypass tunnels and major modifications before it could resume excavation.

"Modifications included a custom-built canopy drill and positioner for enhanced drilling and ground consolidation, gear reducers to adjust torque and RPM to changing ground conditions, and short stroke thrust jacks to double total thrust capabilities.

"After the modifications, advance rates increased dramatically in the difficult ground and soared to 723m in one month as conditions improved."

Hamas engages in tunnel PR

GAZA — Short months after Israel declared victory over Hamas in the underground theatre, the group has posted a propaganda video appearing to show a tunnel from its base in Gaza into Israel.

According to the Times of Israel newspaper, a video on Hamas's 'Media Resistance' YouTube Channel shows work being undertaken at an unidentified location in Gaza, as well as soldiers practicing resistance tactics and tunnel fighting in the finished bore. Practice rescue operations are also demonstrated.

According to the paper, Israel's Channel 10 reported last month that the Izz ad-Din al-Qassam (military) wing of Hamas had recently dug "not a small number" of cross-border tunnels under the border into Israel.

Hamas said the tunnel is 3.5km-long. Israeli forces were said to be aware of 'many' tunnel projects.

News briefs

NORWAY

Skanska has signed a contract with the Norwegian Road Administration (Statens vegvesen) to renovate the Granfoss tunnel in Oslo, the company announced on 7 September. The contract is worth NOK 580M (USD 70.75M) and will be included in order bookings for Skanska Norway for the third quarter of 2015.

The project also includes construction of a concrete cover over an open area to reduce noise and establish new land for housing. Work is expected to begin in mid-October of this year and will be completed in September 2017.

Skanska Norway focuses on construction and civil engineering operations and the unit has approximately 4,000 employees.

Shannon & Wilson makes capital move

USA — Shannon & Wilson, a national geotechnical and engineering company, announced 14 September it recently opened a Washington, D.C. Metro office.

The new location, located at 8201 Greensboro Drive, Suite 300, Tysons Corner, Virginia, 22102, is Shannon & Wilson's 12th office, and allows the company to better serve clients throughout the Northeastern U.S. in addition to its already established offices in St. Louis, Missouri and Jacksonville, Florida.

The new Washington, D.C. Metro office, which will be overseen by new hire Axel Nitschke, vice president and director of operations for underground services, is a part of a strategic move to widen Shannon & Wilson's national underground services portfolio.

Nitschke will jointly lead Shannon & Wilson's underground services department with Red Robinson. In addition, he will be in charge of Shannon & Wilson's upcoming pursuits of underground projects nationwide, the company said.

From this new location, Shannon & Wilson will offer a full spectrum of geotechnical and underground services, and Nitschke will take an active role in strengthening Shannon & Wilson's presence in the Northeastern Corridor.

"Nitschke's hire is a strategic move as Shannon & Wilson widens its national underground services portfolio," the firm said in a release. Later adding, "by hiring Nitschke, Shannon & Wilson has taken steps to become a full-service underground services provider, adding and emphasising structural design, cost estimating, scheduling, and construction management to its portfolio of underground services."

A 20-year veteran of the underground services industry, Nitschke has experience in wide-ranging aspects of tunnelling, including design, management, QA/QC, safety, and construction. He has worked on road, rail and utility tunnel projects for civil infrastructure as well as mining clients in both highly congested urban areas and remote conditions with clients including Sound Transit, New Jersey Transit, CALTRANS, DC Water, and agencies throughout Europe, as well as a multitude of construction companies.

His practical experience builds on a solid scientific knowledge of tunnelling, which he has gained during his graduate and post-graduate studies as a research assistant at Ruhr-University Bochum (RUB) located in Germany.

Devico appoints Japanese agency

JAPAN — Directional drill supplier Devico has hired NLC as its agent in Japan. The company will be responsible for the distribution of Devico instruments in the country, as well as monitoring the opportunities for expansion of the directional drilling market in the wider region.

NLC is a manufacturer of diamond drilling machines for mining exploration, and distributor of 'down the hole' equipment.

A Devico spokesman said: "We expect this business relationship continues for many years and bring many advantages for both companies.

"Devico is proud to work with this dedicated sales team promoting Devico tools all around Japan and with their key clients nearby."

Karlsruhe TBM breakthrough

GERMANY — The TBM broke through on the Karlsruhe Tunnel.

A Herrenknecht hydroshield named Giulia broke into the reception shaft at Mühlenburger Tor in the southwestern German city last month.

The machine was 9.93m in diameter and completed a bore of 2,049m over a period spanning October 2014 to September 2015 through soft ground geology of sand and gravel.

Cover ranged from some 4.5m to 9.5m.

A key challenge was tunnelling close to existing infrastructure, sometimes with clearance of as little as 240mm.

EURASIA TUNNEL BREAKTHROUGH

TURKEY — The Eurasia Tunnel broke through on 22 August at a ceremony attended by Turkish prime minister Ahmet Davutoglu and other dignitaries. The 3.34km-long, 13.66m-diameter bore was excavated by a Herrenknecht slurry TBM through fractured rock and soft ground through water pressures up to 11 bar.

The road project was carried out by a joint venture of Yapi Merkezi Construction and SK Engineering and Construction (YMSK JV) for the Republic of Turkey Ministry of Transport Maritime Affairs and Communications and General Directorate of Infrastructure Investments.

A spokesman for Herrenknecht highlighted to the conjunction of several challenges. "Many tunnels face high water pressure; many tunnels face blocky, fractured, abrasive and difficult rock; many tunnels will have to go through soft ground; and some will have to make the transition between hard and soft. For the Bosphorus job all these factors came together at once."

Head of research and development at Yapı Merkezi, Ergin Arıoğlu

The TBM was named Yıldırım ('Lightning') after an Ottoman Sultan

Special yielding joint technology was applied at two critical points, the joint segments produced and tested in Japan. Along the general route, impermeable reinforced concrete segments with an average compressive strength of 70MPa were used to line the tunnel, and were produced by the Yapi Merkezi prefabrication division.

A key challenge was changing disc cutters at such a high water pressure while maintaining atmospheric pressure inside the shield.

Herrenknecht's head of engineering Werner Burger said the 19in cutters had to be removed from the face along with their housing, and a new housing and disc put in its place. Each changing operation would take two to three hours and overall 500 tools were changed during the drive.

OBITUARY

There are few who manage to grab an equal best in life from their work as well as their private lives and one of them was David Lawrence. David managed to fulfill a career in engineering that contributed to the civil engineering development of major mining projects as well as several defining infrastructure projects.

David died peacefully on 7 July at his adopted home on the Isle of Man in the UK after moving there with his family in the 1990s. A memorial service was held on the Isle of Man on 16 July and a service was also held in Johannesburg on 12 August for South African friends and colleagues.

David commenced his career in Hydro schemes including Cabora Bassa (Mozambique) and Vanderkloof in the Cape in South Africa whilst working for LTA and Shaft Sinkers, part of Anglo American Ltd. In 1976, he was appointed as the Contracts Manager for the Exploratory Contract for the Elansdsberg Pumped Storage Scheme in the Cape. Later in 1976, David was appointed General Manager of Shaft Sinkers, recognised internationally as one of the leading shaft sinking companies in the world and also in 1976 he was appointed Chief Civil Engineer on the 1,200MW Drakensburg Pumped Storage Scheme (Head 600+m).

David showed his engineering capabilities on the challenging and complex Drakensberg project in many ways, including the setting up and training of shotcreting operators. The large underground caverns excavated in weak sedimentary rock formations were supported by relatively thin layers of shotcrete (100mm) and rock bolts up to 7m long. After 40 years the caverns remain in excellent shape.

Following Drakensberg, David was appointed Project Manager for the first phase of the Huguenot National Road tunnel which involved major ground freezing works (innovative in South Africa at the time) followed before he took up the Role of Deputy MD and Executive manager for major Projects for Shaft Sinkers JHB-RSA, this particularly took him into the exploratory contract for the Med - Dead Hydro/P.S.S. in Israel.

A move to Clifford Harris as Managing Director and CEO where there were responsibilities for overseeing the construction of the twin track Isangoyana Tunnel in Natal and the Palmiet Pumped Storage Scheme in the Cape carried out in JV with Holzmann of Germany and Marti of Switzerland. Clifford Harris was taken over by Basil Read JHB–RSA and David took on the role of Group Deputy MD. In that role he founded Basil Read Mining.

After nine years with Basil Read, David sought new challenges and joined KBR (Kellog Brown and Root) to be seconded to the Nuclear Industry's Research Executive (NIREX) as Project Director appointed to the Executive Directorate responsible for constructing an underground Rock Characterisation Facility (RCF) in Cumbria leading to a deep level repository.

This was an exciting and challenging project but unfortunately it met political obstacles before construction could start and David returned to South Africa to become CEO/Managing Director of SRK (Steffen, Robertson and Kirsten), an established global technical consultants based in South Africa to the civil, mining and metals industry.

However, David was not done with tunnelling and when KBR approached him to head up the supervision team on the Dublin Port Tunnel in 2001 he could not resist. This was one of the largest tunnelling projects happening at the time in the UK.

David was married to Helen with whom they had three children, Debbie, Charles and Michele. They have six grandchildren. Helen supported David throughout his professional career and was ready to relocate and travel to where the next project took him.

David was certainly an Engineer and Professional in the international tunnelling business who was determined to present opportunities to others to be part of the real and exciting possibilities of the underground space tunnelling industry. He was instrumental part for so many in the business. His adventurous and committed, yet fun loving approach to a professional career was a significant element of his success and the esteem that so many hold for him. He will be missed.

David Lawrence

Qualifications

- BSc (Eng) (Hons) (University of Cape Town, 1970);
- Chartered Engineer;
- Fellow of the Institution of Engineers, Ireland;
- Fellow of the South African Institution of Civil Engineering;
- Fellow of the South African Institute of Mining and Metallurgy;
- Registered Professional Engineer, Pr.Eng. (ECSA)

Sika announces new production facility in northern Argentina

ARGENTINA — Sika has announced a new production facility in Cordoba. The new site will manufacture concrete mortars and admixtures for the construction markets in northern Argentina. The site is 700km northwest of Buenos Aires and is Sika's second production facility in the country.

José Luis Vazquez, Sika's regional manager for Latin America: "With the new plant in Cordoba, Sika is well positioned to unlock further growth potential in the northwestern provinces of Argentina.

The latest investment in our supply chain brings us much closer to our customers in the region, increases our service level and allows us to optimise our cost base."

A Sika spokesman added: "After years of modest growth, Argentina's economy is expected to pick up speed and grow by an average 3.7% over the next five years, thereby stimulating demand in the construction industry. Several projects for transport, energy and utilities infrastructure are scheduled to start in 2016."

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

editor@tunnelsonline.info

FROZEN FIGHT

Over the last four years, McMillen Jacobs Associates has designed retrofit, replacement, or new icing shields for four railroad tunnels in the US. **Joe Schrank**, **Heather Stewart** and **Gerry Millar** all of *McMillen Jacobs Associates*, explain the installations

MANY RAILROAD tunnels in the US experience severe seepage and icing in winter. The icing can restrict clearances, interfere with rail traffic, cause deterioration of the existing tunnel lining, and require significant maintenance and manpower to keep rail traffic moving. Ice shields are an effective method for insulating the tunnel to solve these issues. Design considerations, construction issues, and lessons learned from case studies in different parts of the US are discussed.

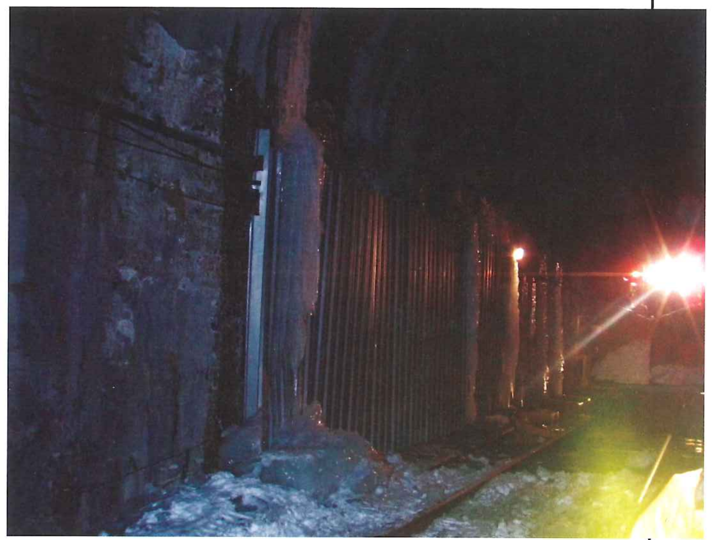
REASONS FOR ICE MANAGEMENT

Groundwater seepage into railroad tunnels is a common problem; water can find its way through discontinuities in the rock mass and find a pathway into the tunnel, whether it is unlined or lined with shotcrete, brick, or concrete. In severe winter conditions, the seepage may freeze, resulting in ice buildup (Figure 1). The icicles can encroach on the clearance available for passing trains, which can lead to speed restrictions. Large icicles may even result in such hazards as damage or penetration of railcars. The time required to remove icicles and the hazards that railroad personnel face during ice removal are also causes for concern. Where ice builds up over the track structure because of poor drainage, the risk of derailments increases.

Icicles also have a long-term impact on structural components within tunnels. Such impact includes the loss of integrity of the tunnel lining, ballast contamination, and unplanned additional weight on utility lines. Over time, freezing and thawing of water in the lining can cause subsequent cracking, whether the lining is shotcrete, brick, or concrete. Additional cracking of the lining allows not only more water to seep through the lining, but reduces the structural integrity. This allows for additional and increasing deterioration, which can increase the chances of shotcrete and rock fall in shotcrete-lined tunnels, brick fallout in brick linings, and deep concrete spalls in concrete linings. Icicles can also introduce waterlogging and clogging of the track ballast, which complicates track maintenance. Utilities within the tunnel may experience heavier loads than expected and could be damaged or collapse from the weight.

TYPES OF ICING SHIELDS

Each icing shield is required to fit in the limited space between the railcar clearance envelope and the existing tunnel lining so that the shield will not interfere with rail traffic. Depending on the clearance available in each tunnel, icing shields are designed either as self-supporting structures or are attached directly to the tunnel lining (a direct fixation system). They can also be either active or passive, depending on whether a power source is available to the tunnel. An active system uses a heat source to supplement the insulation to keep the water from freezing, while a passive system relies solely on the insulation. If a power source is available, active systems are a more certain method of preventing ice. Active systems permit thinner insulation because external heat is being added to the system; however, this may be offset by the cost to provide and run the power source. An available power source at a railroad tunnel



Above: Figure 1. Ice buildup in a railroad tunnel

Heather Stewart
Heather has over five years of hands-on engineering and geotechnical experience

Joe Schrank
Joe is an associate of McMillen Jacobs Associates, based in the Nashville office

Gerry Miller
Gerry is a principal of McMillen Jacobs Associates and is based in the Seattle office.

is also a relatively rare occurrence. Therefore, in our experience, passive systems are more common.

The concept that McMillen Jacobs Associates has developed and proven effective is a multilayered system consisting of waterproofing, insulation, and protection. This system is easily modified for the conditions at any particular tunnel, including the available clearance and whether the system will be active or passive.

Self-supporting icing shield system

A self-supporting icing shield typically consists of evenly spaced steel sets anchored into concrete footings with a layered arrangement of components located between, and supported by, the steel sets. A typical section is shown in Figure 2. This arrangement, going from the field side to the track side, typically consists of a drainage mat, multiple layers of insulation planks, and a protective layer for the insulation, which consists of expanded metal (such as galvanized Stay-Form®) or c-channel lagging. The track side of the steel sets and protective layer are then covered with a thin layer of fiber-reinforced microsilica shotcrete (Figure 3). A waterproofing admixture may be added to the shotcrete or a waterproof coating may be applied to the track side of the protective layer to make the system more robust and prevent any leaks.

The shotcrete layer provides additional protection to the insulation planks from locomotive exhaust gas and also helps form an airtight system, contributing to the effectiveness of the icing shield system. This airtight system can be compared to the insulation of an attic or basement of a house—air does not circulate but maintains heat and acts as an insulator.

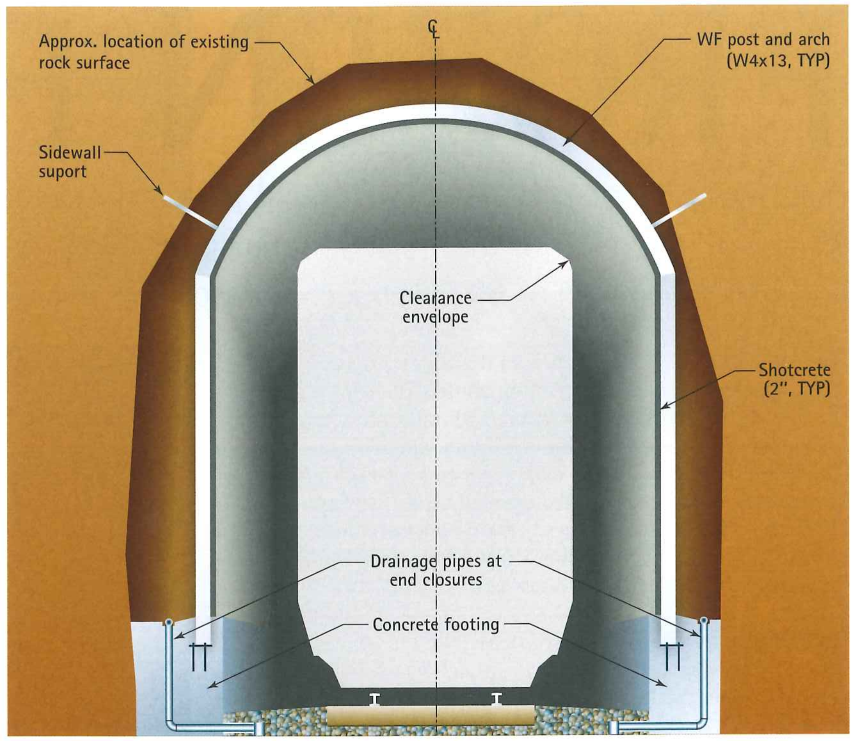
The steel set supported system is not meant to offer structural support to the tunnel ground or ice loads, but rather to inhibit the formation of ice by maintaining the temperature of the seepage above freezing until the seepage enters the tunnel drainage system.

