INTERNATIONAL EDITION
July 2013

Tunnels AND TUNNELLING

FIGHTING FIRES

Quantifying the impact of fire suppression and understanding protection available to tunnel systems

North America • Nuclear Disposal

TWO FACES OF DISCLOSURE

LAST MONTH Edward Snowden, a former low-level NSA technician revealed to the world what it already knew: that the shadowy arm of the world's most powerful government is keeping tabs on its citizens.

The more we know, the less we have to take on faith. And when wrongdoing is detected, a more complete picture is available to the authorities in pursuing whatever course of action they decide.

Wouldn't every client wish for a complete picture of where its money is being spent, and what is happening on its project? Probably. There have been notorious cases where increased inspection or other oversight would have saved a collapse.

But swing this the other way. A whistleblower has, not for the first time in recent history, revealed to the public what is being done in its name, with its tax dollars.

As a responsible client, the state should delight in the opportunity to establish itself as a transparent democracy with an informed public whose interest it serves.

Instead probably begins the deranged pursuit of a true public servant.

The tunnelling industry too is not without the whispers of the dangers of being a whistleblower. And accusations have been leveled against some of the major projects of the world of covering up shoddy practice with layoffs and media-gags.

These are often no secret in the industry, just as no one is surprised by the revelation that a nest of spies is capable of lying both to country and Congress.

And nothing is likely to change. Why should anyone believe a future statement that the NSA has ended its intrusive surveillance? And why should anyone believe that high-profile projects would not, like any slighted government entity, try to save face (and further costs) first and foremost.

It's important to make sure whistleblowers do not stand alone. The tunnelling industry should add its collective voice to the individual when he or she speaks up over less than best practice.

Civil engineers have a too-often under appreciated role in creating the infrastructure that supports society. Tunnelling in particular is quite literally underground and out of the public eye, giving tunnel engineers an even greater responsibility to speak up when something is wrong, and to inform an unaware public who depend on it more than they know.

Besides, unless tolls, a raise in bills or taxes, or the temporary possession of a park is involved, the public does not necessarily have a vested interest in how a project is constructed, let alone worker safety conditions on site. Or an appreciation of deeper issues that such problems might indicate.

It falls solely to the civil engineers then to make sure the work they do is good, the standards held by their employers are high and that the working environment is safe.

Engineers and workers are proud of what they do, and unlikely to jeopardise a project without good cause.

The industry can be better by standing by whistleblowers

editor@tunnelsonline.info

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

Alex Conacher
Deputy Editor

Cover
Fire protection is discussed in detail, with some lesser-known nuances of road tunnel systems under operation

Next issue
In the next issue Tunnels visits the Middle East, with a record breaking number of TBMs working on a single project. Also featured is a technical focus on ventilation, with a discussion of the disorientation presented by even a familiar smoke-filled environment

This month...

10 YEARS AGO

The Irish transport minister Seamus Brennan has provoked another storm of protest over plans to sell the Dublin Port Tunnel, currently under construction. The USD 800M, 4.8km-long twin tube tunnel is the Irish capital's largest infrastructure project and will ease the city's worsening traffic by removing port-bound trucks from the roads. Under the Brennan Plan, it will be sold for USD 1.2bn on a 30-40 year lease, with the obvious tolls. The tunnel has also been controversial for its 4.65m clearance, which will result in larger trucks being banned from the city when the tunnel opens in 2005. Irish haulers claim that up to 400 trucks will be affected by the restriction,
Tunnels and Tunnelling, July 2003, p.14

20 YEARS AGO

The first of the gigantic TBMs for the USD 12bn Trans-Tokyo Bay Highway project has been built and is being put through tests. The 14.1m Kawasaki colossus is a slurry shield EPBM. It also has the potential for totally automated robotic segment handling and erection. The system was designed by Kawasaki and allows for a ring cycle of 110 minutes. The TBM is due to be delivered in February 1994. This, the largest TBM ever built will have to contend with the high-risk earthquake zone Tokyo inhabits, as well as the drive through boundary layers of alluvial and diluvial soils under deep water with 15m of cover.
Tunnels and Tunnelling, July 1993, p.8

Deep underground storage caverns for nuclear waste *on p.48*

Contributors

Andy Evans
Andy has spent some 40 years in mining and tunnelling, including time in research and as a tunnel manager. He has established his own consultancy, Aegis Tunnel Consulting, and is the chairman of the Road Tunnel Operator Association.

Fathi Tarada
Fathi is a leading expert in fire safety engineering, tunnel ventilation and Computational Fluid Dynamics. He is managing director of Mosen, and chief executive of HBI Haerter. As well as being the secretary of the World Road Association (PIARC) Technical Committee on Road Tunnel Operations.

USD 8BN DOHA METRO TENDERS

Qatar Qatar Railways (QR) has awarded four design and build contracts for the first phase of the Doha Metro Project, worth QAR 30bn in total. The construction of Phase One is scheduled to begin later this year and is expected to be completed by 2019, a spokesman for QR said last month.

The 131km Doha Metro Railway will have at least 48 stations and half of the entire facility would be built underground at depths up to 50m.

In his presentation during the World Stadium Congress, QR commercial manager Stephen Lines said to meet the Phase One delivery deadlines, some 26 tunnel-boring machines will be required. "If you put that in context at the moment, the new system being used in London has six boring machines. We are talking about 26," said Lines.

Lines said that the 26 TBMs are expected excavate 17Mcu.m of soil "which is seven times the volume of the pyramids in Egypt." They will also use 800,000t of steel, equivalent to 100 Eiffel towers; over 5Mcu.m of concrete, which is 14 times the amount used in Burj Khalifa in Dubai.

He said the Mushreib station alone will use more concrete and steel than the Burj Khalifa. "The only difference is that it will be underground."

The four contracts awarded last month are for the Red Line North (RLN), the Red Line South (RLS), the Green Line (GR) and the major stations (MS).

The RLN project was awarded to a consortium led by Impregilo, and comprising of SK Engineering and Construction Company and Galfar Al Misnad Engineering & Contracting.

The RLS project was awarded to a consortium led by QDVC and includes GS Engineering and Construction Corporation and Al Darwish Engineering.

The contract for the GRN project was awarded to a consortium led by Porr and includes the Saudi Binladin Group Company and the Hamad Bin Khalid Contracting Company.

The fourth contract is for the major stations project. There will be two stations included in this package, one at Msheireb and the other at the Education City.

This contract was awarded to a consortium led by Samsung C&T Corporation and comprises of Obrascon Huarte Lain (OHL) and Qatar Building Company.

The four lines of the Doha Metro will connect major sites in the city including Education City, West Bay, Lusail, the Hamad International Airport and the Qatar National Convention Centre (QNCC).

The scope of work for the RLN involves design and construction of some 13km twin-bored tunnel, including seven underground stations, between the proposed Msheireb Underground Station and Doha Golf Course via Doha West Bay.

For this, four TBMs are to be used for the required rail tunnels. The tunnels will be built at an average depth of 20m below ground.

Similarly, the scope of RLS contract comprises the design and construction of the underground works below central Doha, including six underground stations, between the proposed Msheireb Underground Station and the Hamad International Airport and incorporates the main depot and maintenance facilities.

This package will approximately comprise 13.8km twin-bored tunnels at an average depth of 25m, utilising five TBMs. The maximum depth point will approximately reach 50m below ground level. In all, there will be eight underground stations, in addition to 16.6km of twin-bored tunnels.

Suruç water tunnel nears completion

Turkey Turkish contractor Ilci Insaat Sanayi Ve Ticaret has excavated some 14,508m of tunnel has been excavated on the 17.2km drive for the Suruç Tunnel, which is planned to be Turkey's biggest water distribution tunnel, the General Directorate of Turkish State Hydraulic Water (DSI) announced last month.

When complete the tunnel will irrigate around 95,000 hectares of arid land. Some 90t of water per second will flow from Turkey's largest dam Atatürk to the Suruç Valley in Southeast Anatolia. The tunnel has been under construction for the past two years.

"We are planning to start water flow from the tunnel by 29 October, Turkish Republic Day," said Numan Gündüz, 15th district manager of the DSI.

The entire drive is being excavated by a 7.83m diameter Seli double shield TBM on a typical gradient of 0.48 per cent. Groundwater is present in a regular profile along the whole alignment, which passes through the Gazientep formation of the Eocene and Oligocene geological period. This formation consists of calcareous and karst members (Teog), calcareous and clayey members (Teogt), and calcareous and clayey members with marnes (Teogm). A 300mm-thick lining of hexagonal precast concrete segments will be installed.

Agricultural productivity is quite low and only dry farming is currently possible in the Suruç Valley. "Over 8,000 farmers will be able to produce more profitable agricultural products after the tunnel is completed. They could produce cotton and corn instead of less profitable products, like lentils or wheat," Gündüz added.

The planning of the tunnel, which forms the most important stage of the Suruç Valley Pumped Irrigation Project, was started in 1990 but could not be completed for years.

Governor to seeks private investment Jakarta's SMART tunnel

Indonesia Not discouraged by the central government's rejection of his proposed deep tunnel to help alleviate Jakarta's perennial flooding and traffic problems, Governor Joko Widodo said late in May that he would continue to pursue the project with private investors.

The governor said the city had already included the multipurpose deep tunnel project in its mid-term development plan, and that the city legislative council had already approved it.

"It will be done through investments," Widodo said of the project. Investors, he said, would conduct their own feasibility study before deciding to invest. "The investors will have to do a cost-benefit analysis, while from us, we will submit our needs for a toll road and contingencies in times of flood," the governor said.

The proposed tunnel, estimated to cost IDR 16tn (USD 1.6bn) to build, is similar to Kuala Lumpur's 9.7km Stormwater Management And Road (SMART) Tunnel.

Jakarta's proposed tunnel will be 22km long at a depth of 40m and will consist of three channels. The upper two channels will be for vehicles, while the lowest one will channel rainwater runoff to the sea and carry piping.

ITA YOUNG MEMBERS CALL

Switzerland The International Tunnelling Association (ITA) held its first meeting with the aim of creating a young members group. Based on the model adopted by the British Tunnelling Society Young Members (BTSYM), the proposal was made at WTC Geveva last month by BTSYM chair Petr Salak of Dr. Sauer & Partners, and BTS chair Damian McGirr of Donaldson Associates.

ITA member nations were called upon by new ITA president Soren Degn Eskesen to form their own young member groups, or if they already exist, to make them known to the ITA.

The aims of such a group were stated as being: to represent young tunnellers internationally; to foster links between young tunnellers around the world; to help the ITA promote tunnelling as a career; and to help the ITA improve academic programs.

McGirr said, "The BTSYM has grown substantially in its first five years and it continues to provide a great input into the operations of the BTS, particularly in the promotion of tunnelling in schools and among other young engineers. The group holds regular presentations for its members and in 2012 held its first conference."

Salak added, "We think it would be invaluable to have an international platform for young tunnellers to engage with. The success of the BTSYM has led us to make this proposal, which we hope to see realised at WTC 2014."

For more information, email the BTSYM: btsym.committee@gmail.com. Or visit: www.britishtunnelling-ym.org.uk.

MMC-Gamuda expected to bag Klang Valley MRT contract

Malaysia An MMC-Gamuda joint venture is expected win tunnelling works and also be a project delivery partner (PDP) for the Klang Valley mass rapid transit two (KVMRT2) project in Malaysia, which is estimated to cost around MYR 25bn (USD 8.1bn).

The development of the KVMRT2, slightly longer than the KVMRT1, connecting Sungai Buloh, Serdang and Putrajaya, is expected to be formally announced in July.

Analysts, after a briefing session with Gamuda's top management in May, were expecting the joint venture to win the contracts.

Maybank Investment Bank (Maybank IB) analyst Wong Chew Hann said that the progress of the KVMRT2 had strengthened its upbeat view of Gamuda, which stood to be the main beneficiary of the project.

"Gamuda believes that MMC-Gamuda JV would bag the tunnelling works expected to be worth around MYR 8bn (USD 2.6bn) and the PDP role, expected to be worth MYR 1bn (USD 325M), given its project management experience and construction expertise.

The KVMRT 2 is now designated as the Sungai Buloh-Serdang-Putrajaya line, spanning 56km, 10 per cent longer than the Sungai Buloh-Kajang (KVMRT1) line.

Bids in for Oman rail preliminary design

Oman Spanish and Korean firms are dominating a field of twelve contenders bidding for the preliminary design contract for the development of a national rail network in the state of Oman.

Technical bids were opened at the Tender Board in Muscat on 6 May, with the following companies having submitted firm offers: Sener, a leading Spanish-based international rail engineering services provider; Consultrans, a Madrid based transportation services engineering firm, part of the IMATHIA Group; ITALFERR, an engineering firm of the Italian state railways group; Saman Corporation, a major multidisciplinary engineering firm of South Korea; Dohwa Engineering, one of the largest engineering design firms in South Korea; and 3TI Architecture & Engineering Consultants, a Dubai-based subsidiary of 3TI Italia - specialist providers of international design & build integrated services.

Also in the fray are SNC Lavalin International, a world leader in engineering and construction; Auding Intraesa, a Spanish rail engineering services firm; Tecnicas Reunidas, a leading Spain-based engineering and construction firm; and IDOM, a Spain-based international engineering, architectural and consulting firm. Dar al Handasah and Asie Etudes Engineering Consultants, both of which have offices in the Sultanate, are in the reckoning as well.

The selected preliminary design consultant shall be responsible for the provisional design of the complete infrastructure and systems covering all segments of the 1,061km railway project, thereby securing the basis of a completed, fully functional, operating railway and inter-operable with the Gulf Cooperation Council (GCC) network. Also as part of its brief, the consultant will undertake the preliminary design of, among other things: the alignment, track works and infrastructure; civil works, tunnels and structures; systems, and; functional design/ specifications of rolling stock.

The consultant will develop the tender documents for the design and build phase of the project. Also slated to be kicked off before the year-end is the prequalification process for the design and build phase, with the first segment likely to be awarded before the end of 2014.

NYC's Seven Line Extension awarded project of the year

USA The Metropolitan Transportation Authority (MTA) has announced that the USD 1.1bn Running Tunnels and Underground Structures contract, the first portion of the USD 2.1bn Seven Line Extension Project will be awarded the 2013 construction project of the year by the New York State Society of Professional Engineers. It was completed five months ahead of schedule and under budget, MTA stated.

The Seven Subway Line Extension will provide transit access to the West Side of Manhattan, including the Jacob Javits Convention Center, by extending the line westward from its current terminus at Times Square to a new station being constructed at 34th Street and Eleventh Avenue. It will help to stimulate economic growth and continuing development of the area, MTA said. The Hudson Yards Development Corporation is overseeing the programme.

The Seven Line Project is to receive this award for outstanding professional engineering efforts in developing creative solutions and innovative technologies in construction of an infrastructure project. The project used the first double-shielded TBMs tunnel under New York City while placing precast concrete segments to line the tunnel.

For the first time in the city, a ground freezing method was used to harden soil to act as rock which allowed the TBMs to maintain proper course while boring and placing the tunnel liners.

Design contract awarded for Norwegian road tunnel

Norway Sweco has been selected by Statens vegvesen to design one of Norway's longest tunnels, located in the Telemark region, it was announced earlier this month. The value of the contract is nearly SEK 40M (USD 6M). Planning and design work will begin immediately and the finished road is expected to open for traffic in 2018.

Sweco's assignment includes planning of a 9km long tunnel on Road E134. The company will contribute specialists such as geotechnical engineers, geologists, environmental experts and design engineers. As a result of the road project, the current hilly stretch of 23km will be reduced to a straight and even distance of 12km.

"This is an important road project in the heart of Telemark. We look forward to developing a solution that increases traffic safety, shortens travel time and reduces environmental impact," said Tron Kjølhamar, president of Sweco Norway.

Britain's HS2 rethink involves tunnel extension

Great Britain The Government has revised its High Speed Two (HS2) rail line route and developed an option involving extending a proposed tunnel under the East Midlands Airport. Britain's HS2 network could be extended to enable plans for a major development next to the airport to progress, transport secretary, Patrick McLoughlin, announced.

During discussions with MPs and local authorities on the proposed route for phase two of HS2 from Birmingham to Leeds, concerns were raised by Leicestershire County Council, and MP for North West Leicestershire, Andrew Bridgen, in conjunction with Roxhill Developments Limited, that the proposed line could affect plans for a strategic rail freight interchange depot (SRFI) next to the airport.

The initial preferred route would have seen the new rail line cross the site of the proposed SRFI, which has the potential to create 7,000 jobs in the region, and threaten the feasibility of the proposed development.