Direct fixation icing shield system

When clearance is limited, direct fixation icing shields may be used. These icing shields are attached directly to the existing tunnel perimeter. From the field side to the track side, these shields typically consist of a drainage mat followed by a single or double layer of insulation planks and a protective layer of expanded metal (Figure 4). Each layer is carefully anchored to the tunnel perimeter to prevent groundwater infiltration. Polyurethane caulking is placed around the edges of the insulation planks and within the anchor holes to further limit seepage from entering the tunnel, since any leaks may form ice and accelerate the deterioration of the system. Expanded metal is then attached to the insulation planks for protection, and a protective shotcrete coating may be applied if clearance and budget allow.

These direct fixation systems may be constructed as either passive or active systems. If active, heat tape is installed directly to the tunnel lining prior to installing the drainage mat and the rest of the system.

Self-supporting systems are more robust and have a longer design life than direct fixation systems. However, self-supporting systems are also more expensive. Because each system has different pros and cons, the severity of the problem, the quantity of seepage, and the condition of the lining are also considered when selecting the appropriate ice-shield solution. For example, even if there is adequate clearance for a self-supporting system, if a power source is present, the owner may opt for an active direct fixation system to save construction costs, since with a heat source less insulation is required for an effective system.



Above: ***Figure 2. Typical tunnel section showing self-supporting icing shield system***

Premanufactured panels

In the 1980s and 1990s, passive icing shields consisting of premanufactured panels were installed in tunnels on the Alaska Railroad and in the Allegheny Tunnel in Pennsylvania (Figure 5). The panels consisted of 3in-thick (75 mm) panels constructed of two thin galvanized steel sheets with a core of polyurethane insulation planks between them. The steel sheets acted as protection for the polyurethane insulation planks, while also providing structural rigidity to the system. Individual steel sheets were connected to adjacent steel sheets with camlock devices. Like the self-supporting systems, the steel shields were not meant to offer structural support to the tunnel ground or ice loads, but rather to inhibit the formation of ice by maintaining the temperature of the seepage above freezing.

These premanufactured panels were constructed as either self-supporting or hanging systems. The panels were rigid enough to form a self-supporting arch within an existing tunnel, or the entire shield structure could be suspended from the existing tunnel lining with hangers attached to the shield panels with screws. Similar to the steel set self-supporting system, the panels are founded on formed concrete footings. For new ice shields being constructed, the steel set-supported system described above has replaced this system as the steel set system tends to be more robust. In addition, the premanufactured panels were specially made and are no longer easily available, but may be available from some international manufacturers.

DESIGN CONSIDERATIONS

Clearance

The importance of clearance in the design of icing shields cannot be overstated. A limited amount of clearance is available in any tunnel. In an unlined or shotcrete-lined tunnel, there may be plenty of available clearance for a self-supporting icing shield. In a brick- or concrete-lined tunnel, the available clearance is usually much more limited, unless the tunnel previously contained two tracks and is now operated as a single-track tunnel. For brick- and concrete-lined tunnels with very limited available clearance, active systems offer the significant advantage of lower insulation requirements because an external heat source is provided and a thinner insulation system can be effective.

Live-track work

Since these installations are in active rail tunnels, the designs have to be implemented in work windows of two to eight hours' duration. The length of available work windows will depend on the quantity of rail traffic and not on the nature of the design. Therefore, the design has to accommodate the track time available.

On a busy main line, a design that requires eight- or 10- hour windows to accomplish key tasks will likely not be effective since the track time will simply not be available. A design that can be built incrementally is much more efficient, particularly if it can take advantage of short track windows and allow for as much preparatory work as possible to be completed away from the tracks. Where tunnels have two tracks, as much work as possible should be performed on one track at a time to minimize the track outages required.

The time and space constraints for construction have an overriding impact on the design of these systems.

Drainage

To be effective, a design also has to incorporate seepage and drainage improvements. The drainage system is critical for the icing shields to be effective for three reasons: (1) the water has to be transported out of the tunnel before it freezes; (2) blocked drainage could impose hydraulic loads on the shields; and (3) effective drainage and seepage control are necessary to ensure that no water gets through the icing shields and to the track side of the tunnel, where it will be exposed to freezing temperatures and can form icicles.

CALCULATIONS

In order for the icing shields to be successful at inhibiting ice formation, adequate thermal resistance (R-value) and a proper drainage system are required. Structural calculations are also needed for self-supporting systems to ensure that adequate structural support is provided during construction and for the life of the system.

8
Hours duration is at most, the time available for implementation

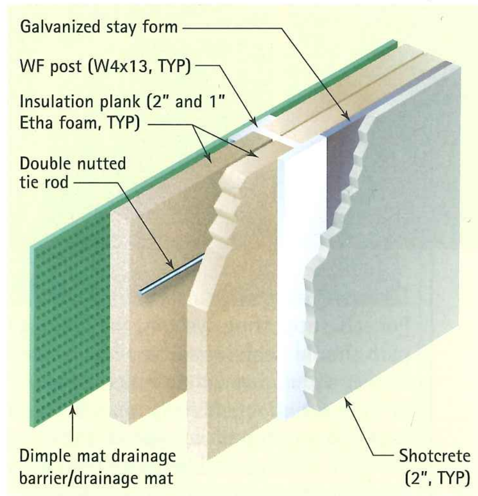
40
to 45 Mil thick for PVC pond liner is the preferred drainage mat

Thermal resistance (R-value)

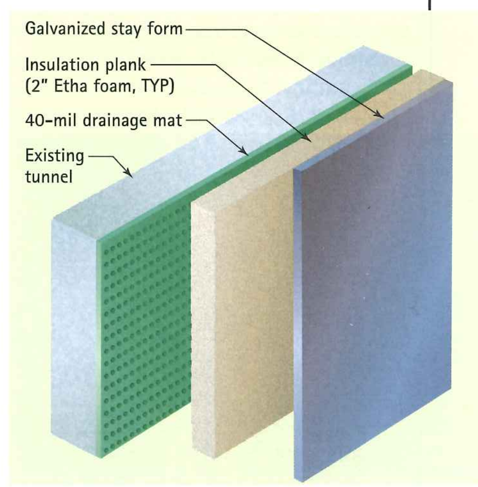
The R-value is a measure used to determine the required insulation parameters for specific structures in a climate location. The minimum required R-value for a project is a function of the geographic area climate zone.

For icing shield design, the minimum required R-value for a project can be determined from the International Energy Conservation Code (IECC, 2009). The IECC minimum R-values are intended for aboveground structures. Because tunnels are more confined, using these values is considered conservative.

Ice shields are less likely to have weather-related issues if they are designed to have an R-value that meets or exceeds the minimum required. The R-values for an insulation system can be determined from the Colorado Energy Organization values for material properties. The different R-values assigned to the different layers making up the ice shield are added together (Figure 6). The single biggest contributor to the R-value is air space.



Above: ***Figure 3. Typical layered self-supporting passive icing system***



Above: ***Figure 4. Typical direct fixation passive icing shield***

Above: *Figure 5. Installation of premanufactured panels*

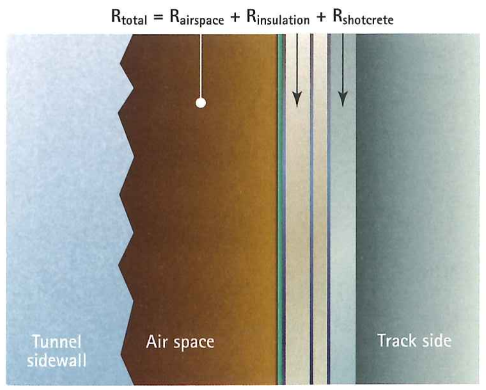
Drainage System

For self-supporting systems, the drainage path should be designed to allow water to seep either down the tunnel lining or the back of the drainage mat, be captured in a trough or pipe on the concrete footing, and be piped out of the icing shield to tunnel invert drains that will take it out of the tunnel. For direct fixation systems, the system should be designed to permit water to flow between the tunnel lining and the drainage mat into invert drains.

In the authors' experience, thick PVC pond liner (40 to 45 mil) is preferred for the drainage mat. Thinner pond liner is much easier to damage during construction. Dimple board may also be used; however, it is stiffer than the pond liner and more difficult to place. For added redundancy to the system, two layers of pond liner may be used. The costs associated with installing a second layer of drainage mat at the time of shield construction are relatively small, especially considering the difficulties involved in repairing a leak in an icing shield after it has been constructed–which likely involves ripping out and replacing the leaking section.

To reduce inflow of water between seams in the drainage mat, it is recommended that seams overlap by at least 12in (305 mm) and a continuous drainage mat be placed over the top of the arch. When two drainage layers are installed, they should be offset by a half-width longitudinally to ensure the seams do not line up.

In direct fixation systems, the pond liners are pinned directly to the tunnel sidewalls and arch with structural concrete roofing anchors. In self-supporting systems, the liners are attached to the steel sets by an adhesive and are often kept in place during construction with weights, such as sandbags.



Below: *Figure 6. R-value determination for a passive icing shield system (from Campbell et al., 2012)*

Structural Calculations

Icing shield systems are designed to inhibit ice formation. However, for self-supporting systems, the steel sets are typically designed for varying loading conditions, including ice formation along various segments of the icing shield.

Steel set geometry is designed to comply with the tunnel clearance requirements and to facilitate ease of construction. For example, steel sets consisting of two column sections and two arch sections with a single radius of curvature spaced on 4 to 5ft (1.2 to 1.5m) centers are often used. All of the steel elements should be corrosion protected.

CASE STUDIES

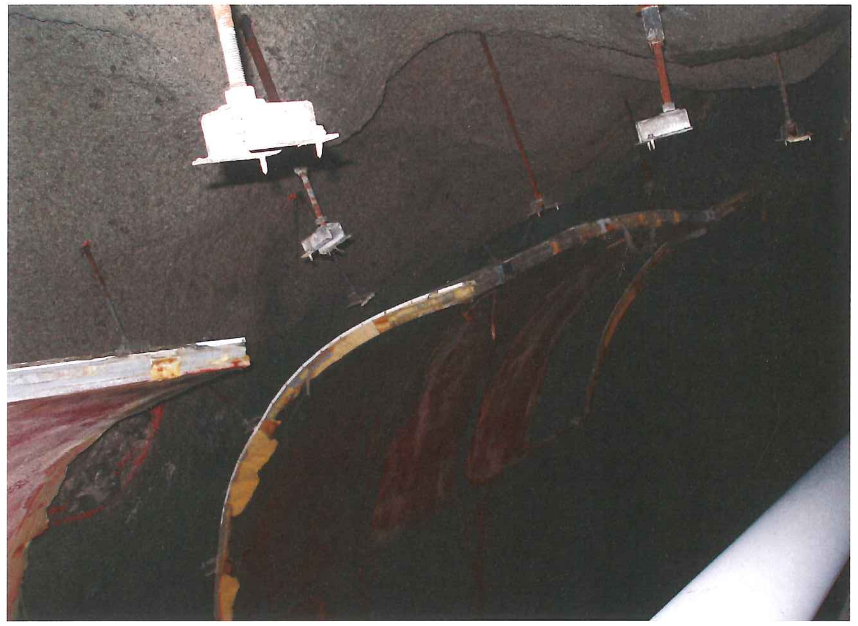
NS Allegheny Tunnel, Pennsylvania

Severe seepage and resultant winter icing were an ongoing problem in the Allegheny Tunnel, restricting clearances and at times covering the track structure with ice for hundreds of feet, interfering with traffic, and requiring significant maintenance.

In the mid-1990s, the tunnel was enlarged to a double track/double stack structure. To control ice formation in the tunnel, a hanging ice shield consisting of premanufactured interlocking panels was installed at that time. After 15 years of use, many of the panels were seriously deteriorated, mostly because of locomotive exhaust blast to the underside and rusting of the rock bolt hangers that connected the panels to the adjacent rock (Figure 7). With extreme winter conditions and record freezing temperatures in 2009 and 2010, large icicles developed from existing seeps within the tunnel. NSR personnel were required to remove them every other day to limit hazards to rail traffic.

To remedy this situation, McMillen Jacobs Associates designed a self-supporting structure consisting of steel sets lagged between the webs with closed-cell polyethylene insulation, a drainage mat over the back of the structure for seepage control, and expanded metal and shotcrete covering the underside to protect the structure from locomotive blast.

Some excavation of the existing shotcrete lining and bedrock was required to obtain adequate clearance to install the steel sets. Unfortunately, the rock excavation was slow and time consuming, and track time was limited.



Above: *Figure 7. Deterioration of Allegheny Tunnel ice shields and supports*

Only a portion of the work was completed by the end of the 2010 construction season.

Based on observations during the 2010 construction season, several modifications were made to the icing shield design to improve constructability and performance. These modifications included thicker pond liner for the drainage mat to make it heavier and less susceptible to damage; altering the shape of the steel sets to minimize the amount of rock excavation required; adding a waterproofing additive to the shotcrete; and increasing the thickness of the shotcrete in the crown of the icing shields. The design modifications were effective, and construction proceeded smoothly with the only major issue being limited track time availability, which caused the construction schedule to be extended. (Figure 8 shows successful installation of a shield.)

Key lessons learned during this project include the importance of good survey data, understanding the effects of material substitutions, and the benefits of good coordination between the contractor and the flaggers. A clearance survey was not performed during the design phase in 2010 because of time and budget constraints. The need for rock excavation during the 2010 construction season was at least partially due to the combination of a lack of good survey data and the irregular tunnel perimeter. At the start of construction in 2010, the contractor requested substitution of the thinner plastic for the pond liner drainage mat because it was more readily available and easier to work with. Unfortunately, the plastic was easily torn and, with the limited track time available, was often placed behind the steel sets but left unprotected, causing it to be blown against the rock surface and damaged. The pond liner used in 2011 was far more successful. Since track time was always limited, a great deal of the work was performed on one track at a time, which required careful coordination and good communication (Campbell et al., 2012).

UPRR Moffat Tunnel, Colorado

The Moffatt Tunnel was opened to railroad traffic in 1928 and has a variable lining that includes sections of concrete lining, unlined tunnel, gunite (precursor to modern shotcrete), and steel sets with lagging. The icing shield was installed in a 70ft-long (21.3m) section of the tunnel that was partially unlined and partially lined with gunite. There were existing drainage ditches on both sides of the tunnel at the invert, which extended out both portals.

Similar to the Allegheny ice shield, this shield is self- supporting. Prior to installing the ice shield, existing drip shields had to be removed and a reinforced concrete footing poured. The steel sets were pinned to the concrete footings and attached to the tunnel sidewalls with anchors. The insulation system consisted of two layers of drainage mats placed on the field side of the steel sets, two layers of insulation (Ethafoam planks) installed between the steel sets, channel lagging with additional Ethafoam on the inside of the channel, a sprayed waterproofing membrane applied to the track side of the channel lagging (Figure 9), and a 3- to 4in-thick steel fiber reinforced microsilica shotcrete (FRMS) layer over the track side of the shields.

Above: *Figure 8. Installation of icing shields in Allegheny Tunnel*

Drain pipes were placed on either end of the icing shields, permitting drainage into the existing drains at the invert of the tunnel.

The system is more robust than the Allegheny system and incorporated the lessons learned at the Allegheny Tunnel. Differences from the Allegheny ice shield included channel lagging rather than expanded metal to protect the insulation, two layers of drainage mat rather than one, and the addition of a waterproofing membrane between the channel lagging and the shotcrete. The waterproofing membrane eliminated the need for a waterproofing additive in the shotcrete mix. The waterproofing membrane worked well, but was expensive. A larger steel set was also used so that an additional 1.5in-thick insulation plank could be installed behind the channel lagging.

Above: ***Figure 9. Applying sprayed waterproofing membrane to steel sets and channel lagging prior to shotcrete application in Moffat Tunnel***

BNSF Stampede Pass, Washington

Stampede Pass Tunnel #3 is located west of Easton, Washington, at an elevation of approximately 2,700ft (823m) above mean sea level, an area that receives more than 30ft (9.1m) of snow between November and May in a typical snow year. Temperatures hover below freezing both day and night during that period. Snow accumulation is so great during storms that a concrete snowshed extends for more than 80ft (24.4m) outside both portals of the tunnel.

Tunnel inspections completed by McMillen Jacobs Associates in 2011 revealed that seepage and icing were concentrated in the first 100-200ft in from the original portals (not the snowsheds), and was especially troublesome at the interfaces of the tunnel and snowsheds.

Wall ice up to 24in thick was observed on the sidewalls, with similar thickness on the track structure. It was also noted that icicles up to 4ft (1.2m) in length were suspended from the tunnel quarter-arches.

During the coldest portions of winter, double crew shifts were needed to keep up with ice removal.

The objective of the project work was to install a low-profile de-icing system that would capture, insulate, and convey water that seeped through the tunnel lining before it could freeze and form icicles or mound on the track structure. Because of the limited clearance in the tunnel, a direct fixation icing shield was required.

Construction was started by filling large spalls in the concrete lining with mortar to create a smooth surface for the icing shield. Slotted PVC drain pipes and heat tape were then installed at 12ft (3.7m) and 2ft (0.6m) above top of rail, respectively, on both sides of the tunnel. Heat tape was placed in the PVC pipes, and the pipes were sloped downward from the east portal face into the tunnel. The pipes were then connected to the existing trench drains.

Following the installation of the drain pipes and heat tape, a drainage mat (45 mil pond liner) was attached to the tunnel walls with structural concrete anchors. Two-inch-thick, 4ft by 9ft (1.2m by 2.7m) Ethafoam insulation planks were then installed on the pond liner inside the tunnel and attached with all-thread bolts drilled into the existing liner and epoxied in place (Figure 10).

Polyurethane caulking was applied around all the edges of the insulation planks and within the anchor holes to limit seepage from reaching the insulation.

Once the epoxy cured, scribe wire was installed, and a nut and two washers (plastic and steel) were used to hold the Ethafoam planks in place.

Contract drawings initially specified the installation of galvanized Stay-Form, but scribe wire was proposed by the contractor and approved for installation because of material availability and a reduction of the insulation section thickness by more than 1in, which was critical for clearance. Two inches of FRMS wet-mix shotcrete were then applied over the wire.

Because it started late in the season, construction was completed in two phases. One hundred linear feet (LF) (30m) of the 300 LF (91m) of icing shield were completed by the end of November 2012. The remaining construction work resumed in mid-June 2013 and was completed in early September. All work was performed under live track conditions, with work windows averaging five hours per day depending on the train schedule.

Because of the late start to the construction season and corresponding below-freezing temperatures, additional measures had to be taken during construction. Water had to be heated prior to mixing shotcrete, so heating cables were used in the water tanks overnight. Where groundwater was seeping into the tunnel, it formed ice that needed to be chipped out to ensure a safe working environment. Low temperatures contributed to machinery seizing up overnight and also created a difficult work environment for laborers.

In addition to constructing the ice shield, other drainage improvements were made to decrease the amount of water entering the tunnel. There is a waterfall located just south of the tunnel portal, and water cascades down the rock face directly onto the top of the tunnel portal. An existing drainage trough was present above the portal, so the contractor cleaned off debris and temporarily installed a pond liner to divert the water and keep it from seeping into the tunnel. Maintaining better drainage above the snowsheds will help prevent water from entering through the showshed/portal interface and causing icing issues during the winter months.

UPRR Tunnel 16, Colorado

Concrete-lined Tunnel 16 is located in the Rocky Mountains west of Denver, Colorado. The east end of the tunnel has a long history of icing issues. Insulation was first installed in the tunnel in the late 1980s by railroad personnel and worked well, except that the insulation did not cover the entire tunnel arch. This allowed ice to develop and led to bulging of the insulation planks. Full perimeter insulation was initially installed near the east portal in the early 1990s, but it deteriorated over time and was replaced by a contractor in the mid-2000s. By 2011, this insulation already needed replacement.

Similar to the Stampede Pass ice shield, the Tunnel 16 shield is a direct fixation system; however, the system is passive. Prior to installing the new ice shield, the existing installation planks and pins were removed. Once removed, the contractor filled in any voids and insulation pinholes with a waterproof mortar to create a smooth working finish. The drainage mat (40 mil pond liner) was then pinned tightly to the tunnel sidewalls and crown. One 2in layer of insulation planks was then installed on top of the pond liner inside the tunnel. Galvanized threaded anchor bolts were drilled into the existing tunnel lining and epoxied in place.

Polyurethane caulking was applied around all the edges of the insulation planks and within the anchor holes to limit seepage.

Galvanized Stay-Form was then installed tight to the front of the insulation planks for protection. Because of limited clearance and budget considerations, shotcrete was not applied to the track side of the shield. The railroad reported that the system was very effective during the harsh winter of 2013/2014.

RELATIVE COSTS

Costs are highly dependent on the size of the project, project logistics including remoteness of the tunnel and available access, and available daily track time. The pay item for icing shields is usually per linear foot of tunnel and includes everything but the shotcrete. It is the authors' preference to pay the shotcrete by the cubic yard, but it can be included in the linear foot price.

Claims are minimized with the use of extra work clauses to cover changed conditions, and delay time clauses to handle the uncertainty related to available track time. The delay time clauses account for the available track time compared to the track time promised in the bid documents.

The bid documents provide an average number of hours of track time per shift, with a bid item for compensation on an hourly basis for any loss of average track time.

For example, if six hours per day of track time are guaranteed in the contract and an average of five hours is actually received over the length of the contract period, the contractor would be compensated for 1 hour x number of shifts x the bid rate for delay time. The delay time can be calculated monthly or over the length of the contract.

Based on the icing shields installed in the last four years, a self-supporting steel set icing shield can cost USD 10,000 to USD 12,000 per linear foot of tunnel (including mobilisation). Direct fixation icing shields can vary from USD 2,500 to USD 5,000 per linear foot of tunnel, depending on a number of factors, including tunnel access, remoteness, and the size of the tunnel.

CONCLUSIONS

Icing is a very common problem in railroad tunnels. The limited clearance and track time available create unique design and construction challenges. The multilayered insulation systems described in this paper provide a flexible design framework that has been proven effective and can be modified as needed for specific tunnel conditions.

With each project, new lessons are learned based on the experience during construction and can be incorporated into future designs

The writers thank Norfolk Southern Railway, Union Pacific Railroad, and BNSF Railway for providing the case studies discussed in this article

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EASTERN EXPANSE

Construction for metro projects, with events such as the World Cup on the horizon, is driving the demand for tunnelling Qatar. Other cities in the Middle East are also investing in infrastructure development, growing the market for tunnelling across the region. Keren Falwell reports

Keren Falwell
Keren joins the Tunnels and Tunnelling team as a contributing editor this year

INVESTMENT IN large infrastructure projects and strategies for economic diversification are driving demand for tunnelling in the Middle East.

From sewers to roads and rail systems, many big-budget projects are under way as governments aim to reduce economic dependency on oil and gas.

"These countries want to be regional hubs for industry and commerce, not just oil and gas, and to do that you have to have cities where people can live," said Nick Chittenden, BASF's regional manager – Middle East, Egypt and East Africa – for underground construction.

And, he points out, the pace of tunnelling development has been very fast, growing from the first tunnels built for the Dubai metro about 10 years ago.

This trend is illustrated by figures from business analyst Timetric. In 2013 the Middle Eastern tunnelling and drilling equipment market was the smallest regional market, accounting for 3.2 per cent of the global market and with a value of USD 528.4m. Saudi Arabia was the largest market, with a 47.7 per cent share, followed by the UAE, Qatar and Bahrain with 47.2 per cent, 2.9 per cent and 2.1 per cent respectively. However, the region is forecast to achieve a compound annual growth rate of 10.76 per cent in the period 2013-2018.

The Middle East's importance to the tunnelling industry was recognised at this year's World Tunnelling Congress in Croatia where the Qatar Tunnelling Society was accepted into the ITA and it was announced that the UAE will host the WTC in 2018. The annual Arabian Tunnelling Conference and Exhibition,

organised by the Society of Engineers – UAE in partnership with the ITA, has also become an established fixture on the industry calendar. This year's event will be held in Dubai from 23 to 25 November.

In Dubai, Expo 2020 has been motivation for a 15km extension to the metro's Red Line from Nakheel Harbour & Tower Station to the expo site. The winning consortium is due to be announced in January next year.

In Qatar, the 2022 Fifa World Cup and National Vision 2030, the country's economic and social development plan, are contributing to construction industry growth which, according to the Construction Intelligence Center, is expected to reach a record 13.28 per cent during the period 2014-2018.

A big part of that is the USD 43bn Qatar Rail Integrated Network, which includes the USD 36bn Doha Metro, the Long Distance Passenger and Freight Rail, and the Lusail Light Rail Transit.

The metro comprises three lines – Red, Green and Gold – which are being built simultaneously and by the start of the second quarter this year, 21 no. 7m-diameter EPBs from Herrenknecht had been commissioned to excavate the soft ground and rock underneath the Qatari capital.

So far four EPBMs are dedicated to the 11.3km of twin tunnelling required for the Red Line North and five for the 12.05km of the Red Line South, which is underground. Tunnelling will be at an average depth of 20m. This 40km line, which extends from Al Wakra in the south to Lusail in the north, will have 12 underground stations, five stations elevated at grade and a major transfer station at Msheireb.

A milestone was reached on the Red Line in April when, for the first time on the metro project, one TBM was lifted from one station site to another. Al Khor TBM, which had finished its first stretch, from Al Qassar station to Doha

Above: The Doha Metro is currently under construction

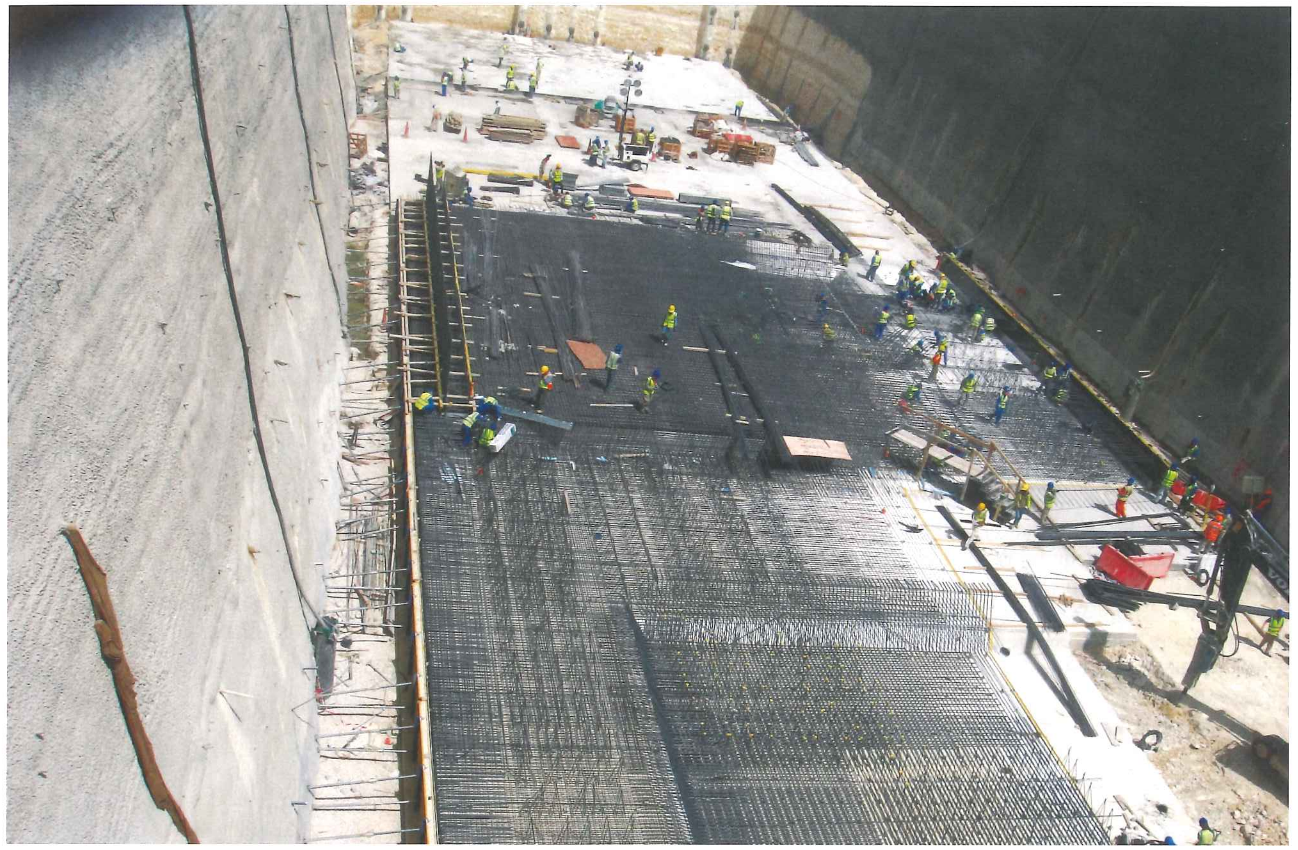
Below: Work on Doha's Gold line

Exhibition & Convention Center station, was conveyed back to Al Qassar for relaunching towards the north of Doha, to complete the tunnelling section between Al Qassar, Katara and Legtaifiya.

Two joint ventures have been selected as design and build contractors for the Red Line – one led by Impreglio, South Korea's SAK Engineering and Construction and Galfar Al Misnad; and the other led by Qatari Diar Vinci Construction, GS Engineering and Construction and Al Darwish Engineering.

The Green Line (Education Line), being built by the joint venture of Porr Bau GmbH, Saudi Binladin Group and Hamad Bin Khalid Contracting, extends from Msheireb Station in the east to Doha West International. Here, six EPBMs are working on the 16.6km, seven-station stretch between Msheireb and Education City, again at a 20m depth.

Six EPBs are also currently working on the 13.3km of tunnelling for the Gold Line, a contract awarded to the ALYSJ joint venture comprising Greece's AKTOR, the joint venture leader; India's Larsen and Toubro; Turkey's Yapi Merkezi and



Sezai Turkes Feyzi Akkaya Marine Construction (STFA); and Qatar's Al Jaber Engineering. Atkins is the lead designer. The Gold Line, which extends from Ras Bu Abboud Station in the east to Sport City in the west, will consist of 10 underground stations and work on all stations is under way.

Precast segments will provide the final lining for the Gold Line and the TBM tunnels will be connected to emergency escape passages excavated using NATM methods.

Omikron Kappa Consulting, which is providing detailed geotechnical – structural designs check and special consultancy and design services for the project's metro stations, tunnels and underground structures, says the Metro Gold line has been a unique and challenging project, not least because of the high specifications and exacting standards required. There have also been geotechnical challenges.

"The most significant geotechnical challenge is the fact that many stations are near the coast line, with karstic channels and features interconnected with sea water so it's of utmost importance to maintain safe drainage during excavation," says

Above: Work for new metro lines being built in Doha

Panayotis Kontothanassis of Omikron Kappa, adding that this has required extensive pumping and a special drainage system.

Excavating the stations has also had its challenges.

"In this case the pumped water coming from the excavated pits cannot be easily discharged to Doha's central sewage system so a special method of deep reinjection wells has been implemented," Kontothanassis says.

The project should also be considered within the context of a busy city, made even busier by the large number of construction projects being carried out at the same time.

"There are private projects, hotels, sport facilities, road and infrastructure

projects being built simultaneously. The fact that within five years' numerous flagship projects will be realised in Doha that would normally take 15-20 years is remarkable," Kontothanassis says.

"And not only are these projects considered landmark projects in the Gulf region, they are considered worldwide flagship projects."

All three lines of the Doha Metro will be completed by the end of 2019, well in advance of the 2022 Fifa World Cup, which is expected to attract 800,000 visitors to the country. A fourth route, the Blue Line, is scheduled to be completed by 2026 during phase two of the metro's development.

Another major project in the city, due to start in the third quarter, is the Inner Doha Re-sewerage Implementation Strategy (IDRIS), which will expand the overloaded existing system and cater for the anticipated rapid population growth. It has a completion date of the fourth quarter of 2019.

The scheme, which will serve an area of 680km2, includes the construction of a 45km main trunk sewer and more than 70km of lateral interceptor sewers. The main trunk sewer will have internal diameters ranging from 3-4.5m, and depths of 20-55m.

In May, Qatar's Public Works Authority, Ashghal, awarded the first contracts under the scheme, the majority of which have gone to Qatari companies or joint ventures involving Qatari companies. The joint venture of Bouygues Qatar and UrbaCon Trading & Contracting has won two pieces of work – the USD 265m contract for construction of the three northern segments of the main trunk sewer in central Doha, and the USD 339m contract for construction of the southern segment of the main truck sewer which terminates in the new Doha South sewage treatment works.

The USD 294m contract for construction of the central segment of the main trunk sewer has been awarded to IDRIS SHP Contractors, a joint venture of Hochtief Solutions Middle East Qatar together with Al Sraiya Strabag for Roads and Infrastructure, and Petroserv Ltd.

Two TBMs will be used to excavate this 14.7km section and after installation of the tunnel's outer ring, an inner lining of an HDPE membrane will be added to protect the concrete from the aggressive gases that build up in the system. In addition to the sewer tunnel, which will have a 4.5m diameter, shafts up to 45m deep will be built, some of which will serve as connectors to other IDRIS construction contracts.

Above: ***Construction work in Doha***

"After the successful delivery of the BARWA Commercial Avenue project [mixed use development], we are very happy to strengthen our presence in the Middle East through this major project," says Nikolaus Graf von Matuschka, CEO of the Hochtief Solutions Executive Board.