After listening to these concerns, the Government has now developed a revised option involving extending the proposed tunnel under the East Midlands Airport, avoiding the majority of the proposed SRFI site. The Department for Transport will consult on the route later in the year as part of its public consultation on phase two, and after that consultation, a decision will be made. In the meantime, the developer will progress its plans for the proposed depot, the Government announced.

Patrick McLoughlin, transport secretary, said: "These changes have the potential to deliver huge economic benefits for the East Midlands on top of the already considerable opportunities HS2 will bring the region.

"They also show that we are both maximising the economic impact of HS2 as well as listening to concerns of those affected by it.

"We will continue to work with stakeholders, to identify critical issues such as Roxhill and propose revisions to the scheme where possible."

Kate Bedson, Senior Development Director at Roxhill added: Our proposals for a new SRFI with 6Msq. ft (0.56Msq.m) of associated warehousing have the potential to create 7,000 jobs, providing a boost to the economy in the region.

"Since the announcement, through our MP and local authority, we have enjoyed an early and positive dialogue with DfT and HS2 and are very pleased with the decision to amend the proposed route. This now allows us to consult with the public and other bodies on our plans before submitting our application at the end of the year."

The East Midlands region is already set to benefit from HS2 with an integrated high speed and classic rail station at Toton, creating a brand new, easily accessed hub station, the Government said. This will see journeys to London take 51 minutes, while the stations in Leeds, Sheffield, East Midlands and Birmingham will each be separated by a journey of less than 20 minutes.

CHINA INTEREST IN KARNAPHULI

Bangladesh China has demonstrated interest in extending investment for the construction of Bangladesh's first ever river tunnel under the Karnaphuli river in Chittagong.

China Communication Construction Company (CCCC) has put forward a proposal to the Bangladesh Bridge Authority (BBA), according to local officials.

CCCC conducted a feasibility study jointly with Ove Arup on the proposed tunnel. "On receipt of the proposal from the Chinese company, we requested the Chinese government fund the project and got positive feedback," said a BBA official.

Investment in the project is conditional on China being allowed to invest in an economic development zone alongside the tunnelling project.

The CCCC study found construction of the 3.4km tunnel across the Karnaphuli River feasible.

Communications Minister Obaidul Quader said the government wanted to construct the tunnel and the funding was under consideration.

"We want to construct the tunnel either with the government's own fund or foreign fund as its impact on the economy is significant," the minister told journalists after a presentation on the study in Chittagong.

Quader, however, said efforts were made to arrange foreign funds and a government-to-government arrangement with China was also under consideration.

The CCCC has proposed a 3.4km multi-lane tunnel with a 4.9km approach road on the eastern side and a 0.74km approach road on the western side.

The twin bore tunnel is estimated to cost USD 692M.

Jakarta Metro contracts awarded

Indonesia Three of five tunnelling contracts for the 9.2km underground section of Jakarta's 15.2km first phase of the North-South metro line have been awarded. A JV of Shimizu, Obayashi, Wijaya Karya and Jaya Construction has won two of the contracts and the third contract goes to Sumitomo-Mitsui Construction JV.

The announcement was made at a groundbreaking ceremony in downtown Jakarta. Dono Boestami, managing director of MRT Jakarta, also confirmed that preferred bidders will soon be announced for the two remaining underground construction packages, together with the three contracts for the elevated section of the line.

Jakarta's governor, Joko Widodo, said he hopes the entire first line of the metro will be complete by 2017. The line will have six underground and seven elevated stations.

ALASKAN WAY LAUNCH PIT COMPLETES

USA Crews have finished building the 80ft deep (24m) launch pit for the world's largest tunnelling machine, Washington State Department of Transportation (WSDOT) announced. It has taken nearly a year to build its underground walls, remove soil and build the infrastructure needed to support the nearly 7,000t machine.

WSDOT stated that its completion clears the way for tunnelling to start this summer, once Bertha's 41 pieces have been reassembled and tested at the bottom of the pit.

Launch-pit construction started last summer in the work zone west of Seattle's stadiums. Before excavation began, crews drilled more than 200 piles as many as 100ft (30m) into the ground to form the pit's walls. The perimeter of the pit is 80ft (24m) wide and 400ft (122m) long.

Assembly of the machine started at the south end of the pit shortly after it arrived last month from Osaka, Japan. Now that the front end of the pit is complete, crews have started building the body of the machine near the spot where it will first push into Seattle's soil.

Crews are also preparing the surrounding area for tunnelling, including strengthening the soil and building protected work areas along the initial section of the tunnel route so they can perform scheduled inspections of the machine before it begins digging beneath downtown. Meanwhile, work continues near the north end of the Battery Street Tunnel to prepare the area where Bertha will emerge at the end of tunnelling.

Station design contract awarded on Gurgaon Metro Phase II project

India Mott MacDonald is to provide the design for six new metro stations on Phase II of the rapid metro rail network in Gurgaon, India. The metro is being developed by Rapid Metro Rail Gurgaon to help meet the growing transportation requirements between Gurgaon and Delhi.

The INR 1500M (USD 27M) second phase of the project will see a 6.5km rail line extend the network southwards and includes six elevated metro stations - DLF Phase 1, Sushant Lok, Sec. 42 Crossing, Sector 54-53, AIT Chowk and Sector 55-56. The stations will be situated above existing carriageways and will include residential and commercial spaces. Phase II is expected to be completed by late 2016. Mott MacDonald will provide architectural, structural and building services design for the six stations.

The project will seek to achieve LEED sustainability certification through the use of renewable energy sources such as solar power, energy efficient design and rain water harvesting. Somnath Nandan, Mott MacDonald's project director, said: "Mott MacDonald has been involved with Delhi Metro for over a decade and we are delighted to offer our multidisciplinary consultancy services on the Gurgaon rapid metro development. Located 30km south of New Delhi, Gurgaon is the financial and industrial hub of the Haryana state. This project is an important step in providing a sustainable solution to the city's traffic congestion by reducing dependency on cars, inefficient urban sprawl and increasing the use of public transport."

Construction of Phase 1, which comprises a 5.1km rail loop connecting Cyber City, NH-8 and Sikanderpur station on Delhi Metro Line Two, began in 2008.

Billy Bishop Airport drift tunnels completed

USA Technicore Underground has completed the seven drift tunnels that will form the crown of the pedestrian tunnel to Billy Bishop Toronto City Airport, the Toronto Port Authority (TPA) announced last month. "The completion of the seven drift tunnels is a major project milestone," said Geoffrey Wilson, TPA president and CEO. "It marks the end of an important phase of construction that takes us one step closer to providing passengers with fast and efficient access to the Billy Bishop Toronto City Airport."

The seven interlocking drift tunnels, three of which will house City of Toronto water and sanitary mains, will form a crown that will prevent water ingress. The drifts were completed using two TBMs dubbed "Chip" and "Dale". The machines will now move onto the project's next phase, which facilitates the excavation of the main pedestrian tunnel. Forum Infrastructure Partners is responsible for the design, construction, financing and maintenance of the tunnel and will be responsible for operating the project for a period of 20 years.

The consortium is led by Forum Equity Partners and construction responsibilities are contracted to PCL Constructors, with Technicore Underground as the tunnelling subcontractor. Project design is led by Arup, with ZAS Architects and Exp geotechnical engineers. Facility management responsibilities are contracted with Johnson Controls. The tunnel project will be privately financed at a cost of CAD 82.5M (USD 82.9M). Construction began on the pedestrian tunnel in March 2012. The tunnel will link Billy Bishop Toronto City Airport to the mainland and provide enhanced service and convenient access for the airport's users. Project completion is expected in mid-2014.

KFC only a tunnel away

Gaza A delivery company is offering Gaza residents a chance to indulge in KFC. The underground tunnels that connect Egypt and Gaza are now being used to smuggle food from the fast food chain.

Customers of Al-Yamama, a delivery company in the Gaza City, will have to wait three hours and pay three times as much for the goods to be smuggled underground from al-Arish in Egypt, some 35 miles (56km) away.

The company posted a picture for the fast food on its website, and soon received more orders from the people in Gaza. Al-Yamama has made four deliveries of KFC food to Palestinians in Gaza over the last month.

Work starts on Thua Thien-Hue tunnels

Vietnam Vietnamese Deputy Prime Minister Nguyen Xuan Phuc issued an order on in late May to begin construction of two tunnels in Phu Loc district, central Thua Thien-Hue province.

The Phuoc Tuong and Phu Gia tunnels on National Highway 1A will be built with a total cost of over VND 1.7tn (USD 83M) under the build-operate-transfer (BOT) model. The 345m Phuoc Tuong and 497m Phu Gia tunnels are both 11.5m wide and include two lanes for road vehicles.

Both of the projects are expected to be completed within 18 months.

Letters

News briefs

AUSTRALIA
The Legacy Way project's eastern worksite was preparing for the breakthrough of TBM Annabell as *Tunnels* went to press.

ITALY
A 5.78m Seli-Kawasaki TBM was tested last month before heading to the Copenhagen metro project.

Cat that got creamed

It is with great sadness that I read of the closure of Caterpillar Tunnelling in *Tunnels* June 2013 (p.5). This company - founded by Richard Lovat, has been producing robust and practical, principally soft ground TBMs, for at least 40 years under the Lovat name.

It was with some apprehension that I noted their takeover by Caterpillar in 2008, doubtless for well founded financial reasons.

However I feel that it is disgraceful that after a paltry five years of ownership that Caterpillar is calling it a day because the company 'no longer represents a strategic growth opportunity'.

This in my opinion is a betrayal of a once proud and family run manufacturer of well-performing TBMs.

Not only will there be 330 experienced and skilled employees out of work, but one of Canada's iconic engineering companies will have ceased to exist because the accountants in the USA feel that it is not profitable enough.

What a grievous loss to the world tunnelling community and an enhanced opportunity for China, Japan and others to benefit from this disaster.

Let's hope that some sensible body or group of entrepreneurs will come riding to the rescue and enable the company to continue operating.

Neville Harrison FICE
BTS member

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

editor@tunnelsonline.info

Fighting the price war

A quick note from Down Under. The editorial from March ('A cost of price', p.5) was a cracker – if it was not the fact that what you described is having a significant effect on the construction industry in Australia it would make a good humorous piece.

We design, fabricate and operate a fleet of microtunnelling machines. The number of projects has been low in the last few years and what you described is a reality here in Sydney.

The market has seen auger boring companies embellish their capabilities and cause considerable havoc around the place due to their failure to deliver – as you said, the cost of price. We have three recent jobs where auger boring has failed badly and we have had to complete the works. Failure is a costly reality for the contractor who engages the drilling company. I am submitting an article to the magazine of the Australian Society for Trenchless Technology providing a case study along the lines of your article. It is not a good environment when work is short and people get desperate.

Jim Shooter
Pezzimenti Tunnelbore

DEBATING NATM

The May 2013 Tunnels and Tunneling issue included a spirited editorial letter from our founder, and former President and CEO, Dr. Gary S. Brierley regarding a February 2013 article about 'NATM', the New Austrian Tunneling Method (aka the Sequential Excavation Method, or 'SEM'). Also included was a response from the article's primary author. Gary's thoughts and opinions were credited to Brierley Associates, despite the fact that Gary formally retired from our ranks at the end of 2012, and we simply wish to clarify that these comments were not issued by our firm. Rather, this submittal was made by Gary in his new position as sole proprietor of the consultancy, Dr. Mole.

Brierley Associates agrees with many of Gary's thoughts and opinions on the state of the tunneling industry in general, including regarding some of the confusion about differences (or lack thereof) between SEM and 'Conventional Tunneling' as practiced in the United States. In particular, we agree that, in some cases, onerously restrictive 'NATM Engineer' qualifications requirements are being written by some owner's SEM designers into project specifications. These requirements to have 10 or 15 (or more) years of experience 'on similar projects, with similar [NATM] designs, of a similar size and shape, in similar ground' serve to protect and do service to a small subset of tunneling professionals practicing in the United States, while keeping well-qualified tunnel engineers and engineering geologists with excellent ground behaviour observation skills and experience from bringing those skills to the table to the benefit of both the owners and the contractors involved in the work. We agree this has gone a bit too far to the detriment of the concept of free trade and the inclusion of well-qualified tunnelling professionals with the tools to successfully implement SEM tunnelling in this country.

However, we also strongly believe in the exchange of ideas and experience across borders and cultures, and welcome working with our Austrian tunneling brethren here in our homeland. Someday, we may even wish to offer our services and experiences abroad, perhaps even in Austria, where we hear both the skiing and beer are excellent! If we do, we hope to be welcomed there as we think many Austrians have been here. We believe that Austrians have made significant "contributions to ground excavation, face support or [and] final linings". Since Rabcewicz, they have helped promote the well-understood concept of arching and using the ground to help support itself with lighter temporary support instead of fighting heavy ground with heavy support installed too late. We believe the industry will be better served by utilizing our collective experience and understanding, from work experience elsewhere, to local geologic knowledge, to an understanding of bidding tunnel work in the American low-bid environment using local labor. We look forward to our future collaborations with our Austrian friends, such as the recent one between Brierley Associates and Gall Zeidler on the highly successful Caldecott Fourth Bore Tunnel in California. And perhaps, also to laughing about what all the fuss was about over a glass or two of Vienna's finest.

Alan L. Howard, PG, CEG
Principal, Tunnel Practice Group, Brierley Associates

Central bank rates

	Rate (%)
AUD	2.75
BRL	8.00
CAD	1.00
CHF	0.25
CNY	6.00
EUR	0.50
GBP	0.50
INR	7.25
JPY	0.10
NZD	2.50
USD	0.25

Rates are taken on the 12th of each month.

Share tracker

Company	April	May	Change (%)
Aecom (NYSE: ACM)	30.69	30.46	▼ 0.23 (0.74)
Atkins (LSE: ATK)	912.5	882	▼ 30.5 (3.34)
Balfour Beatty (LSE: BBY)	250.2	214.4	▼ 35.8 (14.3)
BASF Global (XETRA: BAS)	68.4	73.55	▲ 5.15 (7.53)
Bekaert (BSE: BEKB)	22.5	21.5	▼ 1.00 (4.44)
Bilfinger Berger (DUS: GBF)	79.64	76.22	▼ 3.42 (4.29)
Caterpillar (NYSE: CAT)	85.05	88.19	▲ 3.14 (3.69)
Costain Group (LSE: COST)	291.75	276.25	▼ 15.5 (5.31)
Ferrovial (MCE: FER)	12.78	13.15	▲ 0.37 (2.89)
Hindustan Construction Company (BOM: HCC)	14.15	14.15	▶ 0.00 (0.00)
Hochtief (XETRA: HOT)	50.71	57.5	▲ 6.79 (13.4)
Morgan Sindall (LSE: MGNS)	552	545	▼ 7.00 (1.27)
Sandvik (STO: SAND)	97.75	94.05	▼ 3.70 (3.79)
Shanghai Tunnel Engineering (SHA: 600820)	9.06	8.92	▼ 0.14 (1.55)
Strabag (LSE: STR)	16.73	17.96	▲ 1.23 (7.35)
URS Corporation (NYSE: URS)	46.32	45.67	▼ 0.65 (1.40)
Vinci (EPA: DG)	35.86	37.64	▲ 1.78 (4.96)

Prices are taken on the 12th of each month. NYSE is in USD. LSE is in GBP. STO is in SEK. BSE, EPA, MCE, STR and XETRA are in EUR. BOM is in INR. SHA is in CNY.

New vice president for Atlas Copco USA

USA Dave Pietrzykowski has been appointed to the position of vice president of parts and service for Atlas Copco CMT USA.

Pietrzykowski comes from a recent position as vice president for store operations within Atlas Copco, which he achieved from a background in the company's used equipment ad then rock drilling tools divisions. He was also previously worldwide marketing manager and president of sales and marketing.

Torbjorn Redaelli, Atlas Copco CMT USA president and general manager said: "Dave holds an excellent track record of team building, developing store operations and he has produced resourceful solutions in challenging environments. His skills and experience will continue to deliver exceptional results."

Doig to be presented IOM3 award

Great Britain Pat Doig, a principal project manager for Hatch Mott MacDonald based in Sacramento, California, has been awarded the prestigious International Medal by the Institute of Materials, Minerals and Mining (IOM3) it was announced last month.

Pat's paper "Shaft Construction for Civil Engineering Projects" was chosen as the best paper of the year published by an IOM3 member living outside the UK. Pat will receive his award at a dinner in London in July.

Pat has worked for HMM since 1997, mostly on tunnel projects in northern California, except for a hiatus of almost four years to work on the world's largest tunnelled sewer system in Abu Dhabi.