However, while these large projects are progressing, Reuters reports that Qatar is rescheduling 15 per cent of its development works because of competition for labour, bureaucratic delays and rising costs. One casualty of this move is Sharq Crossing – one of the most ambitious engineering projects ever undertaken in the Middle East.

The Sharq Crossing was to be a 12km series of tunnels and bridges across Doha Bay, connecting Hamad International Airport, Katara Cultural Village and the Dafna/West Bay business district. Construction was to have started this year and be completed in time for the 2022 World Cup. While the project seems to be on hold, it does, however, remains part of the emirate's 2030 Vision.

In neighbouring United Arab Emirates, Society of Engineers – UAE president Essa Al Maidoor told the Arabian Tunnelling Conference and Exhibition in Abu Dhabi last December that tunnelling had an important role in the emirate's developing infrastructure.

"Abu Dhabi is witnessing a qualitative leap in infrastructure projects...that contribute to enhancing the status of the emirate as a global city through higher sustainable levels of economic growth," he said.

Among the mega-projects in the emirates is the USD 1.6bn Strategic Tunnel Enhancement Programme (STEP), a huge wastewater network tunnel which is one of the longest gravity-driven wastewater tunnels in the world. The project will enable the Abu Dhabi Sewerage Services Company to increase its daily capacity of wastewater from 450,000m3 to 800,000m3, and reduce power and maintenance costs through the decommissioning of 34 existing pumping stations across the Abu Dhabi islands and mainland.

It involves the construction of a 41km-deep sewer tunnel which descends from 24m below ground level to a depth of 80m, and 43km of supply tunnels to transport the sewage to treatment plants. TBMs are creating the main tunnel, which has a casing of precast concrete sections, while the pipe jacking method is being used for the link sewers.

Elsewhere in the Middle East, metros are providing work, or potentially fertile contracts, for the tunnelling industry.

Tunnelling is also under way on the USD 22.5bn metro in the Saudi Arabian capital Riyadh. Here seven TBMs will excavate around 35km of tunnels for the 178km transport system. The tunnels for the six-line metro are around 30m below the city.

The design and construction contracts have been awarded to three consortiums – BACS (Blue and Green lines); ANM (Red line); and FAST (Orange, Yellow and Purple lines) – and the project is expected to be completed by 2018.

In Egypt, a joint venture led by Vinci Construction Grands Projets with Bouygues Travaux Publics, a subsidiary of Bouygues Construction, has won a USD 300M contract to build the extension of Line 3 of the Cairo metro.

The project comprises Phase 4 of the transport system, continuing on from Phase 2, and involves construction of a 5.15km tunnel and five underground stations on the east-west line between Haroun and El Nozha stations.

Vinci Construction Grands Projets and Bouygues Travaux Publics will work with Egyptian partners Orascom Construction and Arab Contractors to complete the project within a short design-build delivery deadline of 34 months.

The team will modify an EPBM used on the previous phase, to operate as a slurry pressure balance machine.

Also in Egypt, six tunnels are under construction to connect the eastern and western banks of the Suez Canal as part of the USD 8bn expansion of the waterway, funded by Egyptians buying investment certificates. President Abdel Fattah al-Sisi hopes the project, which involves widening the canal, will reinvigorate Egypt's economy and he has set the ambitious completion date of August this year.

Three tunnels – two road and one rail – will be built under both Port Said and Ismailia. The road tunnels will be 3.1km long and 10.8m in diameter, each with two 3.75m-wide lanes. They will reach a depth of 48m and have five ventilation shafts.

Herrenknecht TBMs are at work on the project and the EPC contract is being carried out by state-owned Arab Contractors Company and the private Orascom Construction Industries, which are working under the supervision of the Armed Forces Engineering Authority.

Work is also expected to start on the Oman Railway Network this year. The 2,135km system will link through to the UAE, as part of the GCC rail network, and stretch south to the border with Yemen. It will include 10 tunnels covering a total 4.7km and two of the tunnels will be 1.57km long.In May Oman Rail opened prequalification tenders for the line connecting Al-Buraimi with Al Duqm and Salalah.

On the other side of the Al Hajar mountains, work is under way on the UAE's section of the GCC rail network. This 1,200km project for Etihad Rail includes more than 10 tunnels.

There are many other projects on drawing boards to whet the tunnelling industry's appetite.

A metro is proposed for the Jordanian capital Amman as part of the city's 2025 Vision, while Kuwait City also has plans for a metro to help ease the worsening traffic congestion. The USD 7bn transport system will comprise four lines and 60km of the 171km will be underground. The project is part of a USD 25bn rail network linking Kuwait with its five partners in the Gulf Co-operation Council – Saudi Arabia, Qatar, Bahrain, Oman and the UAE.

Tehran's metro network is also earmarked for expansion and in Saudi Arabia bidding is expected to open later this year for construction of a metro rail system in the commercial hub of Jeddah, the country's second largest city.

The new system, which is due to start running in 2020, aims to boost Jeddah's infrastructure which is struggling to cope with the city's rapidly rising population. Currently 3.9 million people live in the city but this is expected to rise to 4.9 million by 2020 and 6.3 million in 2033.

BASF's Chittenden believes that although the pace of new tunnelling projects will eventually slow, activity will continue in the Middle East for the next 10-15 years, and much of that will be sustained by Saudi Arabia, which has plans for several new metros.

In the holy city of Mecca, which currently has no public transport system, a 188km metro network with 88 stations on four lanes will cater for the city's 1.6 million permanent population and the 9 million Haj and Umrah pilgrims who visit each year. Work on phase one will start next year and the network is due to open in 2019.

In Madinah, the three-line metro will comprise 71 stations and 92km of railway – around 25km underground. Before the system opens in 2020, engineers face the challenge of tunnelling through lava, as Madinah sits beside the Harrat Rahat lava plain, the largest volcanic field in Saudi Arabia.

Although the lower oil price may impact on future infrastructure spending, for those projects that do go ahead, tunnelling is now a viable option.

"Tunnelling is in a new phase in the Middle East," Chittenden says. "The raised profile is having a positive impact at government level and will now be considered more often as an option"

GULF EXPANSION

The tunnelling industry is not just an appealing source of work for the usual contractors, consultants and machinery manufacturers. Companies working in sectors often regarded as peripheral to a tunnelling project are also following the ebb and flow of underground work carefully. **Alex Conacher** speaks to Bert Biermans, senior projects manager for *WWL ALS*

Bert Biermans
Bert is tasked with expanding the Middle East market for WWL ALS

LOGISTICS AND transportation solutions company Wallenius Wilhelmsen Logistics Abnormal Load Services (WWL ALS) has organised the movement of outsize tunnelling equipment throughout Western Europe. Notably, this has included hefty TBM components through the twisting and inconveniently placed streets and urban detritus of London in the UK.

Excavation-related transportation makes up some of the company's more challenging and impressive work. With a strong base in Europe, and an interest in delivering machinery to challenging worksites, an expansion into the Middle East with the impressive local pipelines of work is its newest speculation.

Lifting a used TBM cutter component out of a shaft

NEW VENTURE

Bert Biermans, senior projects manager for WWL ALS has been posed to the region to develop the local market – the countries around the Persian Gulf and to co-operate with other companies within the Group. Following a year based in the Dutch office at Moerdijk, he has spent a year based in Dubai.

"We have made a quick start here, actually compared with our other regions we have made a remarkable start. We have been successful winning early business and presence, which is not entirely logical because the Middle East is a tough market. There are thousands of freight forwarders in Dubai, and a lot of them are local players who have a long history here."

Biermans says that he has been helped by existing WWL ALS presence and relationships in other sectors, but that about 50 per cent of the work is from new sources. In some cases, opening an office in the Middle East has been to facilitate negotiations relating to projects elsewhere in the world, for example in the mining industry, where there is a good deal of decision making taking place in the Gulf cities particularly for the African mining industry.

"Currently two things are quite clear. We are mainly working on railway projects and in the oil and gas and EPC contractor businesses. These are the most successful and seem to have the most potential. We don't have any confirmed tunnelling jobs in the Middle East. Not like the UK and Europe where we are already very strong and get regular work, in the Middle East this is not yet the case."

The vast numbers of TBMs ordered for metro projects in the region – for example the 21 to be shipped to Doha from Herrenknecht's factories in Schwanau – offer an attractive workload for logistics companies. Unfortunately for Biermans, setting up shop 10 months ago meant that bidding for the Doha Metro was not a possibility, however he sees a lot of potential in this sector although not over the next few months. "But if you look at the very impressive number of projects slated for places such as Qatar, Kuwait, and especially Saudi Arabia, there is a lot of opportunity. So there are certainly challenges, but also huge opportunities."

CHALLENGES

Cultural differences

On the challenges, Biermans explains: "Every region has its own style of doing business. This is mainly manifest in a difference in the negotiations process. For the Middle East, I would say it is key to really gain a relationship with your customer, and to earn their trust. Although price will always be a major factor, you have to prove yourself more than in Europe.

"But at the same time, you cannot talk about the Middle East (or other continents) as one market. Saudi Arabia is tougher than Oman or the UAE for that matter. They are much more involved with local parties, and it takes even longer there for an outsider to gain trust."

Biermans adds that he is helped by WWL ALS presence in other sectors in the region already. "It was a logical step because ALS was already active in different sectors which are of course important here. And we already had a large presence Europe, and in Africa also."

Multiple parties

In Europe, says Biermans, the tendency is to be awarded a contract for site supply from a manufacturer, in the case of large items. In the Middle East on the other hand, it is more common to get involved in project-specific negotiations. "For example, the Riyadh Metro project – an enormous and important infrastructure scheme in the capital of Saudi Arabia – there is not just one single company to negotiate with. These projects are so large and elaborate, that you have to negotiate with consortia, say five such corporate entities at a time, and work together. From a logistical and negotiation point of view, it is much more difficult to get in. This is also because a lot of these projects are state-controlled"

***Above:** Heavy loads handling for European tunnelling projects*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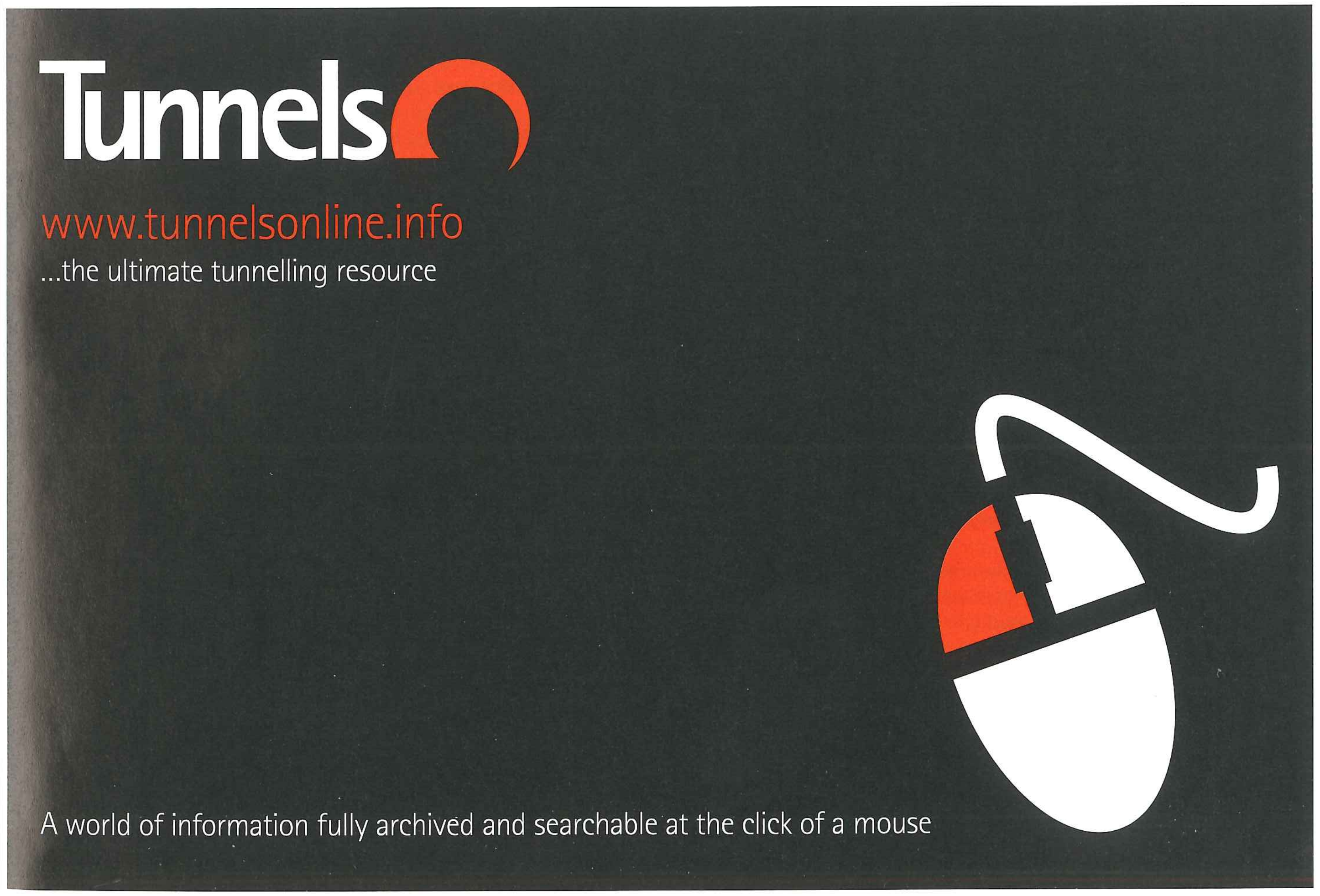
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FIT FOR PURPOSE

An expanded concrete lining was suffering in void-filled, desiccated Lambeth Group geology, before *London Underground* intervention to re-line the operational tunnel with SGI saved the day. **Alex Conacher** speaks to LU's lead tunnel engineer and CDM designer/coordinator **Neel Goorvadoo**

THE JUBILEE Line first opened in 1979, and a section between Baker Street and Bond Street is lined with a 3,810mm expanded precast concrete lining (EPC), with a 3,850mm bolted cast iron lining section on either side.

An earlier version of this type of lining was used for the Victoria line in 1961. The 1970s version consists of 22 segments, with 5 of them forming the invert. A pair of wedge-shaped segments at knee level is used to expand the ring directly against the ground.

It has been used for a number of construction through London Clay for both London Underground passenger and service tunnels – successfully. According to records it facilitated faster segment erection doing away with the need for bolting and grouting, and London Underground's lead tunnel engineer Neel Goorvadoo tells Tunnels and Tunnelling that in all other cases it continues to perform well in self-supporting ground like London Clay.

The design alignment of the tunnel drives between Baker Street and Bond Street is such that the southbound is about 10m lower than the northbound rising to the same level at Bond Street platform.

"The geology of the ground shows that this places the tunnel in the Lambeth Group beds, a comparatively less competent soil than London Clay". The 1974 as-built records shows that the soil to be highly variable, faulted and fissured and containing sand and voids, not uncommon for Lambeth Group beds, which may have been uplifted in this area.

The presence of the voids being key, considering the nature of an expanded lining that requires the ground to act uniformly upon it, to allow it to safely carry the intended load.

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

FIRST CONTACT

The 'problem' as Goorvadoo describes it, was first observed around 2006 when a tunnel inspection revealed localised spalling of the concrete segments with fragments found at track level. This was reported to the London Underground tunnels department who undertook a more comprehensive inspection.

"At first we thought maybe the concrete quality was poor, says Goorvadoo. "However, desk studies and research revealed the lower strength concrete was not the main factor. We then looked at the circularity of the tunnel using an optical surveying methodology, which revealed a non-elliptical profile particularly on the upper section.

The survey was extended to cover other EPC and cast iron tunnel section.

A detailed comparison, looking particularly at the joint eccentricity, revealed a strong correlation between the extent of the large joint eccentricities and the defects observed at this location. This was when we realized that joint rotation was a major contributory factor.

As this is an operational railway tunnel, there was a need to re-assess both the structural and service risks brought about by this manifestation. A trolley mounted laser scanning, using a similar principle to the original optical method, was deployed on a monthly basis to allow us to observe small changes in circularity.

"Additionally a simple method of drumminess testing was used on a monthly basis to locate potential spallings. These two observational approach allows us to stay ahead of the game.

In parallel, further investigations including finite element modelling, analytical assessment and full-scale testing of spare EPC segments broadened our knowledge of the problem. The latter in particular demonstrated post-failure pattern similar to the observed spalling in the tunnel.

A system of real-time monitoring was installed on rings manifesting significant joint eccentricities which acted as early warning system.

THE CAUSE OF THE PROBLEM

Firstly the poor ground conditions encountered affected the build quality resulting in over-dig and misalignment of the tunnel rings. It is highly likely that some of the rings acquired an eccentric shape right from the beginning.

Secondly, the effectiveness of grouting any voids at the construction stage in an EPC type ring is very limited; and it is the case that partially filled voids may well have existed from the beginning.

"Given time, a combination of these factors would have allowed the upper segments to rotate around joints as a response to differences between vertical and horizontal stresses as the pore water pressure changes. "Whilst having little effect on a bolted segmental lining, the implications for the EPC ring with convex-convex joint is significant", says Goorvadoo.

Changing requirements

"Thirdly, over the years, as the line underwent several track, train and signaling enhancements, the "piston" effects caused by faster-moving trains resulted in continuous drying of the ground through the permeable EPC lining.

"As the ground behind the lining became drier and more desiccated, soil-lining interface became more and more compromised.

"So, in the absence of sufficient ground resistance, the segments in the inherently eccentric ring rotate to adapt to the changing stresses. Gradually the location of the contact patches at the longitudinal joints changes accordingly. When these reach sufficiently near to the surface of the segment, the area of concrete carrying the load reduces.

Left: ***Exposed ground in Crown after removal of EPC segments,***

Below: ***The removal of the EPC Crown segments of a ring – with substantial ground fall***

"More load on a smaller area of course creates a higher pressure exerted, which was then leading to the delamination that was detected by the druminess test and subsequently spalling"

LONDON UNDERGROUND ENGINEERS TAKE IMMEDIATE ACTION

A denser real-time monitoring in the form LVDTs (linear variable displacement transducers) was implemented which allowed us to monitor joint movements at an improved scale, as an early warning system. "We went back to first principles trying to determine what would happen if several movements occurred on the same joints or movements occurred on several joints on the same ring.

"We were able to model a sequence of joint movements that could lead to a structural failure. We formulated a set of trigger levels from the results of inspection, druminess testing and real-time monitoring.

When movements reached agreed threshold levels, it was time for physical intervention. Over the years, this took several forms. The first development in 2009, referred to as Heavy Duty strap, consisted of arc steel segments bolted together to form an inner lining that was jacked from the end of a steel beam in the invert to keep the problematic ring in shape and helping it to carry the ground load.

This solution was constraint by the size of the steel members having to be shallow enough to avoid infringing the kinematic envelope, the virtual shape of a moving train.

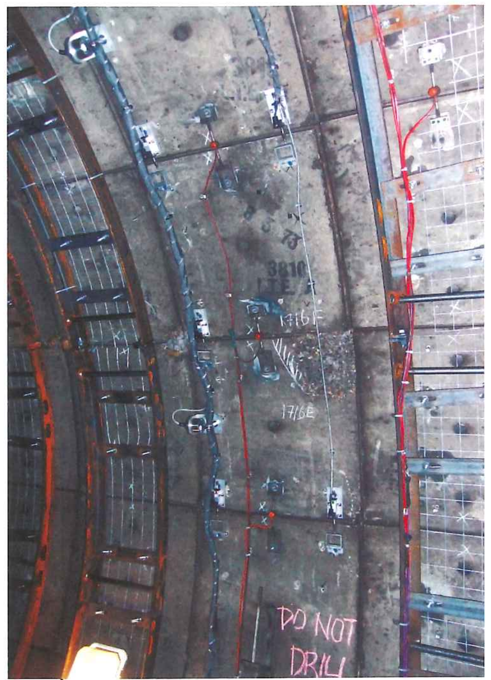
A total of 19 rings were strapped over 3 years.

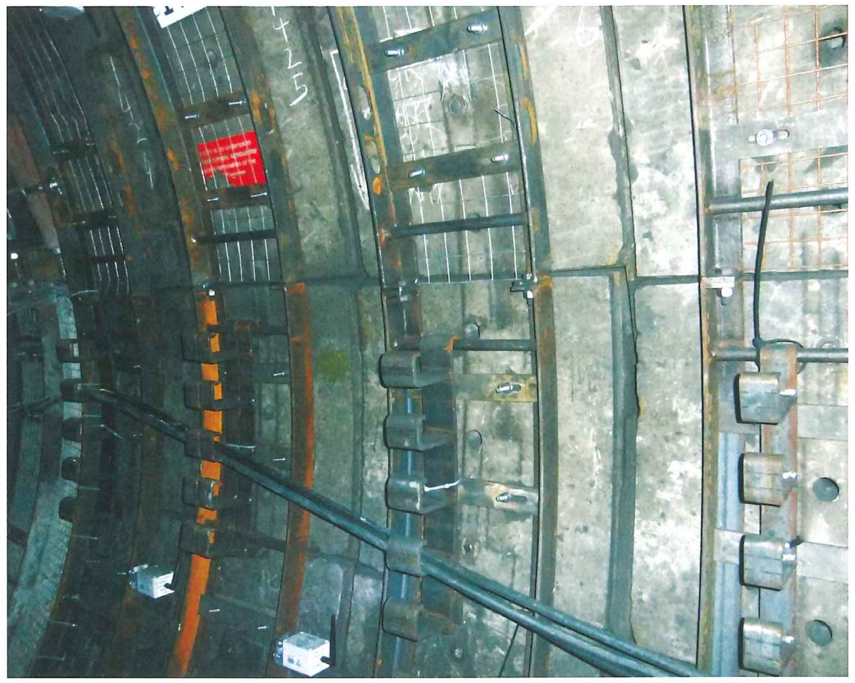
"Although original measurements indicated that the strapping halted the movements, earlier strapped rings were starting to show sudden movements. On the positive side, we had now accumulated a larger population of good monitoring data to improve our analysis.

"We were confident that influencing joint rotation will improve the situation. So, in 2012, we designed a system of steel members that could change to the sudden rotation to a more "ductile" mode. This consisted of a system of curved steel ladder that were bolted to the EPC ring without pre-stressing. As they were lighter and thus much easier to install, these were installed on all the EPC rings.

"They were also designed to support the temporary works for the permanent relining phase."

There was significant costs involved





Above, left: ***Damaged EPC with adjacent monitoring and ring restraints.***

Above, right: ***Temporary Ring Restraints in situ***

with the continuous monitoring and interventions which would have become uneconomical over a longer period. There was a need for a "fit and forget" solution.

THE DEVELOPMENT OF THE IDEAL "FIT AND FORGET" SOLUTION

After a comprehensive feasibility study, a decision was made to adopt a bolted segmental lining as a replacement. One of the major constraint that led to this decision was the need for the project not to impact on the operational service. Therefore the solution needed to be designed such that it could be implemented safely in engineering hours.

"This was a major challenge as this approach has not been used in a modern urban metro before.

"The dedicated design team was assembled that consisted of geotechnical, structural, tunnel and mechanical engineers".

Due to the uniqueness of the proposed design and corresponding risk profile, there was a need to gain confidence by setting up a trial.

There is a short section of tunnel connected to the disused Charing Cross Station that was lined in exactly the same way as the problem section, but in good London Clay. It was the perfect place to practice the procedure.

A first trial saw six rings replaced. The test section was in benign ground according to Goorvadoo, and so there were no real worries of geotechnical challenges for the engineers to contend with, but they wanted to see how easy it was to use the tools. A derrick consisting of a lifting frame and platform was the main launch pad for the works.

It made use of simple block and tackles lifting methodology. The works were labour intensive, the designed temporary works were problematic and working area very constraints. Nevertheless very useful lessons were learnt for design mark II. It was unanimously understood that a more mechanized system was required.

"Back to the drawing board, we used a wagon from the London Underground fleet and modified this as a platform for a self-contained unit consisting of a segment handling arm, cutter/breaker, lifting cranes and conveyor belt type trolley system"

"With our new Segment Handling Plant (SHP), things were improved significantly as it could be hauled to and from site by 2 locomotives."

This new plant and revised methodology needed to be tested, necessitating a further trial operation.

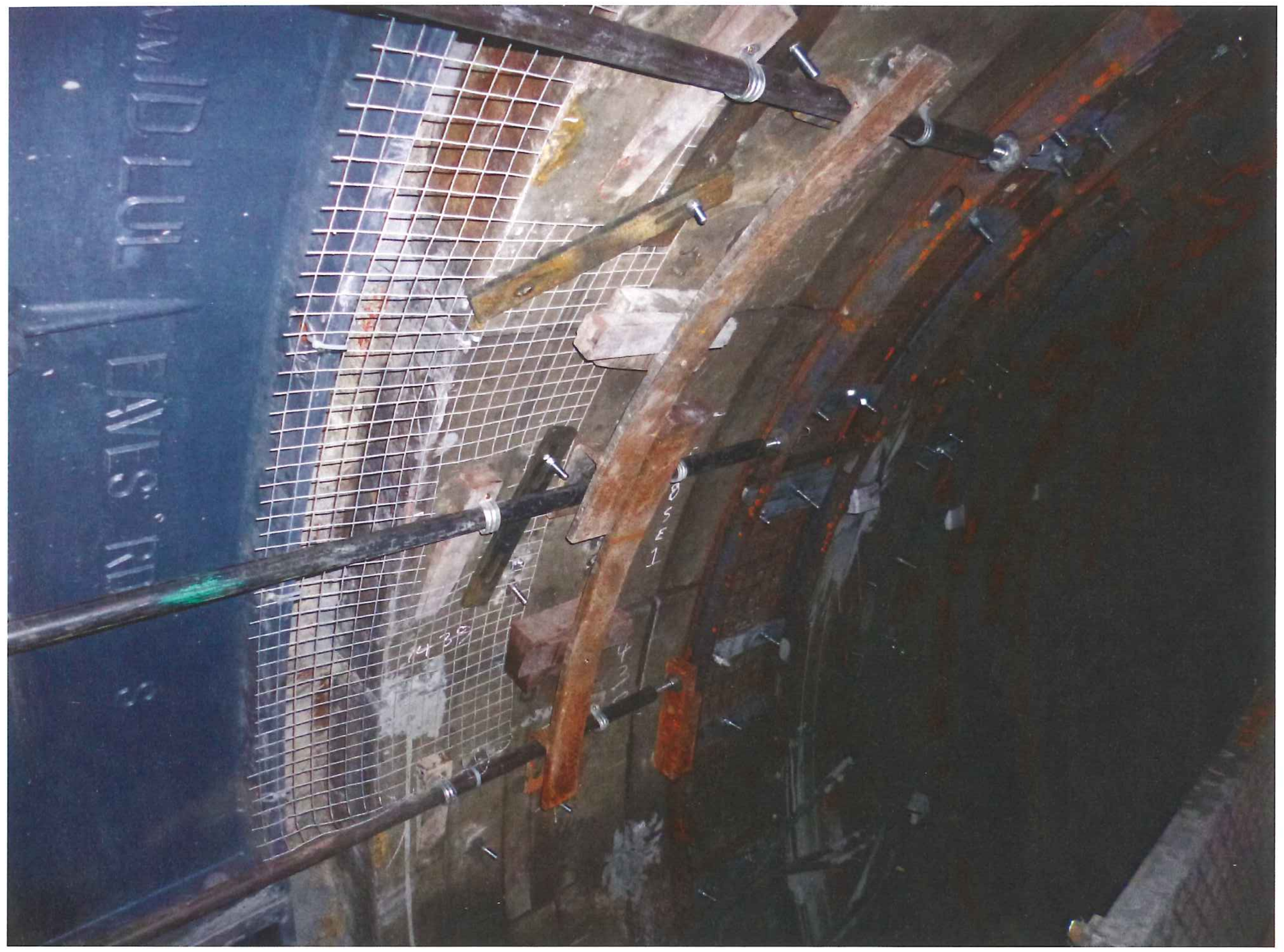
Second trial

"We returned to Charing Cross for a second trail which successfully improved the issues faced in the original trials. As with any new plant, we now had to resolve new issues, including the passage of this modified engineering train on the existing signaling system, emergency access planning and sequencing of activities to make efficient use of the short working window.

"The final trial was undertaken in early 2013, which allowed us to resolve all the know issues and provided much needed experience in using the plant.

"We demonstrated with confidence that at least one SGI segment can be safely installed per shift. After a diligent tender process, bearing in mind the uniqueness of the project, Specialist Engineering Services (SES) were contracted to undertake the work."

> ## Key statistics
>
> - Original lining diameter: 3,819mm ID
> - Original segment dimensions: 632mm long, 600mm wide and 168mm thick
> - Original configuration: 22 standard incl. a pair of 3 wedge segments
> - Original lining type: Expanded precast concrete (EPC)
> - New lining diameter: 3,850mm IDlength,112mm thick
> - New segment dimensions: 1.6 to 2m long, 600mm wide and 112mm thick
> - New configuration: 5 segments (original EPC segments below invert left undisturbed)
> - New lining type: Cast Spheroidal Graphite Iron (SGI)



Above: ***Temporary works in situ***

THE JOB

The key is the removal of the hoop load says Goorvadoo.

"The EPC ring is carrying up to 800kN, so dismantling it required significant control, effort and support.

"The ring is first supported with substantial temporary works which make use of the previously installed ring restraints.

"A disc cutter attached to the manipulator arm is used to make cuts along predefined strategic line.

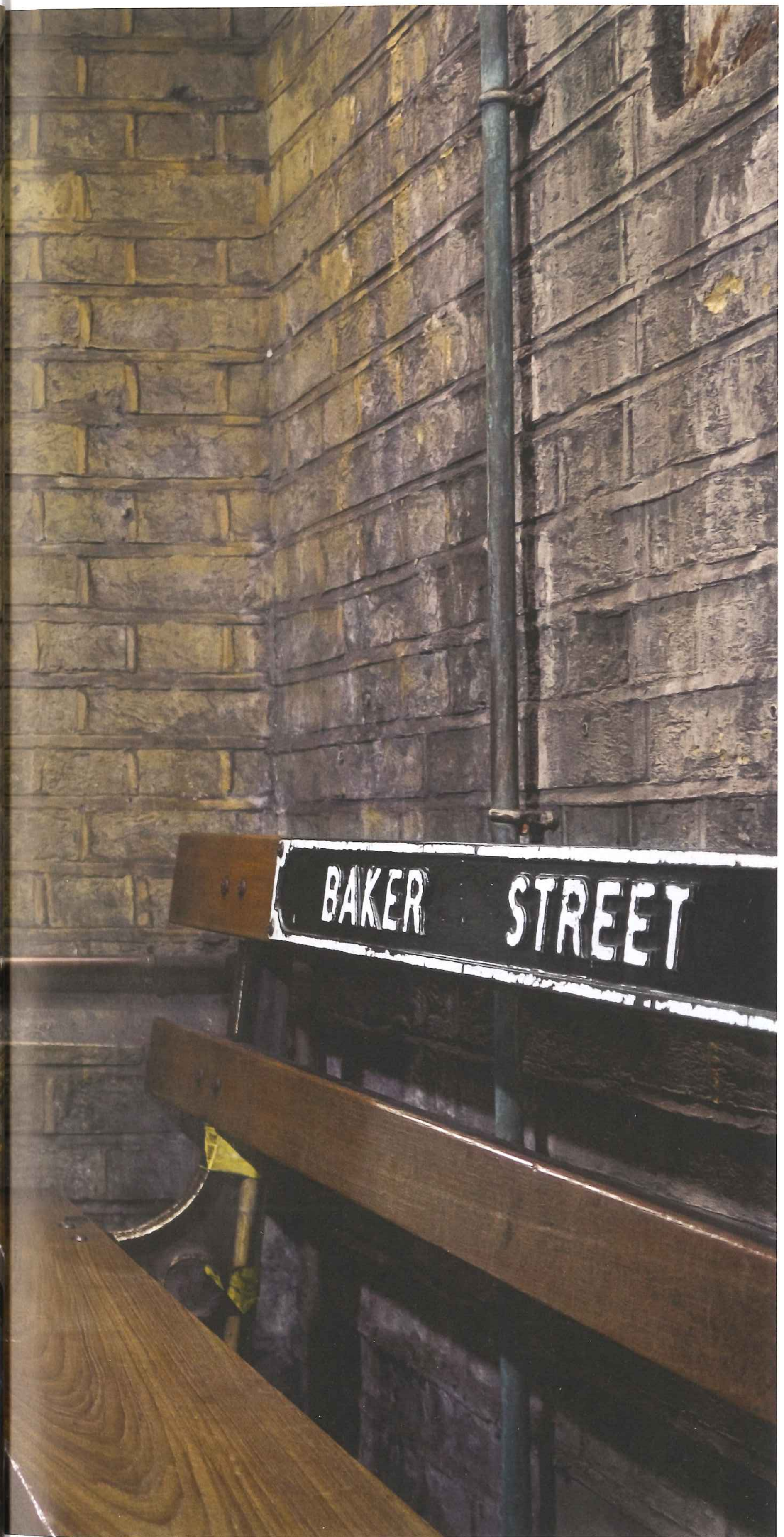
"It is imperative that the depth of cut is controlled, otherwise the disc blade could get jammed in place from the compressive forces in the EPC segment, which is still carrying significant forces. The disc cutter is replaced by a breaker to break the concrete in steps along the cut lines until a portion segment is broken into two parts.

"At that point, there is no hoop load in the rings and the remaining upper segment are now supported by the temporary works consisting of 30mm solid steel build bars which is fixed to the ring restraints ahead and the fully bolted cast iron or SGI ring behind.

"Once the new SGI segment is in position, it is bolted to the previous completed rings.

"Normally the annulus would be grouted but this is not possible in an

> ## An odd choice?
>
> In hindsight the EPC option was probably not the best solution for this section of tunnel. However this type of lining exists on other sections of the tunnel networks and have been found to be in serviceable state. In the right ground conditions the EPC lining can be designed to perform very well throughout its design life. A simple solution at design stage, according to Goorvadoo would have been to include steel reinforcement in a thicker segment. In the 1970s a 168mm thick lining was used, but now 200mm is commonly used.
>
> Another option would have been to have a flatter longitudinal joint having their contact surfaces coated with a high build bitumen/cement, helping to relieve these high contact stresses.
>
> The articulation provided by the convex-convex joint allows rolling without the risk of joint eccentricity at segment to segment interface while transmitting the hoop stresses. However as the load transfer is via a localized line of contact, very high compressive stresses are induced in the concrete just behind the joint.
>
> "There is no evidence to believe that this is a wider EPC lined tunnel issue. The problem as this location is down to a unique set of unfavorable conditions," says Goorvadoo.



incomplete ring. There is an annulus at least 35mm deep that need to be grouted before the tunnel can be safely returned to service (note the limited time window).