"Shaft Construction for Civil Engineering Projects" was Pat's 19th published paper. In April 2012, he presented it in London at the third International Conference on Shaft Design and Construction.

"Pat was chosen as keynote speaker for the event, and shared the podium at the opening session with The Rt. Hon. Nick Raynsford MP, Chairman of the All Party Parliamentary Group for Underground Space. Pat encourages young professionals to publish papers in their field, and offers to advise them or review their work.

Rosa Castro-Krawiec promoted to senior associate in Boston

USA Rosa Castro-Krawiec joined the Jacobs Associates' Boston office as a senior associate the company announced in last month. Castro-Krawiec was appointed of the back of some 29 years of experience as a structural engineer. She notably contributed to the Port of Miami Tunnel.

A Jacobs Associates spokesman said, "Her work has encompassed the design and construction of above and underground structures for transportation, environmental, civil, industrial, institutional, and high technology facilities."

Oil price

100.6
April 2013

102.2
May 2013

Values are taken on 12th of each month.

POWER MACHINE RELOCATES

The 9km Eade Road to St. John's Wood London Power Tunnels (LPT) drive was completed on 1 May. The 4.7m Herrenknecht EPBM emerged into the St. John's Wood shaft before a complex operation was due to see it manoeuvered to its next LPT bore on the project in Haringey. The multiple-trip operation was ongoing as *Tunnels* went to press, and due to complete on 11 June.

Roger Gibbs, general manager (commercial and projects) for specialist logistics solution provider Abnormal Load Services (ALS), part of Wallenius Wilhelmsen Logistics, said: "It is an incredibly challenging procedure to move the [up to 110t] TBM components. The weight and size of the load to be moved along roads that just weren't designed for the job makes things difficult. As a major city, London presents several obstacles to overcome. The north in particular is what I consider a 'cat's cradle' of railway lines.

"The ALS team will face bridge weight restrictions from Tube and suburban rail lines hidden beneath the road, height restrictions from overhead bridges and street furniture - including traffic lights, bollards, and even curbs - that will need to be removed. An enormous effort is put into route planning and liaising with the various statutory bodies.

Gibbs added, "The Edmonton to Haringey route has several pinch points of road junctions and overhead bridges, and we will probably need to go through part of the Tottenham one-way system in a reverse (anti-clockwise) direction"

Nicole Robinson
Managing editor of *Tunnels North America*
Nicole is based in Minneapolis, Minnesota

GO WEST

The market for megaprojects moves to the West Coast as tunnelling wraps up on most New York Subway drives, **Nicole Robinson** reports

LIKE A home-owner with a well worn to-do list, MTA Capital Construction, the agency charged with building New York's transportation infrastructure, should be crossing off a major item come June 2014 with a solid sense of satisfaction. As one of three tunnel mega-projects currently underway in New York, the USD 2.4bn Seven Line extension is on schedule to open that month for revenue service.

Tunnelling, among other underground construction, is still ongoing on the East Side Access (ESA) project, and the Second Avenue Subway (SAS) is making progress on its stations. The ESA is scheduled to complete in 2019, delayed from original plans. And the Second Avenue project comprises only phase one of four, with no funding in place for the final three legs.

With these subway projects wrapping up, while transit and water projects in California are popping up, the industry is seeing a shift of work from east to west.

In his speech at the TAC conference in Montreal last October, Jeff Petersen of Kiewit, mentions this in his remarks about the US market for tunnelling. "I'm sure those that have been around for a while are no stranger to this cycle.

"Granted, there are significant tunnel programs and projects on both coasts and in the middle of the US."

Petersen questions if a shift in the volume of work to the west really exists, or if it is just a perception. What is clear is that funding is available in the west to support new projects.

Both Seattle and Los Angeles voters passed measures in 2008 to finance public transit development.

NEW YORK

A report released in March by New York's comptroller Thomas DiNapoli highlights delays and cost overruns on the ESA project. The MTA's initial estimate of USD 4.3bn has grown to USD 8.25bn, with completion pushed back 10 years, from 2009 to 2019. "The MTA's official cost estimate, however, excludes the full cost of passenger railcars associated with the project, which raises the cost of the project to USD 8.76bn," DiNapoli points out in the report.

In response to a draft copy of the state comptroller's report, the MTA explains that its initial 1999 estimate was based on conceptual plans and that there was virtually no engineering behind the estimate. According to the MTA, it was not until 2006 that the design of the project was sufficiently advanced so that reasonable budgets and schedules could be developed.

The MTA also says the increased costs and delays since its 2006 estimate could be explained by a number of factors, including overly aggressive schedules; the number of large infrastructure projects in New York City and elsewhere, which reduced competitiveness; a contractor that performed poor quality work and subsequently defaulted; unforeseen construction challenges; cost escalation from increased project duration; and an Amtrak rehabilitation project of the East River tunnels.

Construction for the SAS, which will connect 125th Street to the Financial District along Second Avenue, is planned in four phases. Phase One has seen dual tunnels excavated between 92nd and 63rd Streets, and three new underground stations. TBM mining completed in September 2011 for a total of 7,789ft (2.37km) of tunnels by S3, a joint venture of Skanska, Schiavone and Shea.

As of this spring, mining crews at the 86th Street Station have broken through south to north in the upper section of the station cavern excavation, creating a continuous open underground space from 83rd Street to 86th Street. A contractor joint venture of Skanska/Traylor secured the USD 322M contract for the station in August 2011, and is forecasted to complete the work in September 2014.

Drill and blast activity continues through the spring to excavate parts of both the northern and southern caverns.

On 21 March, MTA announced that all blasting for the 72nd Street station structures was completed. The contractor, SSK Constructors (a joint venture of Schiavone, Shea and Kiewit) will continue to waterproof and install the steel reinforced concrete lining of the underground station cavern and tunnels. SKK started drill and blast work in January 2011 and excavated and removed a total of 183,000cu.yd (140,000cu.m) of rock.

The follow-on finishes contract, which will complete the mezzanine and platforms, station entrances, ancillary buildings and the mechanical, electrical and plumbing systems for the station was awarded to Judlau Contracting on 14 February.

While the project makes good progress on Phase One, there is no word on how or when future phases could be funded.

MTA's next capital program, which is schedule to start in 2015 through 2019, is not yet announced.

In October 2012, the state comptroller also released estimates that the MTA could require at least USD 20bn over five years to fund its core capital program, which provides for "a state of good repair, normal replacement and system improvements". Additional resources would be needed to begin the next phase of the Second Avenue Subway and other expansion projects.

THE BOTTOM LINE

Looking beyond Manhattan and its neighbouring boroughs, further a field in the state of New York is the Delaware Aqueduct bypass tunnel project, estimated to cost USD 1.2bn. Heading south, the nation's capital is starting work on a major tunnel project, the first of four for its Clean Water program, which carries a USD 2.6bn price tag.

Hartford, Connecticut, and the Narragansett Bay Commission in Rhode Island, are two of many cities and municipalities working to eliminate CSOs. These programs often include underground construction for shafts, microtunnelling for smaller diameter sewers and often large diameter tunnels. The Metropolitan District in Hartford will spend an estimated USD 1.6bn on its CSO program, which includes the South Storage Tunnel some 28ft (8.5m) in diameter, three-miles (4.8km) long with construction possibly starting in 2014.

Meanwhile, planned transit lines for Boston and Baltimore that would likely require tunnel construction are stalled, as are a several of highway tunnel projects on the east coast. With funding secured, all of this is easily worth tens of billions in contracts for the industry.

On the west coast there are billions of dollars being spent on tunnels in Seattle for the Alaskan Way Viaduct replacement and light rail extension projects, several of which have yet to bid their construction contracts. San Francisco has projects in various stages of construction—the Central Subway, the Bay Tunnel and the New Irvington Tunnel among others.

Those three projects account for more than USD 2bn.

What's waiting in the pipeline boasts the biggest price tags. The Transbay Transit Center/Caltrain Downtown Extension (TTC/DTX), in downtown San Francisco will include underground construction and has a budget estimated at USD 4.1bn.

Though currently funding is lacking for the USD 2.5bn Phase Two.

In Los Angeles, there are tunnels forthcoming for the region's metro line with funding lined up through increased taxes. The West Side Subway Extension of the Purple Line will be delivered in three phases, with the first estimated to start construction next year. The total project is forecasted to cost USD 6.3bn. About three-fourths of those funds are generated locally from Measure R, a half-cent sales tax approved by Los Angeles County voters in 2008. Los Angeles County Metropolitan Transportation Authority (Metro) will be seeking the remainder in federal matching funds through the New Starts Program. It is also said to be pursuing alternate funding scenarios that could accelerate subway construction possibly allowing the entire 9-mile (14.5km) project to be built in one phase at a reduced cost and opened as early as 2023.

The Metro Crenshaw/LAZ Transit Corridor Project is an 8.5-mile (13.7km) grade separated expansion with at least six stations, and possibly two more. Portions of the alignment will be mined by TBM. The project budget is approximately USD 1.7bn with the majority of funding coming again from Measure R. The ever-likely possibility of high-speed rail being built in the state adds more opportunities as well.

Then there is California's proposed Bay Delta Conservation Plan (BDCP), which calls for some 35 miles (56km) of twin tunnels for water conveyance. Governor Brown has proposed 40ft (12.1m) inside diameter tunnels built more than 150ft (45.7m) underground, estimated to coast USD 14bn.

A Draft Environmental Impact Statement/Environmental Impact Report will be released later this year for the entire project.

56
Kilometres of twin tunnels are proposed in California

4.1
Billion is the estimate in dollars for the total TTC/DTX project in San Francisco

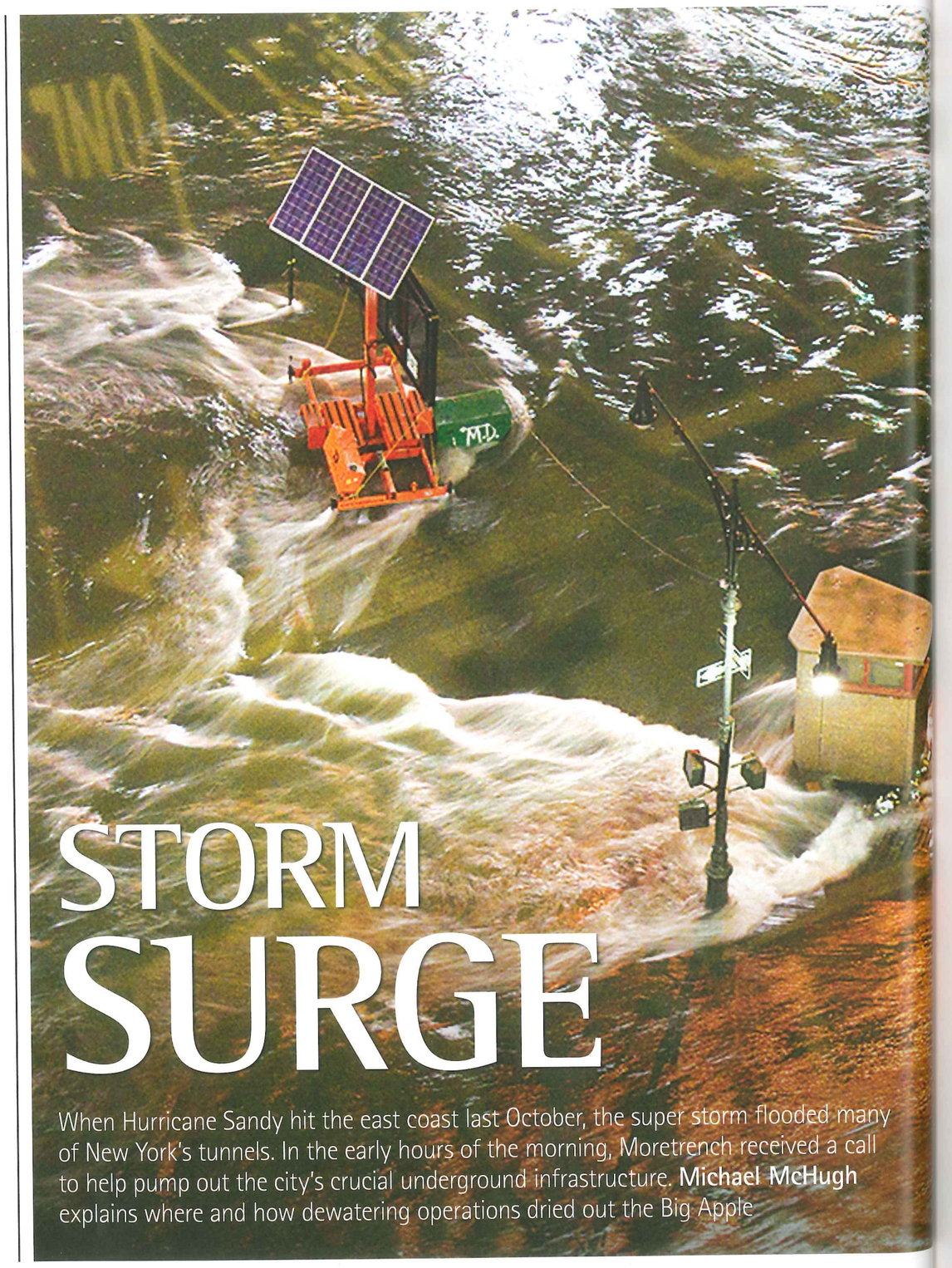
Left: Excavation work on the 86th Street station cavern. METROPOLITAN TRANSPORTATION AUTHORITY / PATRICK CASHIN

SANDY

New York did see an influx of cash last year, though that is under grim circumstances. In the wake of Hurricane Sandy FEMA issued some USD 2.7M of expedited funds to the MTA for work on two flooded road tunnels.

The Hugh L. Carey (formerly Brooklyn-Battery) and Queens Midtown tunnels were collectively flooded with approximately 72M gallons (272M litres) of brackish, oily water when Sandy struck October 29, 2012. The dewatering operations started as soon as possible.

"These tunnels were devastated from floor to ceiling, and it is no small feat to try and make these complex and time-consuming repairs while continuing to move an average 119,000 vehicles through them each day," said Tom Prendergast, president of MTA New York City Transit and also Interim MTA executive director



STORM SURGE

When Hurricane Sandy hit the east coast last October, the super storm flooded many of New York's tunnels. In the early hours of the morning, Moretrench received a call to help pump out the city's crucial underground infrastructure. **Michael McHugh** explains where and how dewatering operations dried out the Big Apple

WHEN IT made landfall just north of Atlantic City, New Jersey, on Monday, October 29, 2012, Hurricane Sandy extended 450 miles (750km) out from the centre. The ensuing storm surge impacted hundreds of miles of densely populated coastline. While hurricanes are categorised by peak wind speed, storm surge potential is correlated to a storm's integrated kinetic energy (IKE) rating, a measure of the wind speed across the ocean area over which the winds blow. Sandy's IKE rating was the second highest in modern history, only surpassed by Hurricane Isabel in 2003.

For New York City's subway system, this was the most devastating storm in its 108-year history. When water from the 13ft (4m) storm surge flooded into Lower Manhattan, eight of the 11 tunnels under the East River, plus a ninth subway tunnel under Newtown Creek, were inundated, crippling the city's transportation network. The New York City Metropolitan Transit Authority (NYCMTA) operates some 300 pump rooms, running on electricity, to deal with the 13-15 million gallons (49-58 million litres) of water infiltration expected throughout the subway system and vehicular tunnels on a daily basis. However, the entire subway electrical system had been shut down ahead of Sandy as a safety measure. The MTA's three diesel-driven pumping trains were brought into service, but additional private sector dewatering crews, together with the Fire Department of New York (FDNY) and the military, were critical to speeding up the drying out and repair processes.

RAPID RESPONSE

Geotechnical contractor and dewatering expert Moretrench received the first calls around 4am on Tuesday, October 30 from MTA Bridges and Tunnels and the NYC Department of Environmental Protection. Shortly thereafter, calls began to come in from a number of private clients. While Moretrench has considerable in-house resources at its Rockaway, New Jersey, headquarters, more pumps were needed to respond to all the requests for immediate assistance. Twenty 15hp submersible contractor pumps, which can tolerate some fines and can provide over 100ft (30m) of lift, were immediately ordered from a Connecticut supplier and delivered overnight to the company's Yonkers, New York premises, enabling Moretrench to mobilise to multiple locations simultaneously.

Moretrench is no stranger to emergency pumping in New York City, having been heavily involved in the pumping and dewatering effort in the immediate aftermath of the 2001 attack on the World Trade Center. As was the case then, time now was of the essence. Within hours of the first phone call, crews had mobilised and a substantial pumping effort was underway at several wastewater treatment plants and pump stations for the NYCDEP. The greatest challenge, however, was to pump out two major transportation links, the Brooklyn Battery Tunnel and the Port Authority Trans-Hudson (PATH) tube at Exchange Place in Jersey City, New Jersey.

BROOKLYN BATTERY TUNNEL

The Brooklyn Battery Tunnel, officially renamed the Hugh L. Carey Tunnel (HLCT) in 2012, runs under the East River connecting the southern tip of Manhattan with the Brooklyn-Queens (Gowanus) Expressway (I-278) in Brooklyn. At its midpoint, the HLCT brushes the north east side of Governors Island, which sits in the Upper New York Bay at the mouth of the East River. At 1.7 miles (2.8km) in length, it is the nation's longest continuous underwater vehicular tunnel and comes under the direct auspices of the MTA Bridges and Tunnels, a division of the MTA.

Since the tunnel was constructed in 1950, the water levels in the bay have risen 9in (230mm), putting the already low-lying tunnel portals below sea level. The storm surge, driven by Hurricane Sandy, a nor'easter, and a full moon coinciding with high tide at New York Harbour, had a height cresting at 13.88ft (4.23m) in Battery Park in Lower Manhattan. This storm surge was unprecedented and was more than 3ft (0.9m) above the previous record set in 1960. It exceeded FEMA's rating for a 500-year storm surge and completely overwhelmed the tunnel drainage system, resulting in an estimated 60 million gallons (227 million litres) of flood water pouring into each of the 31ft (9.45m) diameter twin tubes, completely filling the central two-thirds.

Moretrench met with MTA commercial contractor Restani on October 30 to determine the course of action, and by the following day had mobilised to the Brooklyn portal. Some 1,700ft (520m) of 6in (150mm) diameter hose and piping was laid from the tunnel entrances to reach the floodwater, and the first of five 40hp turbine submersible pumps, each capable of handling 1,000 gallons per minute (3,785 litres per minute) at peak performance, together with a generator and fuel tank, were loaded onto a flatbed trailer and backed in. Four more 40hp pumps and a second generator were similarly set up and operational by Thursday, November 1. Water removed from the tubes was pumped into a sump located at the Brooklyn portal permanent pumping room, which was running on emergency power and operated by MTA Bridges and Tunnels, and from there discharged into the sewer system. With a Moretrench technician maintained on site, Local 15 Operating Engineers then took over responsibility for keeping the pumps going 24 hours a day. A major pumping effort was concurrently underway via the large tunnel vent shaft building situated on the tip of Governors Island. At approximately 150ft (45m) below the surface, the tunnels here are at their lowest point. On Friday, November 2, six 40hp turbine submersible pumps, three 15hp pumps, two generators and associated piping were loaded onto a barge and shipped to Governors Island. Moretrench set up four of the 40hp pumps in the East Tube and two in the West Tube. To accomplish this,

13
The height in feet of the storm surge that flooded the New York area

8
Tunnels flooded during the storm out of 11 under the East River

60
Million gallons of floodwater are estimated to have entered the Brooklyn Battery Tunnel

Left: Floodwaters surged into the Manhattan entrance to the Hugh L. Carey Tunnel. Photo courtesy of Jay Fine and the MTA.

Michael M. McHugh
Michael is a vice president and New York metro area manager for specialty dewatering and geotechnical contractor Moretrench, headquartered in Rockaway, New Jersey

the crew worked within the access ports of the vent shaft airways, cutting through the steel plate damper doors and connecting the 10ft (3m) sections of piping necessitated by the restricted space. As the water level in the tunnel dropped, one of the 15hp pumps was set up in the ejector pit under the pump room between the two tunnels, which was designed to cater to rain events. Two 15hp pumps were left for sumping operations during tunnel clean up and repair after Moretrench demobilised on December 8.

EXCHANGE PLACE

The PATH tube at Exchange Place in Jersey City, New Jersey, provides direct access to Lower Manhattan, with connections to the New York City subway system and the World Trade Center. During the flooding, more than 12ft (3.7m) of water filled the underground station, with tens of millions of gallons flowing into the century-old, cast-iron tubes that run under the Hudson River.

On Saturday, November 3, Moretrench met with the Port Authority of New York and New Jersey and Ferreira Construction, which was directing operations for the Port Authority. Moretrench provided and set up lighting in both tubes, together with large ventilating fans to dissipate exhaust fumes, then mechanically pushed in two 30hp submersible turbine pumps, hosing, and generators all loaded on to a utility cart, and began dewatering the north tunnel. Meanwhile, the FDNY were setting up a train-mounted, 6in (150mm) hydraulic pump to dewater the south tunnel. Pumped water from both tunnels was piped to a sump set up in a utility room in the main station area where the US Army Corps of Engineers operated a 12in (300mm) diameter pump to discharge the water back into the East River. When the Corps obtained an additional large pump and was then better equipped to take over the north tunnel dewatering, Moretrench shut off the two 30hp pumps and focused on maintaining lighting and ventilation. The site was demobilised on November 11.

WORLD TRADE CENTER

Following the attack on the World Trade Center, Moretrench has worked extensively on the rebuilding effort, completing more than 25 contracts between 2001 and 2012, including dewatering for foundation installation for Towers Two, Three and Four, The Freedom Tower and the Memorial site.

At 6am on Wednesday, October 31, Moretrench met with Bovis Lend Lease, construction manager for the World Trade Center Memorial and Museum, and by 5am on November 1 had mobilised to the memorial site and begun setting up a 75hp submersible pump in an elevator shaft. A second 75hp pump was up and running in the museum building by Friday, November 2 and two 15hp pumps were operating at the bottom of a stairwell. By Monday, November 5, the site had been largely pumped out except for localised areas. The large pumps were shut off and three additional 15hp contractor pumps were added, along with four, 2in (50mm) pumps, to handle the remaining water. Pumping continued until the maintenance pumps came back into service on November 28. Moretrench also supplied six pumps to Tishman Construction to handle flood water at Towers Three and Four.

All in all, Moretrench personnel pumped at 20 separate sites, moving in excess of 250 million gallons (946 million litres) of water. Including equipment supplied for additional sites and operated by others, the company mobilised more than 50 pumps in various sizes, thousands of feet of hose and piping, and 12 generators in just three days. "It was a monumental logistical exercise as well as work effort," says Moretrench general superintendent Ryan Barrella.

"We worked around the clock, as did agencies and other private contractors involved"

Above (top): Some 1,700 ft (520 m) of pipe and hosing was needed to reach the flood water in the Brooklyn Battery tunnel tubes.

Above (bottom): Pumping underway to remove the estimated 60 million gallons (227 ML) of flood water from each of the Brooklyn Battery Tunnel tubes. MTA BRIDGES AND TUNNELS

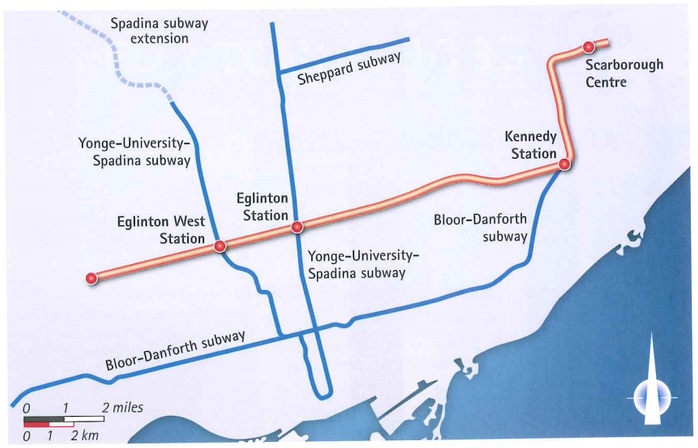
PERFECT FIT

To supply the thousands of segments that will line Toronto's newest light rail project, Munro has expanded its manufacturing facility and process. **Theresa Erskine** of Munro reports on the project

SOME 14,785 tunnel rings. 88,500 tunnel segments. An exceedingly tight schedule. With dimensional and quality control requirements so exacting, tunnelling expert Chris Smith of CRS Consultants called it "the tightest specification I've ever had to meet." ❱

Theresa Erskine
Theresa Erskine is director of marketing for Munro. She is a registered professional engineer (PEO) and holds a MBA from the Ivey School of Business

It's all for the new Eglinton Scarborough Crosstown LRT (ECLRT), a cornerstone of the City of Toronto's transit infrastructure upgrade. Managed by Metrolinx, an agency of the Government of Ontario, the ECLRT will traverse Eglinton Avenue running east/west through the heart of the city—linking 54 local bus routes, three subway stations and the provincial GO commuter rail system. To reduce disruption, it will run underground for 10km at the busiest part of Eglinton, requiring the construction of two 10km tunnels at 5.75m in diameter.



Left: Figure 1, Toronto's light rail expansion, and connections

55
Degrees Celsius is the maximum concrete temperature for the primary cure

244
Places of welded reinforcement on the cage

The project is generating a lot of buzz in Canada's largest city and surrounding suburbs. The Greater Toronto Hamilton Area (GTHA), comprised of the City of Toronto, the City of Hamilton and four regional municipalities (Durham, Halton, Peel and York) is Canada's largest urban region and one of the country's fastest growing areas. More than six million people live in the area today and the population is forecasted to grow to 8.6 million people by the year 2031.

The GTHA's existing network of regional transportation corridors was developed several decades ago, and the infrastructure is old. Congestion is a serious problem, with the average daily commute taking 80 minutes. Construction of rapid transit, which averaged approximately 135km per decade from the 1960s to the 1980s, all but ground to a halt for two decades because of a lack of investment. There was conflict in the various levels of government over who should pay for and how these major projects should be funded. This lack of investment contrasts sharply with what is happening elsewhere in the world. In the US, most large cities have invested heavily in rapid transit. Madrid—only slightly smaller than the GTHA—has built more rapid transit facilities during the past decade (88km) than all of the current Toronto area subway and light rail lines combined (77km).

For the city to be competitive globally, something had to change. Metrolinx created a plan, The Big Move, that outlines a common vision for transportation in the GTHA. The Premier of Ontario and the minister of transportation committed CAD 11.5bn (USD 11.2bn) to begin the implementation of The Big Move.

Metrolinx is upgrading the province's transportation infrastructure

And now Metrolinx is upgrading the province's transportation infrastructure. Fast. And that speed meant they needed to change the way things are done in order to keep pace with their ambition.

TENDER

Contract ECLM6-2 Supply of Precast Concrete Tunnel Lining Segments was released for bid to prequalified companies in late 2010. The manufacture of the tunnel lining segments was not part of the tunnelling contract. Tunnel segment manufacturing was a single contract.

Metrolinx chose to put the manufacturing in the hands of actual manufacturers in a complete reversal of the traditional approach. Historically in this business, tenders were released for contractors to bore the tunnel and supply the tunnel liners. So now, gone are the days of contractors having molds made and partnering with precasters or establishing a temporary facility to make the liners. That practice meant struggling to either amortise the cost of the moulds on that first job, or try to find additional jobs where those expensive molds could be put to use. And when considering that cost-recovery effort had to be accommodated in the lowest bid and tunnel boring is a high-cost, risky business, tunnel lining segments were not the contractors' focus.

That's why Metrolinx and the Toronto Transit Commission (TTC) released a tender for manufacture of the tunnel lining segments directly. The moulds to make the segments were to be purchased by the successful bidder but they would be Metrolinx property at the conclusion of the contract. The quality assurance program for the segments requires QA checks by the manufacturer and by an on-site Metrolinx representative. Once the tunnel segments are approved by Metrolinx, they are available for shipment to the jobsite. The contractor only needs to verify that there has been no damage during shipment and accept the delivery.

SETTING NEW STANDARDS

It's clear that Metrolinx has a long-term strategy on transportation and that allowed Munro, the successful bidder for the manufacture of the tunnel lining segments, to develop a long-term strategy for the manufacturing. The company was awarded the CAD 78.2M (USD 76.1M) contract to manufacture the 88,500 tunnel lining segments.

Located about an hour's drive north of Toronto, Munro manufactures a complete line of concrete and steel infrastructure products. All manufacturing is done 100 per cent indoors, under 100 per cent controlled conditions.

Munro had previously manufactured tunnel lining segments the traditional way, as a sub to a tunnelling contractor

to produce segments for the 510m-long, 2.7m diameter Coxwell Sanitary Trunk Sewer By-Pass, a tunnelled by-pass around a damaged, major sewer line in Toronto. But the ECLRT contract meant an opportunity to invest in a new manufacturing line and processes. That meant adding an additional 100,000sq. ft (9,290sq.m) to the existing manufacturing facility and two additional concrete mixers to the computer-controlled batching system.

Left and below: Munro's production facilities

The production line is a European-sourced carousel system that was improved to increase efficiency by having fewer stations with lower operator intervention. The system is installed flush with the factory floor to lessen worker fatigue and increase safety.

The accelerated delivery schedule of the ECLRT project required the production of 28 rings per day over a period of two and a half years. To achieve this, the entire manufacturing process had to be vertically integrated. There had to be complete control over all components of the process—from inspection of raw materials to manufacture of rebar cages, casting of segments, curing, storage and delivery. Using outside suppliers for any component of the process was deemed to be too risky given the tight production schedule and quality control requirements.

Standard reinforced rings (rebar cages) were specified. The technical and quality specifications were extremely stringent, including RFID tagging of each segment and a two-stage curing process. The primary cure requires a maximum concrete temperature of 55°C and the segments must have 15MPa strength so they can be lifted from the mold with vacuum suction.

The secondary curing process is a five-day cure in 100 per cent humidity. The automated double-cure process ensures the segments are fully cured and at full strength before they are stored in the yard or shipped to the jobsite.

These are considerations necessary to ensure the concrete is fully cured before it is stored outside during the cold Ontario winters.

GOING ROBOTIC

A new rebar manufacturing and handling facility was designed and developed in order to manufacture the reinforcement cages. This was the most aggressive and innovative step taken by Munro in the manufacturing plan, and it was done to be able to consistently achieve the quality and production requirements of just-in-time supply to the filling station. The cage specification calls for 100 per cent pass rate on rebar tests. If reinforcing cages were manufactured externally and orders of reinforcing cages were delivered in batches from a supplier, any quality control issues (such as reinforcing cage dimensions being out of specification) would cause serious production delays running into days and possibly weeks. Also, by bringing the manufacturing of reinforcing cages in-house, Munro decided to apply several technological innovations to the process to ensure that welds on the cages and dimensions of the cages were consistent. And the company implemented in-line production testing to ensure quality at each of the production stages.

The process starts with coiled steel and ends with the 'Brady Bunch,' six robots that weld the tunnel segment reinforcing cage using both vision and touch, a major innovation that results in a robotically welded rebar reinforcing cage, ready for insertion into the tunnel lining segment mould.

The Brady Bunch welds the tunnel segment reinforcing cage in 244 places to 100 per cent weld strength.

Dimensional consistency and quality of welds in tunnel segment reinforcing cages has long been a problem in the industry. The need for accuracy and strength of welds is extremely important so that the installed tunnel ring functions as the team intended.

Now with the assurance through robotic welding, that can be guaranteed. Each segment is tagged with a RFID tag after the cage is produced. The tag contains all the information about the segment, allowing complete traceability of materials and production. The system even has GPS capability that can locate a single segment in the yard.

A NEW APPROACH

The rigid timeline, the precise quality control specifications and the large production quantity drove innovations that can now be used on future manufacturing of tunnel lining segments for other tunnelling projects

HARDING PRIZE 2013

This year's BTS Harding Prize was awarded to **David Clayton** of Morgan Sindall for his paper on the TBM crossing at the Lee Tunnel conection shaft. This is part one of his paper

David Clayton
David is currently a tunnel design engineer for Morgan Sindall employed as a temporary and permanent works designer at the Lee Tunnel project in East London

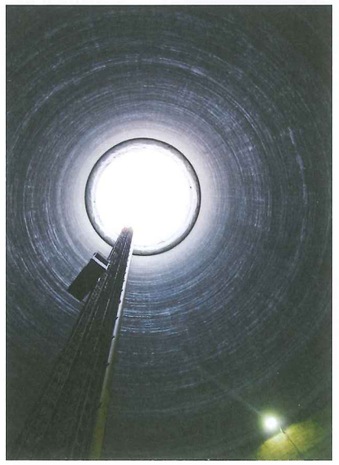
THE LEE Tunnel, part of the Thames Tideway Scheme is currently under construction in east London. A joint venture comprising Morgan Sindall, Vinci Construction Grands Projets and Bachy Soletanche (MVB) is undertaking the works. Thames Water awarded the Lee Tunnel contract, which is the largest project awarded in the UK water industry since privatisation in 1989, to MVB in January 2010. The contract incorporates four deep shafts, the largest of which is 38m in diameter, and, in addition, a 6.9km long tunnel.