BULLFLEX BAG

"The solution we came up with was the Bullflex bag used in tunnelling but modified to suit our needs. The woven sack shaped as large pillow was tailored to fit most of the central area of the SGI extrados, with an inlet attached to one of the grout holes, accessible from the intrados.

"The bag was securely fixed to the SGI prior to installation and once the segment was bolted, grout was pumped to pressure into the bag. This provided the ground support required in the partially relined ring.

"A system of screws and base plates is used to connect the SGI to the remaining EPC to reform the structural integrity of the ring. The remaining EPC segments are removed in similar way over a number of shifts.

The Bullflex bag allowed the teams to safely delay the back grouting process until a full ring with necessary sealing is completed and the interface between the new ring & the existing invert EPC segments are fully grouted.

Engineering supervision was provided on every shift to ensure that works went as planned and any issues resolved as quickly as possible through the office-based team.

CONCLUSION AND FINAL THOUGHTS

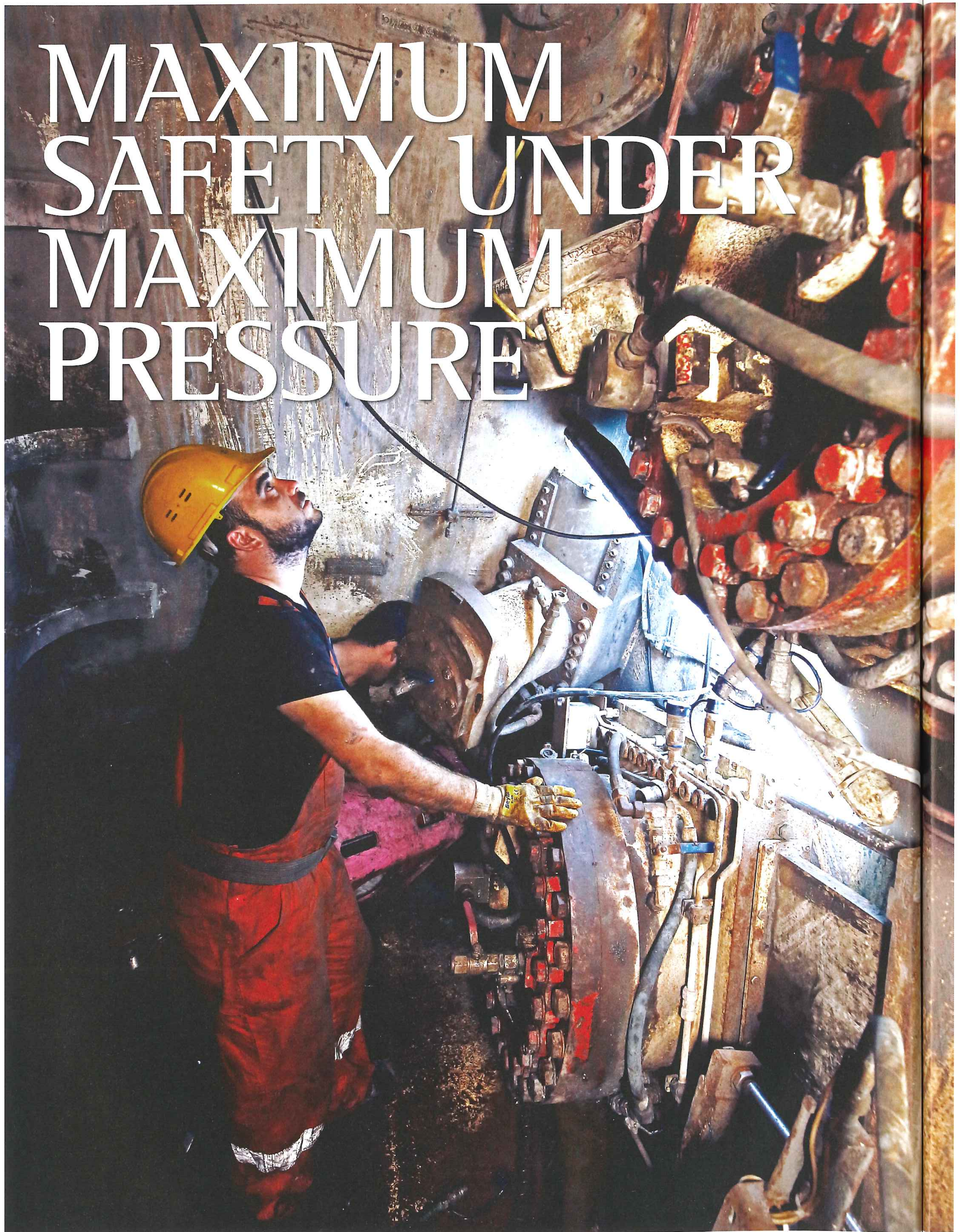
Goorvadoo says he is confident of the condition of the newly lined tunnel. An inspection is due to be undertaken at handover, but really all the problems have been removed. There will not be flaking from an SGI lining, and bolting will also mean that the tunnel acts as a cylinder and has its own strength. The grouting behind the lining also takes care of voids.

A permanent wireless monitoring array that can be checked from the platform has been put in place, but any movements seen so far have been negligible.

"This project is a good example of whole life asset management. It has also been rewarding to be able to deploy our skill set as engineers to solve this unique problem.

"The proof of the successful execution strategy is that passengers on the train were oblivious to the significant works being managed every night without any delays to the service"

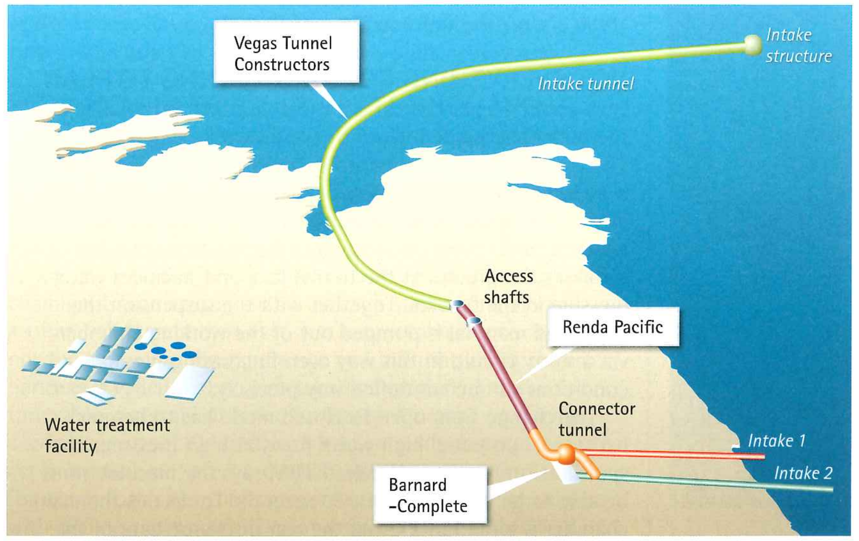
MAXIMUM SAFETY UNDER MAXIMUM PRESSURE

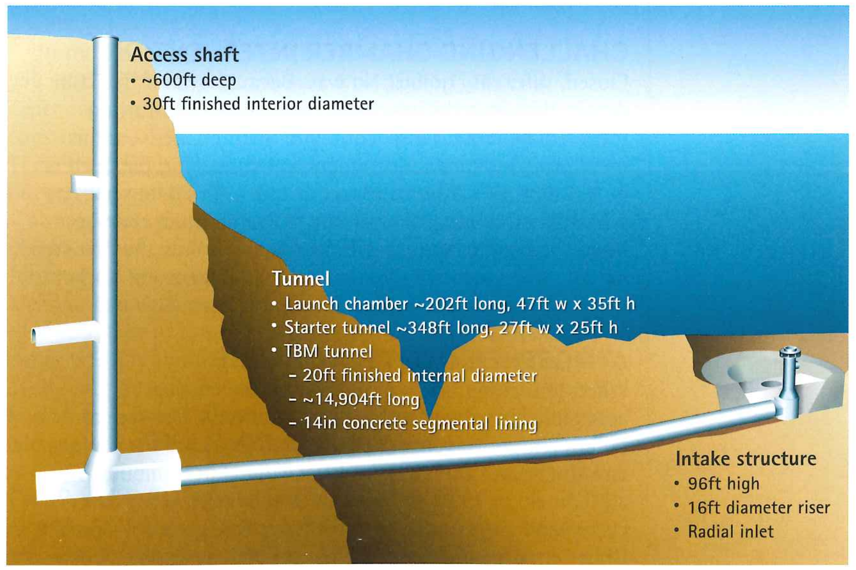


A large road tunnel deep beneath a strait, a railway tunnel through an enormously complex mountain range, a water tunnel under tremendous ambient pressures: mechanized tunnelling is penetrating into new terrain underground. True partnership with contractors and project owners leads to pioneering developments in machine technology. Integrating knowledge from professional offshore diving also contributes to significant progress in tunnel construction. Herrenknecht's **Werner Burger**, Head of Engineering and Member of the Traffic Tunnelling Executive Board and **Georg Küffner**, writer, elaborate

Below, top: ***Underground components of the Lake Mead project***

Below, bottom: ***The alignment for the TBM-driven tunnel at Lake Mead***





FOR ENGINEERING achievements in particular: boundaries are motivation and never a limit. Bigger, faster, deeper, further – and at the same time always safer. That's the idea for mechanised tunnelling. The real engineering challenges await deep down in particular.

In geologies under extreme pressures and where ground, sea or river water penetrating through fissures and other anomalies affect tunnelling. The example of a water intake tunnel under Lake Mead shows how the geotechnologically difficult excavation of such tunnels can be accomplished.

Like a blue diamond, the largest reservoir in the United States lies about 50km southeast of Las Vegas, in the middle of the desert between Nevada and Arizona. Here the Hoover Dam, completed in 1935, dams the Colorado River: over a length of 170km and with a depth of up to 150m (the dam's high water line is at 375m aod). The maximum storage capacity is an almost unimaginable 35 billion cubic meters of water – enough to supply a West European country's private residences for over ten years.

But Lake Mead is no longer full to the brim. Since 1998 its level has constantly dropped – as a result of a previously unprecedented drought phase. Meanwhile its water level is at an historic low: only 332m above sea level. This means the water stands just a few meters above the two existing intakes – and threatens the water supply.

THIRD OUTLET TO SECURE WATER SUPPLY

A new, third outlet must be built. Intake No. 3 is approximately 70m below the lake surface and about 3km from the shore. The intake structure extending 15m vertically from the lake bed was lowered from a floating barge into a previously excavated pit. The foundation was then poured with underwater tremie concrete, fixing the structure in place.

The actual Intake No. 3 consists of a 4.4km long, slightly ascending tunnel that the Herrenknecht TBM S-502 with an outer diameter of 7.2m excavated directly below the lake. The TBM was driven with an accuracy of 10mm into the specially constructed "soft eye" of the intake structure.

Before that, the specially adapted Multi-mode TBM had driven for about three years whilst it worked its way through complex geologies with shattered rock and clay partly filled with water from the lake.

The TBM after breakingthrough at the intake

NEW RECORD

Due to the working depth – under water pressure rises one bar every 10m – over large parts of the tunnelling route an enormous water pressure of up to 15 bars acted on the machine. This was an absolute first for mechanized tunneling requiring significant innovation and development. Until then the record was 11 bar, set by a Herrenknecht TBM used to excavate the Hallandsås railway tunnel between Gothenburg and Malmö, completed in 2013.

The geological and hydrological conditions were very challenging to the construction team of Salini-Impregilo. On numerous occasions tunnelling had to be stopped and parts replaced. The abrasive rock under Lake Mead had destroyed the center disc cutters and parts of the cutterhead. Also the bearing seals were considerably affected by the high pressure and had to be replaced.

THE SEARCH FOR THE RIGHT SOLUTION

Everyone involved had asked themselves the right question long before the project began: how must a TBM be designed so it can constantly withstand such high, previously unmanageable pressures? On the one hand, by including more steel and making the walls thicker the TBM could be designed to withstand the 15 bar water pressure, which equates to 15 tonnes of water bearing down on every square metre of the shield – with a total length of 16m and a diameter of more than 7m that adds up to a huge load. Secondly, with seals that are robustly designed, such as on the main bearing and the tailskin. Furthermore, it must be ensured that even under the extreme pressure conditions both routine work such as cutter changes and unscheduled maintenance can be performed.

Based on the information gathered, Salini-Impregilo decided to use a Multi-mode TBM from Herrenknecht. In good, stable formations it worked in so-called open mode. Here the rock, broken into palm-sized chips by the cutterhead's disc cutters, is mechanically removed from the working area. That happens quickly and is efficient. The S-502 makes "way": 40mm or 50mm per minute. At times it ate its way forward by more than 100m a week through rough terrain.

NOT EVERYTHING GOES ACCORDING TO PLAN

Only about 40 per cent of the route could be driven at speed in open mode instead of the planned 70 per cent. The geology and the water inflow at the tunnel face made it necessary that the majority of the distance was completed in the time-consuming closed slurry mode. Here a liquid medium under pressure – usually a bentonite suspension – stabilises the ground at the tunnel face and balances water pressure in the fissures. Together with the suspension the excavated material is pumped out of the working chamber via a slurry circuit. In this way even fluctuating pressure conditions can be controlled very precisely.

The change from open to closed mode has to be quick because of potential high water flows at high pressure. The specification for the Lake Mead TBM says the machine must be able to be sealed within 120 seconds. To do this the main chamber is locked by closing the rear discharge gate of the screw conveyor.

CHALLENGING CHAMBER INTERVENTION

Closed, safe, easy going? No way. Because even if the TBM digs in the secured slurry mode, cutterhead and cutting tools require regular inspection and maintenance. Various monitoring systems collect important tunnelling parameters in real time via sensors and record them. This data serves as a basis for the machine operator to decide when chamber interventions are necessary. Data analysis is only the first step. Actual replacement of the disc cutters, scrapers and buckets, however, is exhausting, time-consuming manual work.

ATMOSPHERIC CUTTER CHANGE

When tunnelling under high pressure the concept of accessible cutterhead arms has proven itself. The special design feature was first used successfully at 4.5 bar during construction of the 4th Elbe River Tunnel in Hamburg with a Mixshield in 1998. In TBMs with a diameter ≥10m the cutterhead arms can be formed as accessible hollow boxes. Under atmospheric pressure they are then accessible, worn

Intervention

The deeper and longer a person dives, the more protracted is his return to the surface. The problem is the gas that he breathes. It dissolves in the body fluids and is deposited in the tissue – until the body is saturated. Hence the name: saturation divers. If you surfaced rapidly, the gas would be released too quickly, especially in the blood. Comparable to a soda bottle you shake before opening it. This would result in gas embolism, damage to the nerve tracts and in the tissue, with deadly consequences. The diver must therefore release the absorbed gas via his breathing in slowly decreasing pressure – which takes a while. Thus the decompression time after a dive to 200m can be up to seven days.

***Above:* Crew members out front of the TBM**

or defective tools can be replaced relatively easily through the rear area of the cutterhead. Over the past two decades Herrenknecht has continuously developed this principle further and adapted it for significantly higher pressures.

INTUITION NEEDED DURING TUNNELLING

Due to the cramped conditions, TBM diameters of less than 10m do not allow accessible cutterhead arms to be included in the design – as at Lake Mead, for example. Atmospheric chamber interventions are not possible. In this case cutter changes or maintenance work can only be carried out in so-called "safe havens". They allow safe access to the excavation chamber. Encountering such a natural, stable zone along a tunnel alignment, however, is a happy coincidence. It is not the rule. Here the experience and intuition of all project partners is called for: do you take the risk and continue tunnelling a certain distance further in the hope of reaching a safe zone soon? Or are the cutters so worn that you have to act immediately? Safe havens can also be created artificially, for example by means of pre-excavation ground improvement with drilling rigs on the TBM or from aboveground. This is very time- and cost-consuming, however, and not always possible.

In the worst case you turn to the fallback solution: you send divers into the pressure area of the TBM. First experiences with this method were also gained during construction of the 4th Elbe River Tunnel in Hamburg. There the bucket supports needed to be rewelded and the buckets themselves replaced. The operation took six weeks – at pressures of up to 4.5 bar and thus in pressure ranges divers can only under exceptional circumstanced enter with "normal" compressed air. At depths such as under Lake Mead and a pressure of up to 15 bar, that no longer works. Here you have to draw on experience from the "offshore sector". Saturation diving is the magic word. It makes use of the fact that under high pressure the gas intake of the human organism is eventually limited (saturated) – and hence decompression times have a natural, manageable limit.

PREPARED FOR ALL EVENTUALITIES

At the Lake Mead project, jobsite and machine were ideally prepared for saturation diving up to 15 bar. For this a seamless positive pressure transport route was designed and implemented. This leads from the (pressurized) living chamber in the area of the launch shaft, in which the divers sometimes live for weeks, to the pressure lock in the front shield area of the TBM. For a deployment the transfer shuttle must be transported through the entire back-up of the machine. Special design considerations are necessary for this so enough space for the shuttle remains open in the center. Only in this way can the quick and above all completely safe entry of the professional saturation divers into the excavation chamber be enabled. In normal operation, on the other hand, these facilities must cause minimal interference to the tunnelling process.