The deepest tunnel in London, it is intended to capture the discharge from the combined sewer overflow at Abbey Mills preventing it from flowing into the River Lee and ultimately the

Thames. The scheme transfers the flow through the new tunnel for treatment at Beckton Sewage Treatment Works. The TBM being used to drive the tunnel was manufactured by Herrenknecht. It is a Mixshield slurry machine, 9m in diameter, and designed to build an 8.5m external diameter fibre reinforced segmental concrete primary lining.

The Beckton site comprises three shafts; the overflow shaft from which the TBM was launched; the connection shaft, an intermediate online shaft and the pump shaft which is offline of the main tunnel, but connected to the connection shaft via a smaller diameter sprayed concrete lined tunnel. The TBM reception shaft located at the upstream end of the tunnel is located at the Abbey Mills Pumping Station. All four shafts are in excess of 70m deep and have been constructed using diaphragm walling techniques for ground support during excavation and a double sided concrete slip-formed chimney to produce the internal shaft finish.

The focus of this paper is the crossing of the connection shaft by the TBM. Due to ground contamination at Beckton, dewatering of the ground at the shaft for tunnel entry was precluded. Furthermore Thames Water and MVB wanted to ensure that high pressure annulus tailskin grouting was possible on both entry and exit of the shaft. The TBM was required to break into the shaft which had to be partly filled and flooded, at full face pressure in order to balance the groundwater pressure for grouting. This would maintain positive pressure within the shaft and ensure no contamination could migrate through the tunnel eye. In addition to the challenges this presented, a method of changing the TBM tooling and nose cone was required which would not affect the critical tunnelling programme



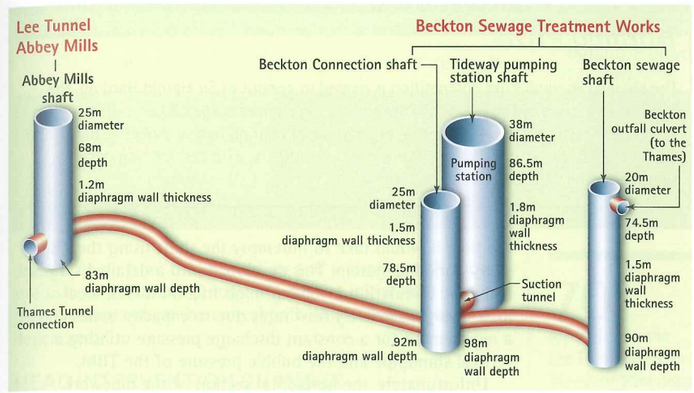
THESIS

This paper considers two key aspects of the TBM crossing of the connection shaft; firstly the part filling and flooding of the shaft to enable the crossing of the TBM without drawing in any contamination and enable annulus tailskin grouting at full pressure;

All four shafts are over 70m deep and have been built using diaphragm walling

secondly the design of the buried sacrificial chamber which enabled a fast tool change with minimum impact on the tunnelling programme within the shaft fill.

As the connection shaft and portals were programmed for construction before the tunnel arrived it was always known that the TBM would have to cross the connection shaft with the axis of the machine 13m above the shaft base slab. Various systems were discussed including, a partial concrete bath to support the TBM up to axis level, a steel crossing can or a foamed concrete fill, both of which would fully encapsulate the machine. Unfortunately due to the presence of the



contamination and the need to maintain positive pressure in the shaft therefore excluding any potential contamination ingress an alternative method of shaft entry was required. This necessitated a full face pressure entry (6bar) from the slurry machine, rendering none of these preferred options possible.

In order to exclude the contamination as the TBM broke through the shaft lining, a partial shaft fill with fluid or solids was required. The fill placed in the connection shaft had to be capable of resisting 6bar of slurry pressure generated by the TBM entering the shaft at full pressure, and also physically supporting the weight of the TBM until the machine had transited 13m into the shaft and subsequently built and grouted tunnelling rings behind itself through the shaft wall break in zone, to close the contamination pathway. Once this point was reached the TBM could then transit across the shaft and stop to perform a tool change on the TBM front face, before exiting the shaft again at full-face slurry pressure.

The shaft was filled with a designed cement bound granular material (CBGM); this consisted of Thanet Sand which was a beneficial use of recycled spoil from the shaft excavations and added cement. The fill was compaction specified at point of placement, batched on site and delivered to the pit bottom in skips, water being added as it was spread out in the shaft by excavators. This CBGM layer was made up of 14.5m depth of material (2m beneath the TBM and 4m above). It was underlain by a bed of single sized stone placed around the shaft bottom permanent works that were completed before shaft filling commenced. Above the CBGM layer was placed a 3.5m layer of Thanet Sand then 50m of water. The CBGM layer above the crown of the machine plus the layer of un-bound Thanet sand was designed incorporating a factor of safety of 1.2 to withstand the minimum operating slurry face pressure of the TBM of 1.2 bar. The remaining 4.8 bar was balanced by the 50m of added water on entry and exit of the machine. Therefore, the shaft had to be flooded before the machine broke in and again prior to its exit.

When placing the CBGM fill around the GRP chamber, to be discussed in further detail in due course, particular care had to be taken to avoid cracking the structure as vibro-compaction was being used. An exclusion zone was put in place around and above the chamber to limit the vibration impact. Furthermore a layer of lean mix concrete was placed above the chamber and lightly compacted with wacker plates. Plywood cladding was used to protect the shaft internal slipform lining from any damage from the plant or fill as this formed a part of the permanent works, the plywood effectively acted as a separation membrane between the shaft lining and the fill. In the two zones where the nose cone (at the centre of the TBM cutterhead) would intersect the shaft lining several cores were drilled in a circular pattern in order to weaken the lining and minimise the damage to the nose cone as it broke into the shaft. This damage limitation detail was of greater importance on the exit of the machine from the shaft as the nose cone would have only just been replaced.

It would have been preferable to keep the shaft flooded whilst the machine transited across the shaft, but in order for repairs to be undertaken on the cutting head, nose cone and brush seals, the shaft had to be emptied of water to prevent the risk of sudden inundation of the tunnel.

At that point in the design and planning, the permeability of the CBGM material for dewatering purposes was as then still unknown and could only be estimated, although due to the coarse nature it was expected to be relatively permeable .

Above: Figure 1, showing the alignment of the tunnel and the location of the shafts

Opposite, top: The lowering of the TBM required 3km of crane rope

Opposite, below: All four shafts were in excess of 70m deep

TRANSIT SEQUENCE ACROSS CONNECTION SHAFT

1. Flood the shaft using the site water supply at the connection shaft site.
2. Approach the outside of shaft with the TBM and breakthrough the diaphragm wall, annulus infill and slipform lining.
3. Transit 13m across the CBGM filled shaft, until tunnel ring building and grouting closes the contamination pathway behind the TBM.
4. Reduce the 6 bar slurry face pressure to 1.2 bar and drain down the shaft through the pipe work positioned within the fill using the TBM slurry handling system.
5. Transit across the CBGM shaft fill and intersect the head intervention chamber stopping 200mm short to avoid damaging it, perform the nose cone and cutterhead changes.
6. Transit through the sacrificial chamber.
7. Build two tunnel rings and then take them down, in order to create enough space to change the brush seals within the tailcan.
8. Transit to within 1m of the internal slipform lining and stop then fill the shaft through the pipework positioned in the fill using the TBM slurry handling system.
9. Exit the shaft at 6bar face pressure
10. Transit 13m out of shaft until ring building and grouting closes the contamination pathway.
11. Drain down the shaft using submersible pumps from the pit top at the connection shaft site.

FLOODING & DRAINING OF THE SHAFT

Initial flooding of the shaft was completed off-line of the main tunnelling programme from the connection and pumping shaft site water supply. This took in excess of a week to achieve but could be accommodated within the programme as the TBM was still several weeks away from breaking into the connection shaft.

Draining down and re-flooding the shaft to safely facilitate the tool changes was achieved using the TBM's own pumps and the large capacity storage of the slurry treatment plant, usually used to separate out the tunnel spoil from the slurry. The water used to fill the slurry treatment plant tanks and then the shaft was taken from the final effluent channel near to the overflow shaft site and fed through the slurry handling system to the face of the TBM. Once there it was transferred into the shaft by a specially designed and modelled piping system. This arrangement consisted of two side by side pipes running along the tunnel alignment (in the path of the advancing TBM). This horizontal pipework ran across the full width of the shaft and then turned vertically upwards emerging at the top of the fill. Where it emerged through the fill a remote controlled actuator was fitted, this allowed flow into and out of the pipe to be controlled remotely and acted as a cut-off against sudden inundation during the shaft crossing.

To resist the internal pressure it would experience, the uPVC pipework had to be encased in concrete on both the horizontal and vertical sections. Further design was required to calculate the time it would take to fill/empty the shaft using the TBM slurry handling system. This developed into a detailed staged hydraulic calculation involving; high friction losses, local losses, varying delivery flow rates due to capacity issues and a requirement for a constant discharge pressure utilising a vertical standpipe and the bubble pressure of the TBM.

Unfortunately, the horizontal section of the pipework become blocked as the TBM transited across the first section of the shaft, just after breaking through the shaft lining approaching the intervention chamber. This was due in part to the alignment of the pipework which had been diverted below the intervention chamber effectively creating a trap. It was thought that the high pressure of delivery of the water would clear any blockages but draining the shaft before the head intervention took much longer than expected, due for the most part to the semi-blocked pipework. In hindsight this horizontal section should have been detailed to include a slight rise all the way to the opposite side of the shaft to the point at which it turns vertical.

Once the head intervention had been completed and the TBM transited across the shaft to within 1m of the internal lining, the shaft again had to be re-filled. At this point there was very little of the horizontal section of the pipework remaining, the TBM was effectively in direct contact with the vertical section of the pipework. This meant the shaft filling performed much better and behaved in-line with the hydraulic predictions and modelling. Once flooded, the TBM safely exited the shaft at 6 bar slurry face pressure in order to keep the contamination from moving into the shaft. Finally when the TBM had exited the shaft and transited sufficiently far to build and grout tunnel lining rings into the breakout zone, the shaft was drained down again, but the tunnel was now sealed from the connection shaft. Therefore the shaft had to be

Harding Prize

The biennial Harding Prize competition is named in honour of Sir Harold Harding, the founder Chairman of the BTS and is open to young engineers aged 33 or under at the end o 2012. Entrants must submit an original paper relating to any aspect of tunnelling which they consider of interest to the tunnelling industry, with the winning paper selected by the BTS Committee.

Below: Figure 2, geometry of head intervention chamber

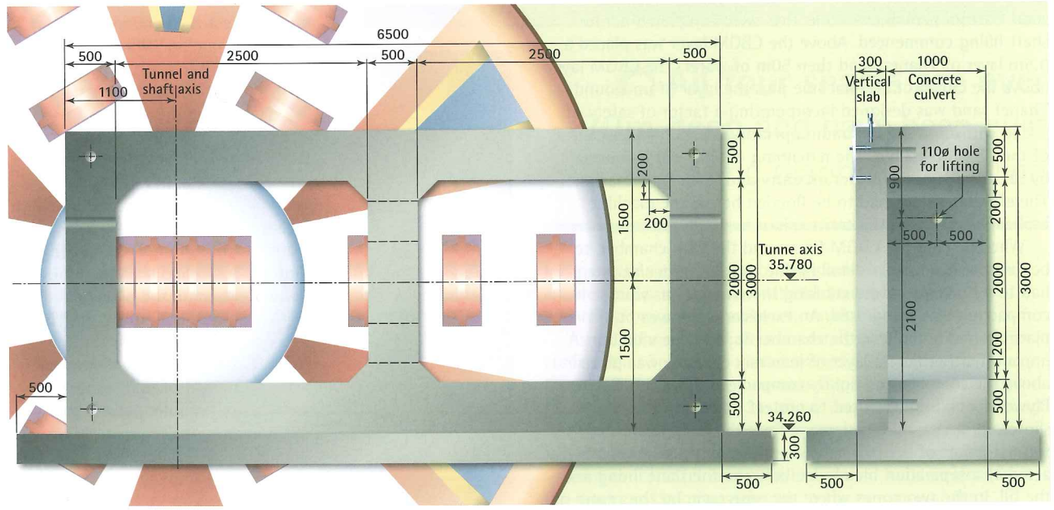


Table 1. Design Values for Chamber Structural Components

Item	Axial Force N_w (kN/m)	Moment/m of wall (kN.m/m)	Shear/m of wall (kN/m)
Culvert Side Walls	419.0	146.7	80.5
Culvert Cen. Wall	971.7	0.0	0.0
Top & Bottom Slab	199.5	248.1	289.8

Source: Author

drained down from the connection and pumping shaft surface site using submersible pumps, as with the initial shaft filling this was now not on the critical path and therefore not time dependent.

HEAD INTERVENTION CHAMBER

The option to fill and flood the shaft solved the contamination problem but gave rise to another. When the TBM was to pass through the connection shaft this presented the final opportunity in a 'safe' and dry environment to replace the nose cone and perform any potential welded repairs on the cutter head. This, if not for the contamination and grouting requirement leading to the shaft fill, would have been undertaken in the shaft whilst the TBM was positioned on a steel or concrete cradle arrangement. In our case the depth to the nose cone of the cutter head was over 10m within a saturated CBGM block. Access to undertake these works could be gained through the head intervention doors on the TBM but a large void would have to be created in order to provide enough working space to change the cutter head tools and the nose cone. This could have been completed using a staged timber heading, but due to the programme pressures on the tunnel drive this was ruled out.

Sheet piling and excavation from the surface of the fill was also discussed but dismissed due to the depth, plant requirement and again time constraints.

In a weekly tunnelling temporary works meeting between Morgan Sindall Underground Professional Services (MSUnPS) and the MVB TBM site team, the author put forward the idea of a sacrificial 'intervention chamber', constructed from concrete. This chamber would be precast on the surface (off of the construction critical path), and could then be lifted into position at the appropriate level during the shaft CBGM filling and buried to await the TBM. The buried intervention chamber had to be capable of supporting the fill above and around it, especially during the TBM approach, which would, due to the high torque exerted by the TBM cause high lateral loading. As the design of the chamber was undertaken before the shaft fill material was finalised, the fill material parameters and the depth of material above had to be conservatively assumed. Due to this very high torque generated by the machine it was decided that the TBM would stop 200mm short of the chamber to avoid any direct contact between the TBM cutter head and the concrete, to avoid causing damage before miners and engineers entered the chamber to undertake the nose cone inspection and any required work.

The head intervention chamber was placed directly on the alignment of the tunnel in order for work to be undertaken on the front of the TBM. The structure had to be sacrificial, i.e. the machine had to be able to cut through the chamber once the repairs were finished, and this presented a problem. The TBM is capable of breaking through concrete and could cut traditional steel reinforcing rebar but the steel would block the slurry pumps and separation plant on the surface and had the potential to cause significant damage to the system.

70
All shafts on the Lee Tunnel were in excess of 70m deep

6
The slurry pressure in bar on exiting the shaft

33
Engineers entering the harding prize must be younger than 33

The geometry of the chamber had to be such that it could facilitate work on the entire cutting head surface. This resulted in the need for a 5.5m clear span working area 2m in height and 1m in depth. By positioning the chamber such that the nose cone (at the centre of the TBM) was in elevation on the far left of the box, by then rotating the cutting head the entire face could be sequentially accessed. Due to the very large span required and in order to keep the structural sections relatively thin a central wall was added with a localised recess to maintain access to the entire cutter head, effectively creating a twin bore culvert.

ANALYSIS

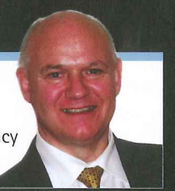
The loading on the head intervention chamber l modelled using the finite element package Plaxis 2D, the fill geotechnical parameters were not known at the time of analysis and design. The material properties had to be conservatively assumed to have minimal shear strength and a unit weight of 19kN/m³. Importantly only the ground loading was applied to the chamber. The 50m head of water pumped into the shaft was ignored as the permeability of the coarse material and the presence of large openings in the chamber (it had an open front face) meant that the water pressure could equalise as required and therefore not transfer any load to the chamber structure. In addition to this high permeability, water pathways existed throughout the shaft between the internal lining and its plywood protection, and the shaft flooding pipework. Clay had been discussed as a capping layer option as opposed to the CBGM; it was thought that due to its cohesive properties clay would better contain the face slurry pressure from 'blowing' the fill layer.

However if a clay layer had been used it would have drastically increased the load on the chamber as it would act as a barrier to the flood water finding its way into the chamber for pressure equalisation

This paper continues next issue

Departing from the usual fire protection staples of safety improvements and reaction times, **Andy Evans**, chairman of the Road Tunnel Operator Association, gives this insight into the myriad issues concerning tunnel systems in a fire situation

WIDER VIEW



Andy Evans
A former miner, researcher and tunnel manager, Andy now runs his own consultancy Aegis Tunnel Consulting

THE SAFETY of tunnel users is the tunnel operator's raison d'etre. The majority of papers addressing the use of active fire suppression in road tunnels review the improvements to user safety that a properly engineered active fire suppression system can bring. However, this paper will explore some of the wider issues in the specification, ownership and use of these systems. The knowledge of many years, arising from experiences of many different tunnel incidents, has impressed upon

tunnel operators the seriousness of the structural damage likely to be caused to a road tunnel by a large tunnel fire. Tunnel fires can generate large quantities of very hot (up to 1000°C) smoke. This smoke is thermally buoyant and tends to accumulate in a hot layer immediately below the soffit of the tunnel.

PASSIVE PRACTICE

In the UK, as in many other European countries, it has become standard practice to include the installation of passive fire protection as a part of the design considerations for a tunnel refurbishment. The application of passive fire protection serves to thermally insulate the structure of the tunnel from the effects of a fire, thereby protect it from fire damage. The application of thermal insulation does not, of course, reduce the amount of heat energy emitted by the fire. It simply prevents that heat energy from being absorbed by the tunnel structure. It follows that the heat energy from a fire within a thermally insulated tunnel must, substantially, propagate within the bore. The overall effect must be an increase in temperature within the bore.

Commonly cited design specifications are that under fire exposure, the surface of the tunnel concrete should not exceed 380°C and the reinforcement temperature should not exceed 250°C. These factors are used to help determine the design for the passive fire protection.

But what are the equivalent heat exposure factors for the tunnel Life Safety Engineering Systems (LSES)?

It is worth defining what is meant by LSES and the use of this term. LSES is a collective term for what many people refer to as 'the tunnel M&E' and 'the tunnel ITS'. The author uses LSES because Life Safety Engineering System actually tells you what the system does for you – very much in the same way that the terms 'Bridge', 'Vehicle Restraint System' or 'Pavement' do. As an added bonus it can also make accountants think twice before they strike a red line through the requirements to install or replace an essential tunnel safety system.

CABLING CONCERN

All tunnel LSES contain wires and/or cables - maybe a good starting point to start to look at potential fire damage is to examine in more detail the structure of tunnel cables. Tunnels contain a lot of cables: lighting cables, ventilation fan cables, CCTV power and video cables, instrumentation cables, communications cables and so on. The traditional UK specification for these cables is that they should be 'Low Smoke Zero Halogen' – they do not emit toxic gases in a fire.

1000
The temperature in °C to which smoke can rise in a tunnel fire, damaging cabling, lining and other installations

Cables traditionally used in UK tunnels were manufactured to BS 6724. This is not a fire-resistant cable standard (a fire-resistant cable is defined as a cable that is designed to continue to function whilst exposed to fire). There are still many thousands of miles of such cable in use in UK tunnels (at opening, the A55 Conwy tunnel contained 240km of BS 6724 lighting cables). For newer tunnels, or tunnels that have undergone major refurbishment, it has become common to install BS 7846 cables within the bore as they are likely to be exposed to fire. In construction, BS 7846 cables are very similar to BS 6724 cables; they are manufactured using Low Smoke Zero Halogen materials though they also include a mica tape inside the cable that binds the inner cores together. This tape ensures that the cable maintains its structure (and hence continues to function) when exposed to fire. Following fire exposure, such cables are also unfit for continued service – just like BS 6724 cable, BS 7846 cables also have to be replaced.

RELEVANT APPROVAL

The British Approvals Service for Cables (BASEC) provides a few very relevant facts regarding electrical cables. Cable life expectancy is a function of cable operating temperature. At 70°C the design life of an electric cable is 20 years. If the same cable is operated at 80oC the design life reduces to seven years. At 100°C the design life is "a matter of months". Cable life expectancy is highly dependent upon operating temperature. For most road tunnel applications the electrical distribution design results in the cables being operated far below the 70°C design temperature, with 30°C to 40°C the much more normal operating temperatures, with in the cable life sensibly extending to 40 years or more.

Another important issue is the materials used to manufacture the insulation for be "Low Smoke Zero Halogen" cables. In the British Insulated Callender's Cables (BICC)'s 'Electric Cables Handbook' by Professor G. F. Moore, we are advised that "Low Smoke Zero Halogen" cables insulation filler material includes:

- Alumina Trihydrate – this degrades at +200°C and forms water
- Magnesium Hydroxide – this degrades at +300°C and also forms water

DAMAGE ASSESSMENT

Discussions with cable manufacturers indicate that there is no authenticated method of assessing the reduction in residual life of a cable that has been subjected to fire, or high temperature, exposure. Whilst the cable might continue to function (electrical pressure testing would indicate that the cable is ok),

Above: The normal running conditions of a tunnel can, in some cases, extend the service life of installations

> Being able to supply a **significant volume of water** to a fire has a certain quality

the life expectancy of the cable would have been significantly reduced. Cable manufacturers advise that such cables are replaced. From personal experience, the author has witnessed the testing of two cables installed immediately adjacent to each other within the same part of a tunnel fire zone. One cable was on fault (phase – earth) the other tested ok – normal phase – earth insulation levels were recorded.

To summarise the above; tunnel fires generate significant quantities of very hot smoke that accumulates around the tunnel soffit and envelopes the tunnel LSES. Passively fire protecting a tunnel will result in an increase in temperature in the bore during a tunnel fire as compared to an equivalent tunnel without passive fire protection. In addition to the tunnel cable infrastructure, tunnel LSES contains cables. All of these cables are temperature sensitive and degrade when exposed to temperatures above ~200°C. If you have a reasonable fire, for example a ~20MW coach fire in your tunnel, there could be very significant and potentially unquantifiable damage to the tunnel LSESs exposed to the hot smoke.

In the UK if 'street furniture' is damaged by a vehicle it is common practice to recover the damages from the vehicle's insurer. If we are unable to quantify the damage caused by a fire, how are we able to recover the costs? Indeed, how can we even prove that the damage (specifically the reduction in residual life) has occurred?

Clearly, we need to ensure that the information we are able to obtain about the heat exposure to which our tunnel LSES has been exposed is quantified. If (for example) we were to install thermocouples at the tunnel soffit (say) every 25 to 50m and log the data from them as a part of our normal SCADA logging systems then we would have some heat exposure data and be in a position to substantiate our damages claims. Similarly, it might be possible to obtain such data from suitably configured linear heat detection system. The method of data collection isn't really the important issue; it's having the data

such that we can substantiate our insurance claims.

CHANGING POLICY

The attitude of insurers is also starting to become very interesting. UK insurers appear to be taking the view that damage to tunnel LSES is now a foreseeable consequence of a tunnel fire and the tunnel owner ought to take steps to mitigate such damage. For a modern tunnel, the tunnel LSES costs can amount to many millions of dollars. The post incident recovery time can also be very significant. It was estimated that the long-term closure of the Mont Blanc tunnel caused some EUR 2.5bn (USD 3.22bn) in regional economic damage.

Rewiring our existing tunnels with fire-resistant cables will help to ensure that essential LSES stand more of a chance to continue to function during a tunnel fire – but it would still have to be replaced after a fire.

Given that in a road tunnel a BS 6724 cable installation could have in excess of a 40-year life expectancy, it seems poor value to replace it half way through its life with a BS 7846 cable that is equally as susceptible to being written off through fire damage (despite being able to continue to function during a larger fire). We could also consider enclosing the cables within a thermally protected enclosure. The specification for this would have to be to ensure that the cables inside the enclosure did not exceed 200oC as a maximum (100oC would provide a more comfortable factor of safety). Such an enclosure is likely to be significantly thicker than the equivalent thermal protective system used for concrete, as we only need to limit the concrete surface temperature to 380oC. Enclosing cables within a thermally protective enclosure prevents them from dissipating heat to the environment during their normal operation. Such a measure is likely to result in the necessity to de-rate the cables (perhaps to 1/3 of their previous rating), so we'd probably have to replace them in order to be able to do this – for a large number of existing tunnels this could be a pointless exercise.

An alternative approach might well be to install active fire suppression.

Above: If the number of activation zones is increased, duration of visual obscuration is reduced

Active fire suppression systems are usually designed to control fire growth. It is usually the case that a tunnel fire starts small and grows, sometimes very quickly, into a large fire. Timely activation of a tunnel's active fire suppression system can limit fire growth to an extent that the fire never becomes a large fire, that the high temperatures associated with a large fire are not generated and the damage to the tunnel LSES is significantly reduced. Similarly, it is also possible to design the systems to provide active cooling of the tunnel LSES and structure. This technique has been used for many years in HV distribution systems.

From this perspective, active fire suppression starts to look like a very attractive mechanism for limiting damage to LSES – this is in addition to the well-established tunnel user safety considerations. Active fire suppression seems to have the potential to be both a tunnel life safety system and an asset protection system.

TYPES OF ACTIVE FIRE SUPPRESSION

There are numerous different types of active fire suppression systems; mainly either water based or foam based. A full review of all of them is beyond the scope of this paper. For the purpose of this paper, the consideration is restricted to the salient aspects of the two main types of system commonly in use throughout the world. High-pressure 'mist' systems are systems that generate a fine mist, while low pressure 'deluge' systems are systems that produce an intense water spray.

The main characteristics of a high-pressure mist system:

- It generates a fine mist that is an effective block to radiant heat and produces significant visual obscuration
- Fine mist is more susceptible to tunnel ambient or ventilation induced air flow than water spray owing to the much smaller water droplet size and correspondingly lower droplet momentum from a mist
- It uses less water (1/3) than a deluge system to create the same fire suppression capacity
- It uses high pressure water distribution of ~140 to 200 bars throughout the tunnel
- It uses a large number of high pressure pumps that require a high electrical supply capacity (approximately 1 – 1.5MVA / installation) or large prime movers
- It requires the supply water to be finely filtered
- System maintenance and support is relatively specialist necessitating specialist support

The main characteristics of a low-pressure deluge system:

- It generates a water spray that is a less effective block to radiant heat than fine mist – the deluge is also likely to produce visual obscuration
- Water Spray is less susceptible to tunnel ambient or ventilation air flow than fine mist owing to the much bigger water droplet size and correspondingly higher droplet momentum from a spray
- It uses approximately three times as much water to create the same fire suppression capacity as a deluge system
- It uses low pressure water distribution of around 5 to 10 bars throughout the tunnel. Zone valves and so on also operate at a low pressure
- It uses a few low pressure high volume pumps that do not require a high electrical supply capacity, at around 0.35 to 0.55MVA / installation
- It does not require the supply water to be finely filtered
- ystem maintenance and support is relatively commoditised and more widely supportable

From the above it quickly becomes apparent that the retro-fitment of a mist system may necessitate extensive increases in the tunnel electrical network and supply capacity or large prime movers, and the associated increase in electricity supply costs. It also appears reasonable to expect that the maintenance and support costs would be comparatively high.

The flooding risk appears lower than a deluge system.

Similarly, the retro-fitment of a deluge system can be expected to necessitate modest increases in the tunnel electrical network and supply capacity or smaller prime movers, and a comparatively smaller increase in the associated electricity supply costs. It also appears reasonable to expect that the maintenance and support costs would be comparatively low, though the flooding risk would be higher.

SYSTEM SELECTION, INSTALLATION AND OPERATIONAL ISSUES

Designers of both types of system appear to standardise the basic operation of each system type on the simultaneous activation of three zones – a zone typically being 25 to 30m in length.

A tunnel operator knows that there is a much higher probability of experiencing a car fire than a lorry fire. Following an in-depth study for one tunnel, the projected ratio was 43 :1 (i.e. 43 car fires for every 20 to 30MW lorry fire). To put another way, 97.5 per cent of these fires will be small car fires. This really begs the question of why an operator needs to flood 75 to 90m of tunnel to control a small car fire.

Defining the activation zones for an active fire suppression system to be, for example, 10 to 12m would enable the tunnel operators to activate the AFS in accordance with the size of the fire.

A further consideration is that of inadvertent system operation (a zone 'goes off' during normal traffic flow). At 50mph (80kph), a 10m activation zone would cause visual obscuration for less than 0.5s travel time.

A 30m activation zone would cause obscuration for nearly 1.5s travel time. The quantity of water used by a deluge system would be more likely to cause localised carriageway flooding and the possibility of aquaplaning than would a mist system. A reduction in activation zone length (i.e. increasing the number of activation zones) appears to have some considerable merit from the perspective of tunnel operations.

MOVING TO IMPROVE

A key question for tunnel operators is how to operate these systems. The Road Tunnel Operators Association (RTOA) has recently, in conjunction with the Awarding Body ProQual, issued a Qualifications and Credit Framework (QCF) Level 3 Diploma in Road Tunnel Operations.

With an eye to the future, this Diploma contains a module entitled 'Operating Tunnel Life Safety Engineering Systems – Active Fire Suppression'. This module can be taken either as a part of the Level 3 Diploma, or as a part of a Level 3 Certificate or on its own as a stand-alone module.

This mechanism allows a tunnel operator to configure an approved training package for the systems they intend to install – much of the technical training content for the system could be procured as a part of the AFS system procurement.

Of vital importance is the occupational competence of persons involved in the provision of training. It is the employer's legal responsibility to ensure that their employees (including external training service providers) are competent.

The RTOA has tortured itself getting to grips with this issue.

It has now established an Occupational Competence Validation Committee (OCVC), headed by a senior industry operation practitioner. The function of this committee is to assess the occupational competence of individuals involved in the tunnel operational training industry, much in the same way that we use prequalification procedures to ensure that tenderers for works are competent. Initially, we expect this to be focussed on training assessors, though there is, of course, an opportunity for the scope of this to be expanded should the Association consider this to be desirable.

The Diploma in Road Tunnel Operations should now provide tunnel LSES designers with a firm basis on which to agree the necessary Operator input to tunnel system designs such that the required level of overall system safety is achieved.

FINAL REMARKS

Whilst the industry does currently appear to be tending to the use of mist systems, the author would argue that for many applications a deluge system may be a better proposition, as it is likely to be cheaper to retro-fit, to own and also to maintain.

Being able to apply a significant volume of water to a fire has a certain quality about it – as Joseph Stalin once observed - "Quantity has a quality all of its own"

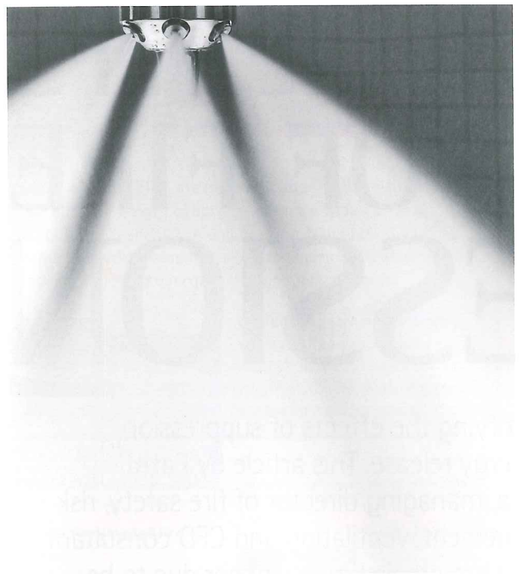
- *The remarks made in this paper are those of the author and do not necesarily represent the views of the RTOA*

BENEFITS OF FIRE SUPPRESSION

Quantifying the effects of suppression on energy release. This article by **Fathi Tarada**, managing director of fire safety, risk management, ventilation and CFD consultant *Mosen* is a preview to his paper due to be published in the forthcoming International Symposium on Aerodynamics, Ventilation and Fire in Tunnels due to be held in Barcelona in September

Fathi Tarada
Fathi is managing director of Mosen and chair of the tunnel operations committee of PIARC. He has written in past years for *Tunnels*

THE FIRST tunnel fire suppression systems in the UK were commissioned in the New Tyne Crossing in 2011, and the installation of high-pressure mist systems is currently ongoing in the Dartford Tunnels between Kent and Essex. Other tunnels in the UK are actively considering such fire suppression systems. However, with the Dartford mist systems costing in excess of GBP 8M (USD 12.5M), tunnel operators are certainly justified in asking what the benefits of fire suppression are, and whether their price tag can really be justified.