In the end, the complicated and time-consuming use of saturation diving was fortunately not needed during tunnelling under Lake Mead. Nevertheless, in such difficult pioneering projects at the limits of technical feasibility, in addition to plan A you always need to have a plan B or even plan C in your pocket.

In future it is therefore very likely that all TBMs deep below the earth's surface will be equipped with such technology. Tunnelling depths of 200m are no longer a fantasy. In Turkey, saturation divers are also the fallback solution: a 13.60m diameter Herrenknecht TBM is deployed to mine a tunnel directly under the Bosphorus and all possible facilities for chamber interventions are on board. At its deepest point the 5.4km-long road tunnel of the "Istanbul Strait Road Tube Crossing Project" is about 100m below the water level

FILDER TUNNEL

Progress is good so far on the Filder, biggest of the Stuttgart 21 rail project tunnels in southern Germany

Adrian Greeman
Adrian is a former editor and long-standing regular contributor of *Tunnels and Tunnelling*

IN MID-OCTOBER the Austrian contractor Porr, part of the Atcost 21 joint venture with Hinteregger & Söhne, Östu Stettin and Swietelsky, will stop the TBM drive on first bore of the Filder tunnel less than halfway along its 9.5km length. The Herrenknecht multimodal machine will be dismantled and brought back to the portal.

But this is not because of problems; just the opposite, the TBM has been progressing very well, up to 40m/day, through first clays and silts and then harder saturated sandstones, says Porr project manager Norbert Hörlein.

It was planned from the beginning that the machine would stop. In fact it is to make four drives for the tunnel, two of 4km downhill from the southern portal and then two for the other end, doing two parallel sections of about 3.6km at the city centre end.

Work on the tunnel, part of the new Stuttgart 21 high speed rail system, began in November last year starting from a short 130m stub entry at the portal. In this conventionally excavated soft ground section the 10.82m diameter machine had been assembled, before setting out on its 4km drive completed in just under a year.

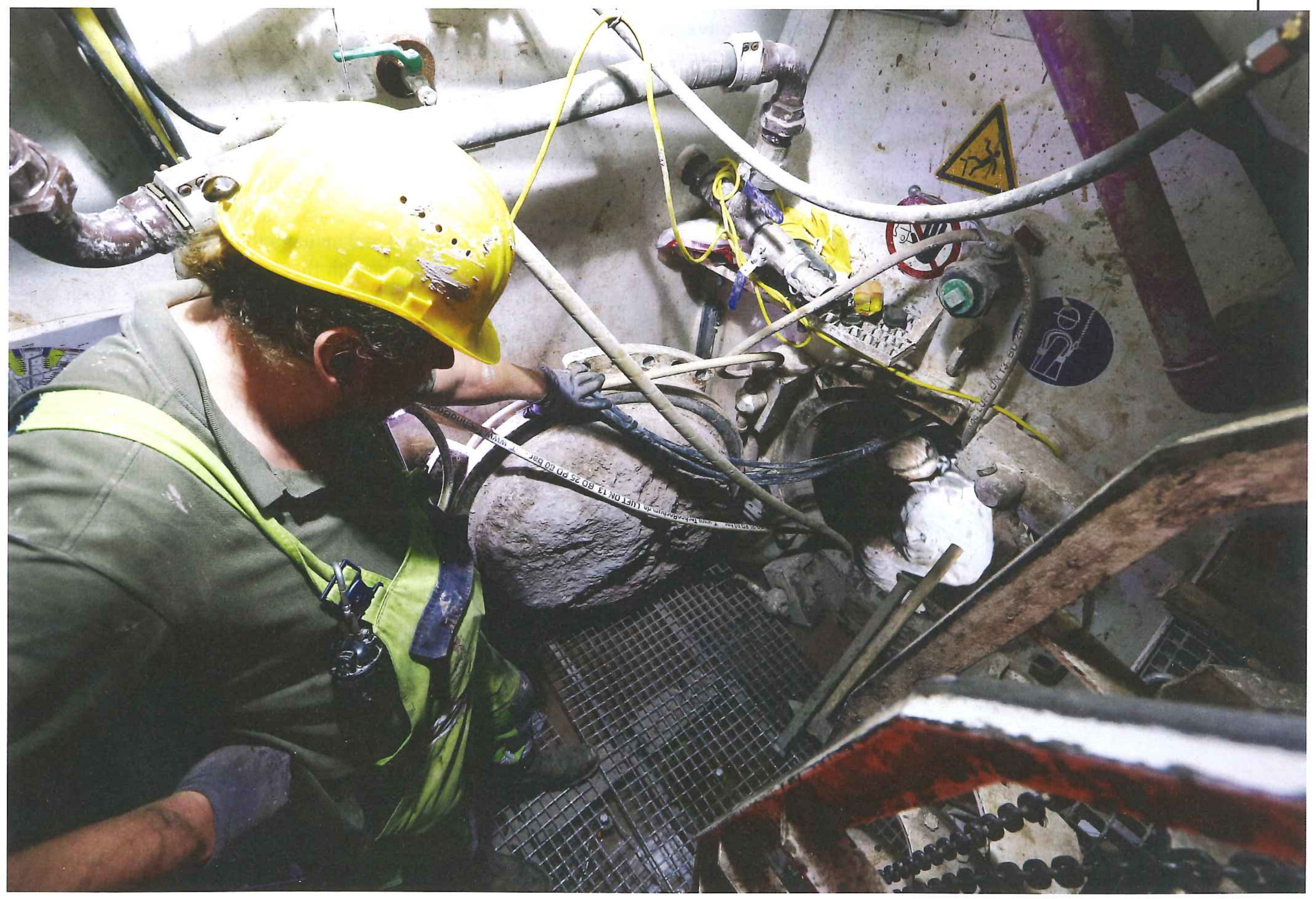
According to client spokesman Thomas Berner from Deutsche Bahn, progress was good for much of the drive "although there were some problems with clogging where the ground became more silty". Disc wear was good but increased in the last sandstone section and progress has slowed a little, down to 80m a week.

"The sandstone is okay but there are parts with mixed sandstone and mudstone layers," says Walter Wittke, a professor whose consultancy is specialist tunnel design adviser for several of the major tunnels on the Stuttgart 21 project. "That means both sort and hard rock in the same face, causing some clogging."

The machine ran first in EPB closed mode for the early soft clays and silts and then in what might be called "semi-open" mode later, still using the screw conveyor for spoil removal from the face but without the need for a pressurised face.

This major part of the drive is through a complex layering of sandstones, claystones

Below: ***As Tunnels and Tunnelling went to press, the Herrenknecht machine was soon to undertake a planned stop***



and mudstones.

The second drive, on the parallel bore of the twin tube tunnel, begins next spring once the machine is serviced and reassembled, once again heading downhill towards the city.

The reason for the odd sequencing is geology, to be precise a band of anhydrite Keuper gypsum about halfway along the tunnel. The reactive rock has been sealed between impermeable layers until now, and never exposed to water. Were it to be wetted it would hydrate much in the way that Plaster of Paris does, which is a form of gypsum.

"The tunnel runs through a layer which is about 30 per cent of gypsum anhydrite distributed through mudstone and claystone," Wittke explains. He has some 30 years of experience in the region's rock including numerous experimental studies on its properties, results of which were used for previous tunnels.

The anhydrite form is highly reactive

Above: **Aerial view of the project showing proximity to motorway**

Below: **Conveyor system serving the tunnel**

with water he says. "It dissolves and then recrystallises in a hydrated form in which it expands by around 60 per cent." This particular rock layer could expand some 18 per cent therefore he says, "which is enormous," and creates significant rock pressure.

WATER BLOCK

To prevent this, and the danger of trapping the TBM, the central 1,500m of the tunnel is being dug with drill and blast and given a watertight lining. Additionally Wittke has devised an innovative water block system for the tunnel bore which aims to prevent any groundwater movement into this section of the tunnel alignment for its entire 100-plus years lifespan.

It works something like a hugely enlarged water stop in concrete it might be said. First, along a small length of the tunnel the bore will be enlarged and an extra thickness of concrete lining be installed as a collar. Through that, a radial pattern of drill holes for grouting will fan out into the rock around the bore which will be sealed using a fine penetrating resin mixture with a viscosity close to water.

"It should seal the finest cracks," Wittke says. The grout curtain will extend outwards to 4m additional radius, which should ensure the area of relaxation around the tunnel bore is sealed. Beyond that, he says, the rock is naturally tight and unaffected by excavation work.

The grouted water stops will be installed at three points along this southern uphill end of the central tunnel, allowing for complexities in the overlying rock strata; as well as the most saturated sandstone layers there are others which are potentially water bearing. In between the stops there will be a thickened lining of up to 1m thick of concrete along the bore.

There will also be a water stop at the far end of the gypsum section, though here only one stop is needed to seal off a single rock layer beyond.

The drill and blast drive will be extended by a side passage to the line of the second bore, which will have this 1,500m central section and its water stops excavated during the time the TBM is making the second drive, and completing before it arrives.

Once it reaches this section, rather than be dismantled, the TBM will be pushed through the central D&B section to the end from

Stuttgart 21

The Filder tunnel is the largest single tunnel on the controversial Stuttgart 21 project, but by no means the only one. A series of tunnels are being made through the city centre which will reroute existing tracks and incorporate a new high speed rail line.

Within Stuttgart the project aims to reconfigure regional and local train networks, adding high speed railway but also freeing up regional and commuter train flows. Stuttgart is hilly, rising steeply on either side of the Necker river valley and with more hills blocking the south-west end. Trains come in at present from the north-east, finishing at a terminus where they spread out over 17 platforms.

There is also a local city train, the S-bahn, which passes through the city hills in tunnels, and an underground U-bahn.

Deutsche Bahn wants to replace the main station and its blind-end platforms with just eight platforms all completely underground. New lines run at right angles to the existing ones.

"But they would be through lines, which makes train operations more fluid" says German railways client Deutsche Bahn which set up a special project company for the scheme. Currently trains converge onto five exit lines and are often held up; despite fewer platforms the new layout would increase capacity by up to 50 per cent. Simulation studies show a particularly significant improvement during peak hours.

With the station underground, there would also be land released above for development, though less than originally foreseen.

The scheme has been highly controversial particularly with the Green political groups and there were significant demonstrations against it five years ago.

Plans to demolish the old station have since been amended and the pre-war building will mostly remain as part of the complex.

The Filder carries the new high speed rail tracks south-east towards Stuttgart station firstly and then connects to a new high speed line between Stuttgart and Ulm. The Stuttgart-Ulm line is a concurrent and significant project itself with a number of major tunnels up to 8km long in construction.

Taken together with the Stuttgart project the total investment is around EUR 10bn (USD 11bn), the largest tunnelling works in Europe outside of the London Crossrail scheme.

where it will re-launch for the last 3,600m-long drive to the lower, city centre, portal emerging in the central part of Stuttgart. One final drive will then remain.

For this the machine will be turned in a large cavern, currently under construction, and will now drive back uphill to complete the final part of the first bore, another 3.6km-long section.

Both these drives will be done with the machine fully reconfigured in open mode and kept as dry as possible.

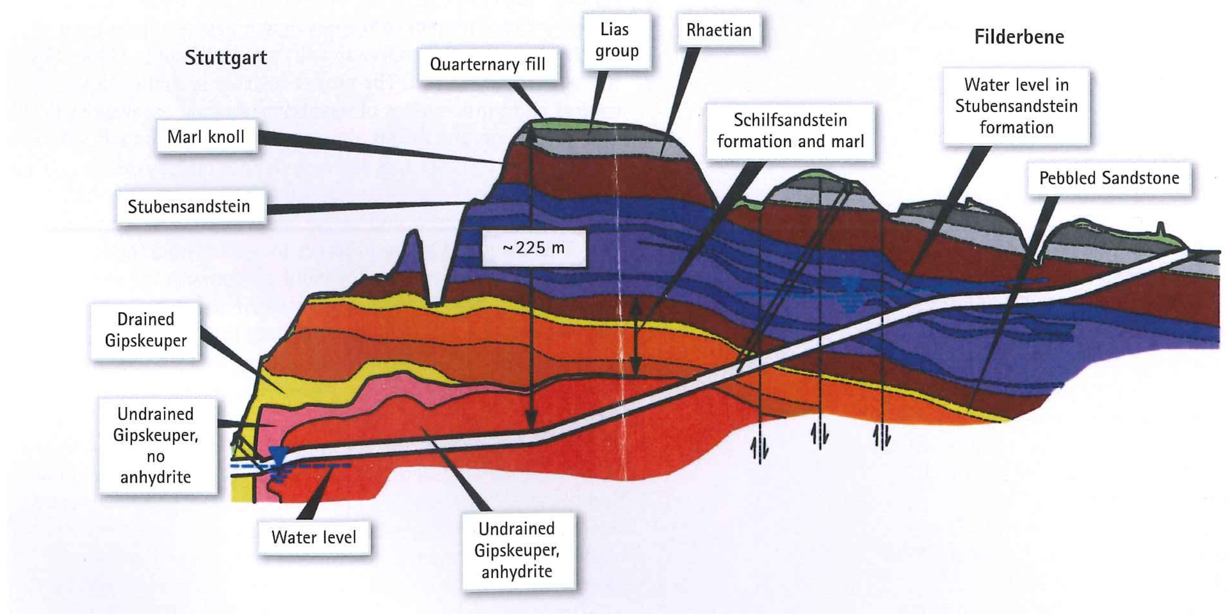
At present the plan is to service all these drives from a site at the southern portal explains Hörlein. It is a convenient enough location in the southern suburbs of the city just adjacent to the A8 autobahn towards Ulm and Augsburg, the same axis along which the new high speed rail line will run after it emerges from the Filder tunnel. The motorway is important for spoil disposal and site supplies including segments.

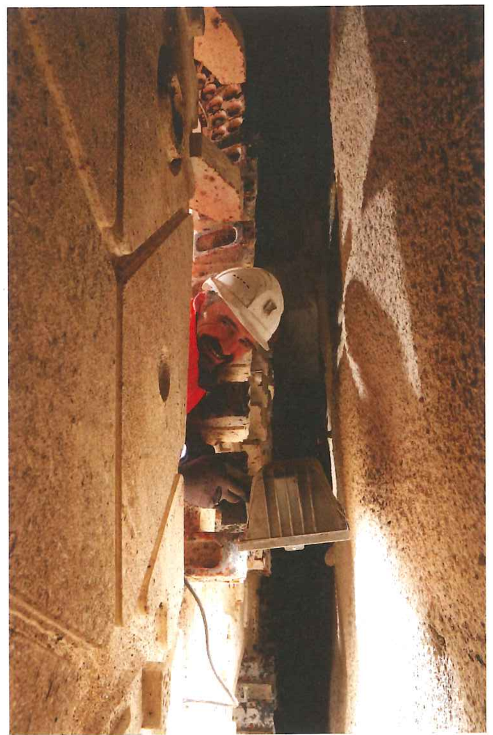
"We do not have a direct entry from the site onto the autobahn and trucks have to take a 2km route locally to get onto it but it is still relatively convenient," says Hörlein. It is just as well as the site itself is relatively small in area and has little room for storage. Quite a section of it is taken up with cement storage and a batching plant and much of the remainder is a TBM starting area. For both segment supply and spoil disposal there is a need for an efficient "just-in-time" approach says Hörlein.

Segments are quite large, with six full size pieces and a halfsize key for each ring. Each is 2m long and either 400mm thick or for some critical tunnel areas even 600mm.

"We are using separate left and right rings" he says which adds to the storage needs since both types need to be available. In the tight space available this

Below: **Geological profile of the project**





Above: *View of the excavation face (left) and rear of the shield*

means only about three days supply for the machine can be accommodated.

It means a complex logistical management exercise to ensure the correct rings are available for the machine as it progresses, he says "and we have an engineer dedicated to managing that".

The segments are being made in the Max Bögl plant at Neuenmarkt near Berlin, using Herrenknecht forms and are delivered using rail for the long 400km journey. They arrive every couple of days explains Atcost site engineer Katharina Hertel, coming into a larger storage area about 20km from site. From there the rings are brought to site by truck where they are unloaded using a 45t Teichmann portal crane.

They are delivered to the TBM with a rail system using Schöma locomotives.

Spoil is equally complex to manage as there is very little space to stockpile anything. Once again it is virtually a full time operation to manage the logistics says Hörlein and two more engineers have to concentrate on its just-in-time organisation. Up to 10,000t daily has to be moved. As is increasingly the norm, spoil is carried by conveyor in the tunnel, in this case a system from Swiss manufacturer Agir. Once delivered to surface the material is immediately loaded into trucks which take it to various disposal sites, mostly old quarries, up to 80km away. "We have up to 75 trucks daily," says Hörlein, "which we can run between 5am and 10pm".

Spoil will continue to be handled at this site for the second bore and the NATM excavated sections in the centre.

The centre parts will be done with drill and blast, hopefully says Hörlein with Atlas Copco boomers being used by the same contractor on a project for the Stuttgart-Ulm line which will have completed by next year. But it has not been decided yet how spoil it will be removed. The options are to use more conveyors or perhaps rail trucks. If the conveyor continues to be used for the first drive then it will be necessary to fit a second one for the next TBM drive starting in the spring. Equally the contractor is still deciding on the method for the final drive back out of the city centre and whether the logistics should be done back through the then completed second bore, with a possible 12km of conveyor, or through the central city logistics area.