Whether the costs can be justified is a question that cost-benefit analysis should answer

Vehicle fires, particularly those from heavy goods vehicles (HGVs) can damage the tunnel structure and equipment, and can cause significant traffic disruption while repairs are being carried out. Recent incidents include the Brynglas Tunnel fire on the M4 near Newport, Wales in July 2011, and severe damage to the Brattli Tunnel at Tysfjord, northern Norway in January 2013. Mercifully, neither of these fires involved human casualties. However, lives have been lost in previous fire incidents including in the Mont Blanc (1999), Tauern (1999) and Gotthard (2001) tunnels.

None of these tunnels had fire suppression systems installed at the time of the incidents.

Suppression systems have the potential of reducing the intensity of any fires, so as to reduce the extent of any damage to the tunnel structure and equipment, and also serve to protect tunnel users from the effects of fire.

The Burnley tunnel fire involving three trucks and four cars which occurred in March 2007 in Melbourne, Australia caused only minimal structural damage due to the operation of a deluge system. However, three people died in the accident – two from the effects of fire, and one from multiple injuries. Arguably, the combined effect of the smoke ventilation and fire suppression systems helped to avoid a much greater loss of life in that incident.

Above: Fire suppression systems can drastically retard the development of a fire

OBSERVATION

Although tunnel fire suppression systems have been installed in Japan and Australia for decades, detailed experimental evidence of their effectiveness in reducing heat release rates and minimising concrete temperatures had not been available. The availability of the limited test data was heavily restricted by fire suppression manufacturers who sponsored the tests. To address this dearth of information, a number of research projects have recently been undertaken. The German SOLIT2 programme investigated the performance of high-pressure mist systems, and tests were undertaken with low-pressure deluge systems, the Singapore Fire Test Programme (SFTP) sponsored by the Land Transport Authority (LTA) in Singapore.

The SOLIT2 tests were undertaken with simulated HGV loads corresponding to a potential heat release rate of up to 150MW, as well as pool fires with potential heat release rates of up to 100MW. The fire tests were conducted in the test tunnel of San Pedro des Anes, in northern Spain. Unfortunately, the publicly available SOLIT2 reports were heavily redacted for commercial reasons and do not contain any information regarding water application rates, which significantly reduces their usefulness for research and engineering design. However, some information can be gleaned from the reports.

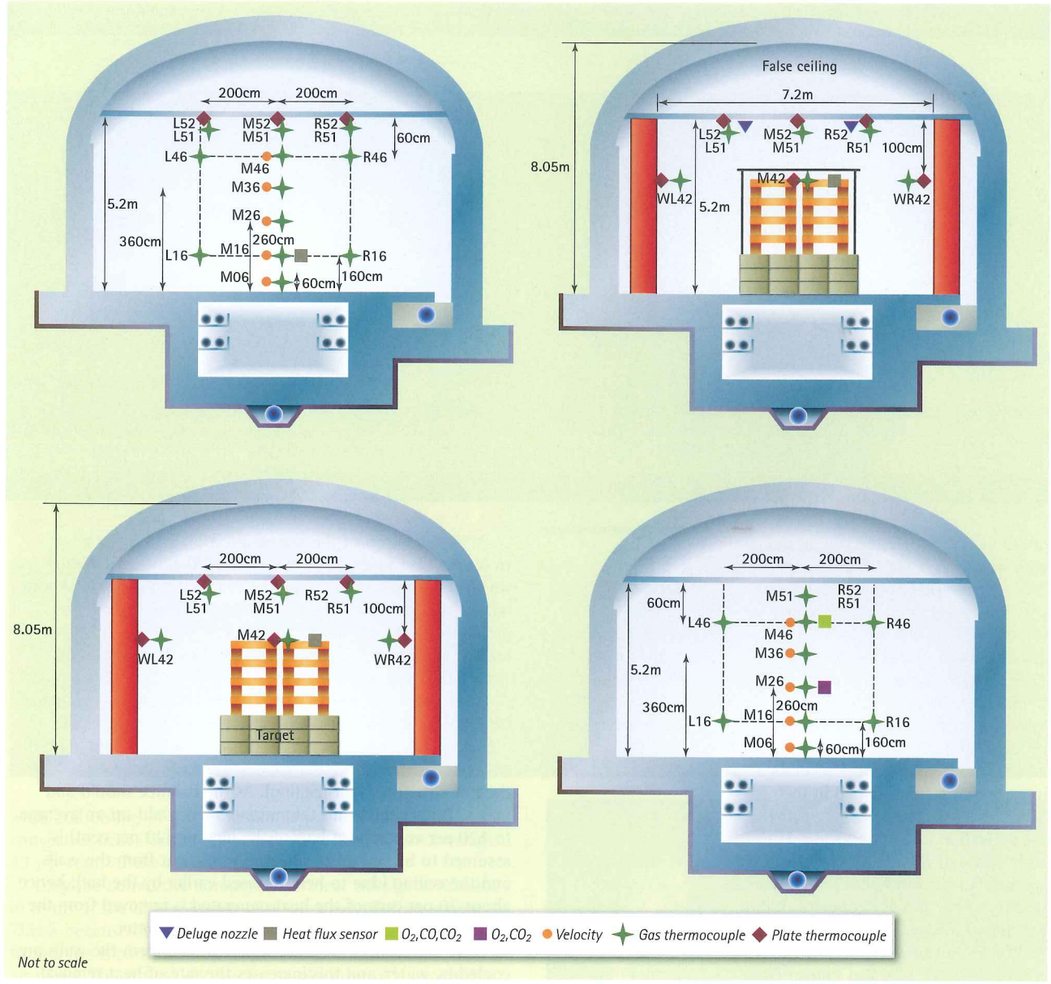
The San Pedro test tunnel has a length of 600m with a slope of one per cent. It is a two-lane road tunnel built in concrete, with a lower gallery for emergency and services, and three emergency exits. The width of the original tunnel is 9.5m with a height of 8.2m, but the tests were undertaken within a reduced tunnel section measuring 7.5m in width and 5.2m in height. The HGV mock-up was made of wooden Euro pallets with less than 20 per cent humidity. To simulate the impact of driver's cabin and solid rear doors on the ventilation conditions inside the fire load, steel plates were mounted onto the racks on the front and rear sides of the mock-up.

The SOLIT2 tests indicated that the heat release rate from an HGV fire can be limited to 30MW or less, if the mist system is operated seven minutes after ignition. Ceiling temperatures were limited to 800°C immediately above the flame zone, a value which can still lead to concrete spalling. However, ceiling temperatures at a location 15m downstream of the fire were limited to 200°C, which should not cause spalling. The air velocity through the tunnel varied during the test between 2 and 3m/s, but no back-layering of smoke was identified during the operation of the mist system.

Table 1. Large Scale Fire Test Schedule

Test	Test description (variation)	Discharge density (mm/min)	Nozzle type	Activation time (min)	Fire in suppression zone
1	Directional nozzle	12	Dir 180°	4	Centre of zone
2	Directional nozzle	8	Dir 180°	4	Centre of zone
3	Standard spray nozzle	12	Standard	4	Centre of zone
4	Standard spray nozzle*	12	Standard	4	Centre of zone
5	Standard spray nozzle	12	Standard	4	End of zone
6	Standard spray nozzle	12	Standard	8	Centre of zone
7	Unsuppressed	n.a.	n.a	n.a	Centre of zone

Source: Author



Above: Figure 1, Cross-section of the test tunnel and instrumentation set up

The mist system limited the heat release rates for pool fires to less than 80MW, and ceiling temperatures to less than 700°C immediately above the flame zone. Flames spread beyond the fuel trays, and ceiling temperatures were therefore in excess of 500°C at locations 15m downstream of the fire location. The measured longitudinal air velocity was between 3 and 4m/s, but that was not sufficient to overcome smoke backlayering prior to the activation of the fire suppression system. After activation of the mist, all the smoke was blown downstream.

The SFTP was carried out at the same test facility as the SOLIT2 tests, but were concerned with the investigation of low-pressure deluge systems rather than high-pressure mist. The objective of the SFTP was to investigate the magnitude of the heat release rates and temperatures generated with and without a low-pressure deluge fire suppression system.

Detailed results from the SFTP are due to be published in the forthcoming International Symposium on Aerodynamics, Ventilation and Fire in Tunnels due to be held in Barcelona on 18-20 September 2013, but some key results will be presented here, with kind permission of the management of LTA.

The minimum dimensions of the rectangular test section at the location of the fire source were 7.3m wide and 5.2m high. At the location of the fire source, walls are constructed inside the real test tunnel to protect the concrete against damage. The resulting cross-section is shown in figure 1. Jet fans at the northern end of the portal are used to generate an air velocity in the tunnel for the entire duration of the fire test.

The effects of various fire suppression parameters such as deluge nozzle type, discharge density and activation time were investigated. The simulated heavy

Table 2. Schedule of fire tests carried out

Test no.	Nozzle type	Discharge density (mm/min)	Activation at	# Pallets	Fire load
0 (pre)	Standard	7	13 min	10 full width	Uncovered
1	Standard	11.2	Max HRR	19 full width	Uncovered
2	-	-	-	15 partial width	Covered
3	-	-	-	15 partial width	Uncovered
4	Dir. 180°	12.2	Max HRR	15 partial width	Covered
5	Dir. 180°	12.2	Max HRR	15 partial width	Uncovered
6	Dir. 180°	7.9	Max HRR	15 partial width	Covered
7	Dir. 180°	7.9	4 min	15 partial width	Covered
8	Standard	7.9	4 min	15 partial width	Covered
9	Standard	7.9	Max HRR	15 partial width	Covered
10	Dir. 110°	7.9	4 min	15 partial width	Covered
11	Dir. 180°	12.0	4 min	15 partial width	Covered

Source: Author

goods vehicles consisted of 228 pallets with 48 plastic pallets (20 per cent by volume) and 180 wooden pallets (80 per cent by volume). A longitudinal air velocity of between 2.8 to 3m/s was applied in the tunnel fire tests.

Peak heat release rates of 27 to 44MW were measured for deluge operation at four minutes, 97MW for delayed deluge operation at eight minutes and 150MW with no deluge intervention were obtained in the SFTP. This fire test series shows that the activation of deluge system at the early phase of the fire development is important as it helps to reduce the severity of the fire development during the growth phase.

In addition to the full-scale fire tests within a tunnel, LTA also sponsored a series of reduced-scale fire tests, in order to consider certain issues in more detail. The fire load in the laboratory fire tests consists of wooden and plastic pallets, with the number of plastic pallets equalling 20 per cent of the total number of pallets. In order to sufficiently represent the fuel layout as in the large-scale tunnel tests, the same stacking height (relative to the nozzles) was used as in the large-scale tunnel tests. A pallet stack height of about 3m from the floor was used, and the top of the pallet stack was thus 2m below the sprinkler nozzles.

ENERGY ABSORPTION

Measurements were undertaken of the water flowrates and thermal energy budgets during the LTA laboratory tests. A total of 11 tests were carried out, as summarised in table 2. The heat release rate was determined using oxygen depletion calorimetry.

25
The maximum per cent of released energy that is abosrbed by evaporation of suppression water

After activation of the fire suppression system, some 31 to 49 per cent (average 39 per cent) of the released energy was found to be absorbed by the evaporation of water. About half of this is assumed to be absorbed by the water vapour generated in the combustion products; hence 15 to 25 per cent of the released energy is absorbed by evaporation of suppression system water.

After activation, some 25 to 55 per cent (average 38 per cent) of the released energy is absorbed by heating of the (liquid) water. The energy absorbed by heating of the (liquid) water is assumed to be partly due to energy absorption from the hot structure (walls/ceiling). As the balance should add up to 100 per cent, and the measurements add up on average to 120 per cent, about half of the heating (20 per cent) is assumed to be caused by absorption of heat from the walls and the ceiling (due to heat released earlier by the fire); hence about 20 per cent of the heat generated is removed from the setup due to heating of suppression system water.

After activation of the fire suppression system the walls are cooled by water, and this increases the rate of heat removal from the fire source. An average of 23 per cent to the total (chemical) fire heat release rate is gained from the floor,

Below: Damaged lining in the Channel Tunnel following the 1996 fire

walls and ceiling of the enclosure. It was estimated that the convective heat transfer represents 25 to 51 per cent (average 43 per cent) of the released fire heat release rate.

Only the convective component of heat transfer is relevant in terms of the dimensioning of a tunnel ventilation system. This is because the thermal buoyancy of the hot gases issuing from a fire is controlled by convective heat transfer, i.e. hot air rising. The critical velocity for smoke control is dependent on buoyancy effects, as described by the ratio between the inertial and buoyancy forces. Since only a fraction of the heat transfer in suppressed fires flows out via convection, it follows that appropriate allowances may be made in the relevant calculations, including estimates of critical velocity and the setting of boundary conditions for aerodynamic calculations.

For unsuppressed fires, it is common practice to assume that 70 per cent of the fire heat release rate is convectively transported, with the balance being lost due to radiation to the surrounding environment and to the fuel source. Calculations of the critical velocity for smoke control are typically based on the convective component of fire heat release rate only.

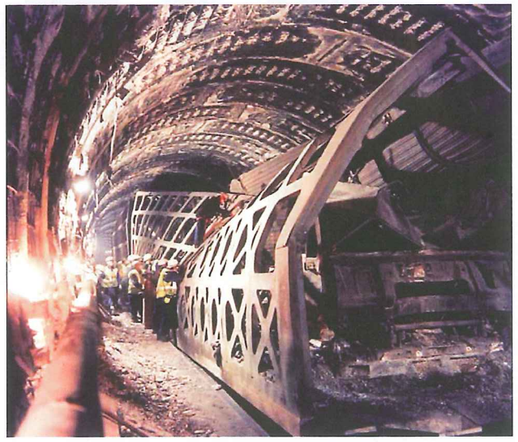
It was observed that the convective heat transfer was generally less than 50 per cent of the suppressed fire heat release rate.

Depending upon the risk assessment process undertaken, and the degree of confidence attached to the performance of the fire suppression system, a significantly lower value for convective fire heat release rate may therefore be assumed for suppressed fires.

FINAL THOUGHT

Fire suppression systems in tunnels are no panacea, as the recent false discharge in the Tyne Tunnel in Newcastle, UK has demonstrated. However, their potential utility in reducing the risks to tunnel structures and users, and to minimise downtime following an incident, are clear.

Whether their price tag can be justified is a question that a careful cost-benefit analysis should answer. Ultimately it will be the client that drives the uptake of these systems



Above: A wrecked carriage following the 1996 Channel Tunnel fire

NORTHERN LIGHT

Progress on underground disposal of nuclear waste is limited internationally, but Finland and Sweden are striding ahead, reports **Patrick Reynolds**

LONG A dream to securely contain high-level nuclear waste deeply underground for millennia, no burial vault for the ages as yet exists. US politics kicked the proposed Yucca scheme in Nevada into the long-grass a few years ago, and only a few months past at the end of 2012, the UK heard that a favoured site for a proposed scheme in England had been rejected by the local county, Cumbria, that would have played host.

Bucking the international trend, though, Sweden and Finland have been making particular progress with the strategic challenge. If all goes to plan and schedule, they could have their first shipments of high-level nuclear waste being taken far underground for burial starting around the early 2020s – approximately a decade away, and possibly less.

The elected site in Sweden is at Forsmark, north east of Stockholm, and it had to compete for the right to be the candidate site; a rival community in the south of the country had wanted the honour; the not in my backyard problem, or at least lukewarm enthusiasm witnessed elsewhere, was not the issue in Sweden.

The Forsmark site is already a complex, home to a nuclear power plant and also an existing underground vault (SFR complex) for lower-level nuclear waste, which is being extended. After years of site investigation, the Swedish Nuclear Fuel and Waste Management Co (SKB) filed an application for the licence to construct and operate the high-level waste vault in 2011.

Finland filed its own constuction permit application a few months ago to build a vault at Olkiluoto, north of Turku, where nuclear power plants are located. The site is already under initial development by the national nuclear waste agency, Posiva, however, with the first major tunnel already excavated.

In an approach differing from that of Sweden and many other nations, Posiva – as required under legislation covering the waste storage, and in absence of its own local, existing, rock characterisation facility – has had to go underground to test the rock insitu by creating its own laboratory (called Onkalo), in effect.