The latter is an option because there is further work to complete the Filder tunnel at the city centre end, part of a complex of underground works and other tunnels that make up the Stuttgart 21 project. (see box, page 43)

"We, are doing the work but it is a different section of the contract" says Hörlein. Initial work has been to create an access tunnel underneath part of the city centre near the main from which four drives are underway with materials and spoil logistics through the access adit. The project involves several complex caverns and tunnels using observational method excavations in soft ground. The ground here is also the same Keuper formation but no longer sealed by other rock layers underground" says Wittke. "That means the gypsum has been leached out leaving a weak rock." These caverns form the end of the Filder and also separate tunnel links into the new station. In places they must hold four tracks as they lines converge from the eight platforms in the station. Further along there is another point where the tunnels widen out again as lines split off heading eastwards into other tunnels to Untertürkheim and Bad Cannstadt. These branching lines will also provide a link for trains to join the original main line to Munich.

"Caverns up to 20m across and 18m high are needed," says Wittke, "The height is necessary in order to achieve arching in the ground." The huge spaces are just 8m below building foundations and complex compensation grouting is being used as a measure against settlement. Extensive monitoring is being installed.

He says that the initial work has been going well although slowly, particular with complexities around a central reinforced concrete piller that separates to diverging tracks

A PERFECT STORM

The UK pipe jacking industry is in a sharp, albeit brief slump. Several factors have come together to make what was supposed to be an end to the rollercoaster of water work, into a complete halt in activity. **Alex Conacher** reports

FOR THE last 25 years the water utility tunnelling market in the UK has undergone five-year cycles governed by its Asset Management Programmes (AMPs). These tranches of work have typically resulted in, for pipe jacking and microtunnelling activity, lean first and fifth years with three fat years between.

This 'rollercoaster' was never an ideal situation for contractors or the supply chain, with sizeable changes in workforce to control overheads during the down periods. So in the middle of AMP 5, which ended in March 2015, there was a cross-industry effort to think about mitigating the effects of this cycle. To flatten the rollercoaster.

However despite best intentions, government reports, and an 'Early Start' initiative for AMP 6, which began in April 2015, the result has been a total absence of work.

STOP THE WATERWORKS

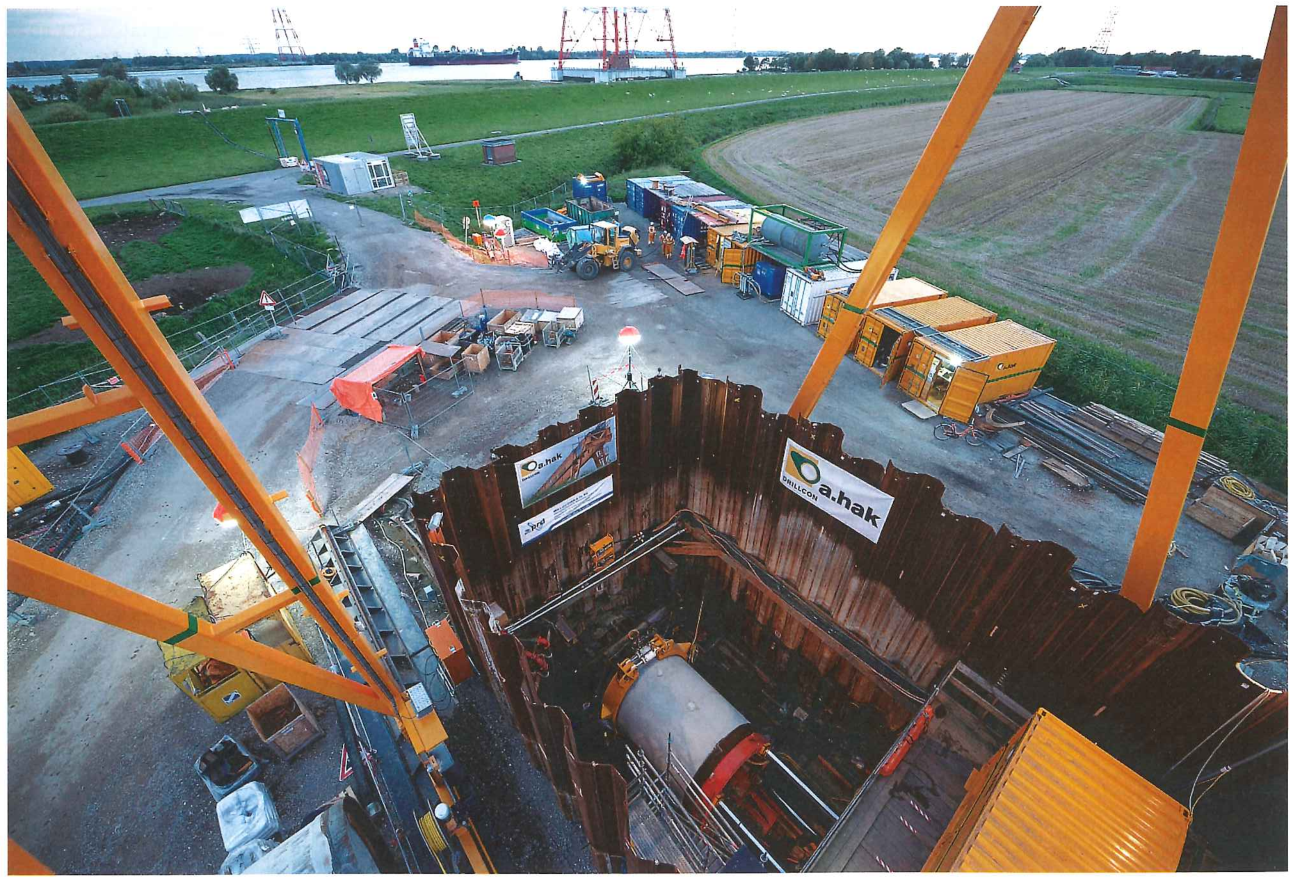
"We fell off a cliff when it came to AMP 6," says Andy Flowerday, managing director of contractor Barhale. "Normally there is a slowdown at this stage in the cycle, but this time we were caught in a bit of a perfect storm and there is almost no capital expenditure work at all."

Flowerday explains that a fundamentally different regulatory model has entered the industry that manifests itself in three ways:

- Firstly, a huge efficiency challenge has been laid on the water companies requiring a major step change for them.

- Secondly, a shift from separate CAPEX (capital expenditure) and OPEX (operational expenditure) assessment approaches by the regulator to a new concept called TOTEX. CAPEX and OPEX have always been dealt with separately by the regulator, and was seen as wasteful. So a new concept, TOTEX (total expenditure) was introduced that looks at value to the customer from spending. It means that if there is a requirement from customers, or regulation, then a decision needs to be made to decide whether maintenance of existing, or capital investment into new infrastructure is needed.

Below: *Illustrative photo of the start of a pipe jacking job*



- Thirdly, a new set of key performance indicators called Outcome Delivery Incentives (ODIs). There are large amounts of money in the industry that are now triggered by outcome performance. Outcomes being the results promised to customers. So where previously payment could be made on output, constructing a certain amount of new pipe for example, now it is in the slightly less tangible, although admirable, criteria of benefit to the customer.

"This change in model, although definitely a good move, has made water companies uncertain in the short term, and they will pause and seriously think differently about the way they run themselves as a business," Flowerday says. Some of the ODIs for example, if you miss something you can be hit with a GBP 15M fine. Which means a re-evaluation for the water companies, and also that the work being done at the moment is the really essential work, such as maintenance, and not the type of work that involves pipe jacking and tunnelling, which will come later in the programme."

KICKED WHILE DOWN

A general slow down across the other utility tunnelling sectors: gas and utility pipelines, flood defences, and developers have meant that contractors have struggled for work, which is normally available in other sectors, to cover the lull during the AMP changeover. This has only added to the 'perfect storm' described by Flowerday.

A BRIGHT FUTURE FOR NO DIG

Although this has been a sharper start to an AMP than usual, things are expected to improve in the near future in the water sector.

Flowerday concludes: "There's a lot of good things about working in the water industry, and we tried really hard to flatten the rollercoaster. Unfortunately we just got this perfect storm of new regulatory model: TOTEX, ODIs, and efficiency.

"Water companies are quite correctly taking stock and the unfortunate supply chains got caught in the middle of this.

"There will be a recovery. Looking ahead, year two of AMP 6 is going to be really busy. And there's another positive happening in the pipe jacking and microtunnelling industry generally: the drive for low carbon solutions is really taking off, and that's a positive factor. AMP 6 is the first to have carbon reduction factored into the tender documentation.

Andrew Marshall of the Pipe Jacking Association adds: "The other year we produced our Carbon Calculator (see box) to compare no dig solutions with open cut ones. And feedback has been entirely positive.

"All work independent by the Transport Research Laboratory (TRL), and it was based on ICE data and other sources so we know it is good quality. This tool was then verified by the Water Research Centre so it has got serious approval.

"It has been persuading people of the need for carbon reduction. That is really coming through in AMP 6, now there is a requirement to look into those things. And also to consider carbon as part of the contract.

This is a considerable requirement that is expected to increase with time, and I understand OFWAT is putting pressure on the water companies to consider that.

Marshall muses: "Actually, we produced the carbon calculator a bit ahead of the game and it is only now that people are implementing the saving requirement. We knew this was coming, and now that the carbon element is in tender consideration for the Asset Management Programmes, it is a real positive for us. It takes just two minutes to do this pipejacking vs. open cut comparison on the website to verify it.

"Low carbon is good for business," adds Flowerday.

Joseph Gallagher's tunnelling director Dickie Dexter has another positive view on the lull in underground construction work and general situation: "There are some trends that do not go away, and mean that a dip is just a dip. Both nationally and abroad, the surface world is getting more and more crowded, raising demand for underground solutions"

Latest from the Pipe Jacking Association

- The Pipe Jacking Association (PJA) granted its first bursary in September. MSc work at Portsmouth University is underway to work on the development of fibres in concrete tubes to see if costly cage reinforcement could be phased out of the industry.
- Other research that hopes to discredit what the PJA suspects might be excessive steel temporary works at portals being designed by consultancies. A lot of money is currently being spent on this as an insurance measure because the stresses and strains are currently unknown.
- Feedback from the Carbon Calculator, which compares pipe jacking to open cut solutions, has been positive despite the PJA being somewhat ahead of the relevance to tendering. Now with AMP 6 including Carbon reduction in tender consideration, usefulness is expected to increase further. The calculator can be found at: www.pipejackingCO2calculator.com

Below: Cage reinforcement in a pipe jacking pipe

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What's on

2015

Workshop on Innovations and Challenges in Tunnelling
5-6 October 2015
Kingston, Ontario
Save the date for the Tunnelling Association of Canada's 2015 Workshop, AGM and annual awards dinner, to be held at Queen's University's Grant Hall.
www.tunnelcanada.ca

Tunnel design and construction short course
7-8 October 2015
Brisbane, Australia
A short course managed by the Australasian Tunnelling Society and held at the Brisbane Marriott. Contact rboak@engineersaustralia.org.au for more information
www.ats.org.au

8th Annual Health and Safety Excellence Conference
7-9 October 2015
Amsterdam, Netherlands
This conference will help companies to develop their safety culture and achieve optimized technical safety through increased engagement. Cross-industry experts will deliver practical case studies on how they have successfully implemented an optimized safety culture
www.marcusevans-conferences-paneuropean.com

Eurock 2015 & 64th Geomechanics Colloquium
7-10 October 2015
Salzburg, Austria
The ISRM Regional Symposium EUROCK 2015 Future Development of Rock Mechanics, is to be held in conjunction with the 64th annual Geomechanics Colloquium also in Salzburg. Annually attracting over 1000 participants, this event promises to be another success.
www.eurock2015.com

Shotcrete for Underground Support XII
11-13 October 2015
Singapore
This event aims to pool the consolidated efforts of engineers to share and update state-of-the-art technology and best practices in rock engineering
bit.ly/1ONw9ou

ITACET and Tongji University Training Course
17-18 October 2015
Shanghai, China
To encourage uses of underground space for the benefit of the public, environment and sustainable development, and to promote international exchange and collaboration on underground technology and experience, ITACET and Tongji University have organised a two-day training course for professionals in the tunnelling industry.
www.ita-aites.org/fr/wg-committees/committees/ita-cet

25th World Road Congress
2-6 November 2015
Seoul, South Korea
The World Road Congress has been held every four years for more than 100 years. Since the first meeting in Paris in 1908, it has toured the member countries of the non-government organization, Permanent International Association of Road Congresses (PIARC).
www.aipcrseoul2015.org

Controlling exposures and health risks in construction
10 November 2015
Birmingham, UK
The Breathe Freely campaign has been launched recently with a view to raising awareness of the occupational health issues related to respirable materials.
www.breathefreely.org.uk

TBMs in Difficult Ground
18-20 November 2015
Singapore
TBM DiGs 2015 is to be held in Singapore, jointly organised by the universities and supported by the tunnelling community worldwide, interested in TBM tunnelling technologies. The organisers would like to welcome researchers and practitioners to the event.
www.tbmdigs.org

ITA Tunnel Awards
19 November 2015
Hagerbach, Switzerland
The International Tunnelling Association has launched its own independent awards to recognise industry achievements.
www.awards.ita_aites.org

Third Arabian Tunnelling Conference and Exhibition
23-25 November 2015
Dubai, UAE
This conference is the industry's opportunity to share the knowledge, projects and application experiences, and provide you the opportunity to hear what others have to say. Case studies, which show real-world applications and the implementation of new technologies.
www.atcita.com

Stuva Conference
1-3 December 2015
Dortmund, Germany
Held every two years, this conference sees 1,500 participants and visitors from about 20 countries. It is numbered among the world's leading get-togethers for underground construction experts. In 2015 the chosen venue for this premier event is Dortmund.
www.stuva-conference.com

Building simulation
7-9 December 2015
Hyderabad, India
This conference is the 14th International Conference of the International Building Performance Simulation Association.
www.bs2015.in

2016

International Symposium on Tunnel Safety and Security
16-18 March 2016
Montreal, Canada
Tunnel safety and security is a challenge for both private and public sectors. ISTSS provides a forum to discuss current practice and emerging trends and research in the field of tunnel safety and security.
www.istss.se/en

NASTT's No Dig Show
20-24 March 2016
Dallas, USA
The overall No-Dig Show program is focused on one objective: helping you maximize your investment in trenchless technologies, services and applications.
www.nodigshow.com

Bauma 2016
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.
www.bauma.de/en

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 conceptual design up to operational emergency rescue.
www.cmct.cn

World Tunnel Congress and North American Tunnelling conference 2016
26-28 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 the UCA's North American Tunneling conference. Bringing the events together in the US is unprecendented.
www.wtc2016.us

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 issues.
www.geochina2016.geoconf.org

2017

World Tunnel Congress 2017
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

AFTES 2017
13-15 November 2017
Paris, France
The French engineering event is themed 'the value is underground'.
www.aftes.asso.fr

The British Tunnelling Society

The BTS has a membership of almost 700 individual and 60 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971.

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 events.

Canning Town Flyover, London, UK
15 October 2015
The presentation will look at the requirements with regard to settlement mitigation concerning Crossrail tunnelling. The design and structural form of the viaduct will be considered along with the solution in terms of the instrumentation measurement and hydraulic control. The real time information and alerts that were available to engineers will be covered in the talk, along with how the movement was managed when the TBMs passed under the structure, and other potential uses of the technology.
Speakers: David Holland, Mabey; Kim West, Arup

BTS Underground Health and Safety Course
23-24 November 2015
The Health & Safety Course is organised and run by the British Tunnelling Society (BTS), an Associated Society of the Institution of Civil Engineers. The purpose of the course is to provide a comprehensive introduction to Health & Safety in tunnelling. It has been decided to repeat the two day format of the last five years to allow more time on specific subjects and include more discussion and debate. Booking is now available on the BTS website
Fees: BTS Members: GBP 100; Non-Members: GBP 150

The Abu Dhabi Strategic Tunnel Enhancement Project (STEP)
19 November 2015
The Strategic Tunnel Enhancement Project (STEP) consists of 45 km of gravity sewer and 43 km of link sewers taking sewerage flows out of Abu Dhabi city to a new treatment plant and accommodating average sewerage flows of up to 29 m3/s. The talk focusses on the challenges of designing and constructing the deep gravity sever, which started at a depth of 24 m in the City and ended at 80 m depth with a diameter of 6m at the new treatment works. 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 experienced gained is relevant to coming major tunnel projects in the UK.
Speakers: Shahzad Orakzai, Abu Dhabi Sewerage Services Company; Richard Graham, Salini Impregilo; Carola Edvardsen, Cowi

BTS Christmas debate
10 December 2015
The traditional end of year debate will this year argue the proposition "This house believes that developments in recent years relating to sprayed concrete lining thicknesses is heading in the wrong direction, noting that sprayed concrete lining has managed to double the lining thicknesses in the last ten years". After hearing the arguments for and against, some more serious than others, a vote from the floor decides the issue.
Speakers for and against have yet to be confirmed

If you have a topic or project you feel would be suitable for a BTS evening presentation, please contact:

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See the society website for further information:
www.britishtunnelling.org.uk

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