Posiva has constructed what would be the vault's spiral access tunnel, extending down to the depth of the main storage zones and, only slightly above, site investigation and other tests are being carried out. The main tunnelling work on the ramp was completed over 2011-12. Currently, Posiva anticipates that the initial sections of the Olkiluoto vault to be opened up and operational, able to take high-level waste, from 2022, potentially, and slightly earlier than SKB's plans for Forsmark.

Above: Figure 1, Suggested layout for the SFR expansion

FORSMARK

After about 20 years of studies and field research across Sweden, Forsmark won the race to be Sweden's choice for the nuclear waste vault in 2009, overcoming competition from its last rival, Oskarshamn, to the south of the capital.

To securely and safely house high-level nuclear waste, distance is the vital barrier – in this case depth below ground, in excellent rock mass with acceptable groundwater characteristics. Every metre down adds vital points in calculations for protection, keeping waste away from the general environment. What began tipping the scales in the search in favour of Forsmark was SKB learning that the site could have a vault constructed far deeper than previously thought.

> At Forsmark SKB learned a vault could be constructed **far deeper than previously thought**

Site investigation data had revealed stresses in the granitic rock mass, which is part of the Fennoscandian Shield, to be less than expected; the stress profile did not rise with depth as quickly as had been estimated. Less stress meant more opportunity to excavate, and at deeper depths, to create storage vaults without detrimental stress release and negative effects on the quality of the rock mass.

The result was that a vault could be located about 470m below the surface at Forsmark, or almost the same depth as Oskarshamn. With the rivals on almost even scores for depth, there was little difference either in the total excavation volumes needed for shafts, access tunnels and the caverns that would hold technical rooms. What was left, then,

Patrick Reynolds
Patrick is a freelance technical journalist who has covered tunnelling projects all over the world for *Tunnels*. Based in the UK, his background is originally in the mining industry

and fell heavily in Forsmark's favour, was that it only required 1,850,000m³ of excavation to create the required storage zone grid of tunnels, or two-thirds the volume needed by the Oskarshamn option.

Forsmark had it.

At Forsmark, the deep repository has been conceived to its KBS-3 storage concept, referring to a particular arrangement of holding the waste in copper canisters that are slotted and sealed into vertical boreholes in grouted, highly competent rock. With a tight fit, the canisters are packed all around with bentonite clay.

Around 40-45 vertical boreholes will be excavated at 6-6.8m distances apart along each of the 300m long placement, or deposition, tunnels which themselves will branch off main tunnels, running parallel at about 40m centres depending on thermal conductivity of the rock.

Multiple deposition tunnels would be open, taking canisters. As each canister is placed and sealed then that section of tunnel will be backfilled. Eventually, the entire deposition tunnel will be blocked off. It is expected that the operation life of a deposition tunnel will be no more than five years, says Rolf Christiansson, a senior rock engineer with SKB.

With this concept, only a small percentage of the tunnels in the grid of the repository masterplan would

Above: The various sites competed on rock quality and volume of excavation required to create the complex

Long a dream to contain nuclear waste, **no burial vault for the ages as yet exists**

be available for access and holding of waste canisters at any time. This approach of incremental but consistent, high-quality tunnelling, and then sealing off, should give the deep repository an operational life spanning decades.

Aspo Hard Rock Laboratory, located near Oskarshamn, has been used to test excavation quality research as well as examine different storage and sealing concepts for a high-level waste vault. Though far from Forsmark, the tunnels enable SKB to test underground for the storage project, whereas in Finland no such existing facility is available.

The Aspo facility has a maximum depth of 450m and has been expanded to create new test areas that will help with preparing for the tunnelling, and long-term performance, of the high-level waste vault at Forsmark.

Rolf Christiansson, a senior rock engineer with SKB, says a prototype system for digital photogrammetry has been developed for geological mapping, and which gives accurate documentation of the excavated tunnel geometry. Further test work will include investigating the use of electronic detonators.

"We hope to be able to give fast feedback to the contractor," says Christiansson. That way, constant adjustment can be made in each round of drill and blast to ensure the quality of perimeter control, and minimise the excavation damage zone.

He adds: "We have worked with both grout design and development of grouting materials." Saying that key parameters include there being no chemical components in the grout, no organics and also that the pH alkalinity should be less than 11 in leached water.

More recently, he says, SKB has added efforts to brief the Swedish tunnelling sector in preparation for the particular high-quality excavation needs of the large, long-term work coming up. The nuclear waste sector demands better performance to minimise disruption to rock quality; rock mass integrity is more imprtant that production speed.

Christiansson says drilling precision is one of the keys to

delivering the careful blasting needed, and for effective charge distribution it will be vital to ensure 'good control of the amounts of exploves put into the holes.'

A construction period of approximately seven years has been envisaged to get the vault's shafts, ramps, tunnels and caverns of the initial storage zone operational.

The schedule was for construction and tunnelling to start around 2017.

However, to allow more flexibility around the licensing process, last November a buffer of about two years was approved by SKB's board, putting the possible start of works back to about 2019-2020. That does not automatically also reset the initial operational date, however, says SKB, as ways would be sought and examined to help reduce the construction period, if possible.

If so, the originally antcipated date of around 2024 will be able to be held, otherwise it would stand to be about 2025-26, it is estimated.

SFR Expansion

SKB is planning to expand the existing SFR, low-to-medium level nuclear waste vault at Forsmark by adding far more storage volume, as mutiple caverns next to, but deeper than, the present repository depth of around 60m. The extension project would more than triple the total storage volume of the SFR complex to approximately 200,000m³.

Plans were revised late last year to place the new section of vault deeper than the existing caverns, at about 120m below the surface, or about twice the current storage depth, says SKB spokesman Jimmy Larsson-Hagberg. Consequently, these 'rather big changes in the layout' will mean the 140,000m³ extension will take longer to build, pushing back the start of operations in the new vault from the initial schedule of 2020 to around 2022-23, again 'depending on the licensing process.'

The agency anticipates submitting its licensing application for the SFR expansion about late 2013. However, it says the final layout of the expansion vault has yet to be decided.

Under the 2020 schedule, it was anticipated that tunnelling might commence around 2016. As yet, no explicit change to the start of the construction schedule has been decided, only that the task will take longer to go deeper.

Therefore, it is possible that the tunnelling for the SFR expansion could be at least well advanced, and possibly even majority completed, by late in this decade when excavation for the high-level waste vault – to be built under a totally separate project – is getting underway, depending on its licensing progress, of course.

OLKILUOTO

The Olkiluoto site, in Finland, is to have the deep repository constructed about 400-450m below the surface, almost as deep as at Forsmark, in Sweden. Work began nine years ago at the site, gradually excavating down the spiral ramp to the storage level, and excavation contractor Destia completing the majority of that initial tunnelling by 2011, and some further works undertaken into 2012-13.

However, the works doubled-up as the access route to create the Onkalo rock characterisation facility in the absence of there being one in Finland. Although it takes the scheme underground earlier in its development schedule, the need to excavate – to conduct tests for licensing approval for the project – has been major effort for Posiva.

The Onkalo research facility includes a series of tunnels: a central, 70m long access tunnel (8.5m wide by just over 6m high); 50m long Demonstration Tunnel One (3.5m wide and less than 5m high); and, 120m long Demonstration Tunnel Two. In each demonstration tunnel, following exploratory pilot holes, there are 1.75m diameter boreholes excavated to depths of almost 8m. The boreholes were excavated using Sandvik subsidiary Tunnel Raise Borers' prototype Rhino 500HSP unit.

Rock test data confirmed the suitability of the bedrock to host the the deep repository and the construction application was filed in late December last year.

Pending award of the construction permit, Posiva expects that main tunnelling for the repository and construction of the associated facilities, such as the surface encapsulation plant, could commence in 2015, says Reijo Sundell, president of the agency (which is owned by TVO and Fortum).

Speaking in February, he added that should Posiva be able to submit an application for an operating licence by 2020 then first waste might be able to be taken at the Olkiluoto vault by 2022.

"We will keep testing the final disposal concept and gathering more information on the functionality of the associated equipment, systems and methods," said Sundell.

The engineered barriers of the disposal concept are similar to that for Forsmark – canisters capable of withstanding corrosion, then case in bentonite clay to decouple the container from the bedrock, and a progressive backfilling and plugging system.

Last year saw tests of borehole excavation for waste containment canisters. This year the site will see the arrival of the transfer and installation vehicle for the canisters, and also the benotonite block installation device.

The sealing-off technology for the repository will be tested full-scale as part of a larger, European development project – DOPAS.

The project is budgeted at EUR 15.7M (USD 20.8M) and runs from 2012-2016.

FUTURE IN THE NORTH

With their appications submitted for the respective nuclear waste storage projects, Sweden and Finland have a few years yet to go and much tunnelling to undertake before they know which will be first vault to come into operation.

It is not a race, and there is keen liaison between SKB and Posiva, and the authorities and engineers of both nations, but however it plays out the eyes of the international nuclear waste sector, politicians and, not least, tunnelling peers, will be watching keenly the developments in the far north

470

The depth in metres that a vault could be located at Forsmark. Several of the sites have the same potential

editor@tunnelsonline.info

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

To advertise here call Tom Willard on +44 20 7406 6599 or email *twillard@tunnelsonline.info*

CHEMICALS

BASF
The Chemical Company
MEYCO
Expanding Horizons Underground
www.meyco.basf.com

CUTTER TOOLS

PALMIERI TUNNELLING - DRILLING
CUSTOM-MADE CUTTERHEADS FOR TBMs MICROTUNNELLING AND VERTICAL OR DIRECTIONAL DRILLING MACHINES.
BACK UP AND MUCK HAULAGE SYSTEMS.
ROLLING STOCK AND SPECIAL TUNNELLING RELATED EQUIPMENT
T: +39 0534 32511 F: +39 0534 32501
E: info@palmierigroup.com W: www.palmierigroup.com
Agents wanted in selected countries. Please apply to: a.tasselli@palmierigroup.com

T.B.M. CUTTERS Ltd.
DESIGN AND MANUFACTURE OF TBM CUTTING TOOLS AND WEARPARTS
CUTTER HEADS MANUFACTURED & MODIFIED
TEL. +44 (0) 1430 427954
FAX. +44 (0) 1430 427955
EMAIL. office@tbmcutters.com
www.tbmcutters.com

DIRECTIONAL DRILLING

DRILL and BLAST

OSSA OBRAS SUBTERRANEAS
1952 - 2012
Polígono Industrial Alcobendas.
28108 Alcobendas (Madrid)
T. +34 902 678 808 | F. +34 915 618 894
www.ossaint.com

ELEVATORS

ALIMAK HEK
Rack and pinion elevators for inspection, maintenance and emergency escape in road and railway tunnel shafts.
www.alimakhek.com

ENGINEERING CONSULTANTS

TONY RIDLEY HYPERBARIC ASSOCIATES LTD
Consultancy, Expertise and Personnel
Specialist Tunnelling Services
Compressed Air - TBM Intervention - Safety - Rescue - Occupational Health
Tel +44 (0) 1508 538 838 Fax +44 (0) 1508 538 938
Email info@hyperbaric-tunnelling.com
www.hyperbaric-tunnelling.com

ENGINEERING CONSULTANTS

Your Trustworthy Tunneling Consultant Since 1962
CONSULTING ENGINEERS
SAANIO & RIEKKOLA OY
Laulukuja 4, FI-00420 Helsinki, Finland
tel. +358 9 530 6540, www.sroy.fi

Alan Auld GROUP LTD
TUNNEL AND SHAFT DESIGN SPECIALISTS
Telephone +44 (0) 1302 329911
Fax +44 (0) 1302 329922
Email mail@alanauld.co.uk
Website www.alanauld.co.uk

Tunnels - Caverns
Foundations - Slopes
Consultants in Rock Engineering
GEO-DESIGN
www.geo-design.co.uk

ENGINEERING CONSULTANTS

GEOCONTROL
BRASIL | CHILE | ESPAÑA | PERÚ
GEOTECHNICAL SERVICES
DESIGN OF TUNNELS
SAFETY EQUIPMENT DESIGN
ROCK MECHANICS APPLIED TO MINING
ON-SITE TECHNICAL ASSISTANCE
Cristóbal Bordiú, 19-21, 5º - 28003 Madrid (SP)
T: +34 91 553 17 63 | F +34 91 554 93 96
geocontrol@geocontrol.es

EQUIPMENT

The one-stop source for the tunnelling industry.
It's only a *mouse click* from here!
tunneltrade.com your tunnel internet portal

METAX® CIMA GROUP
29122 Piacenza - Italy - Via Orsina, 33
Tel.+39 0523 0103 Fax +39 0523 593106
www.metax.it - info@metax.it
Jet Grout, Mud, Slurry Pumps
Batching Plants - Injection Plants
Drilling Rods - Ancillary Parts

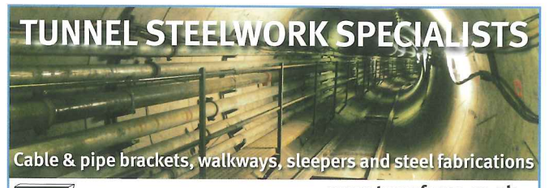
EQUIPMENT

SP SPECIALIST PLANT
TUNNELLING EQUIPMENT HIRE & SUPPLY
Specialist Plant Associates Ltd
Agents for CIFA
Tel: +44 (0) 1234 781 882
Email: info@specialistplant.co.uk
www.specialistplant.co.uk

FUEL TANKS

WESTERN GLOBAL **ABBI**
YOUR PERFECT REFUELLING PARTNER
T +44 (0) 1454 227 522
www.western-global.co.uk

FABRICATION



TRANSFORGE UK LTD
www.transforge.co.uk
+44 (0)1733 249260
info@transforge.co.uk

FIBRE REINFORCEMENT

MACCAFERRI
Engineering a Better Solution
Fibre reinforcement | Tunnel drainage | Fibreglass reinforcement
Self-drilling anchors | Steel arches | Ceramic linings
www.maccaferri.com

GROUND CONTROL

DYWIDAG-SYSTEMS INTERNATIONAL **DSI**
AWAG SYSTEMS
GROUND CONTROL SOLUTIONS
DSI UNDERGROUND SYSTEMS INC.
www.dsi-tunneling.com

hw hoelscher dewatering
· dewatering
· groundwater control
· water treatment
www.hw-dewatering.com

MICROTUNNELLING

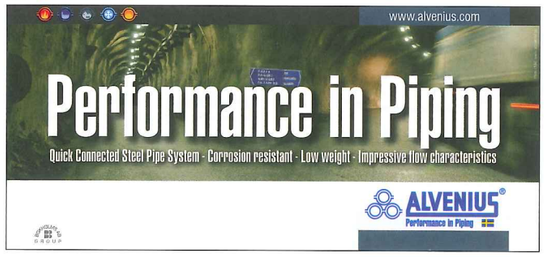
WHEN THE GOING GETS TOUGH...
...Iseki microtunnelling machines come smiling through!
Microtunnelling equipment - for hire or sale
ISEKI MICROTUNNELLING
Iseki Microtunnelling
Wellingborough UK
+44(0)1234 781166
www.isekimicro.com

MONITORING EQUIPMENT

Tunnel Atmosphere Monitoring

Carbon Monoxide
Nitric Oxide
Nitrogen Dioxide
Visibility
Air Flow & Direction
Low cost high precision tunnel sensors proven over 20 years
CODEL International Ltd
World leaders in tunnel atmosphere monitoring
+44 (0) 1629 814351
sales@codel.co.uk
www.codel.co.uk

PIPES and COUPLINGS



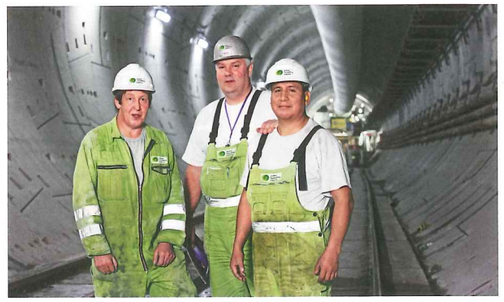
PIPES and COUPLINGS

SVEBRA
LIGHTWEIGHT PIPING
Quick Coupling Pipes And Fittings
Strandvägen 25 | 686 30 Sunne, Sweden | T: + 46 565 689410 | F: + 46 565 711215
www.svebra.se

RAIL and ROLLING STOCK

Clayton
World Leading Locomotives & Haulage Solutions...
...for Mining, Tunnelling & Surface Transport
Clayton Equipment Ltd
www.claytonequipment.co.uk
Tel: +44 (0) 870 112 9191

Maschinen und Stahlbau **MSD** Dresden Branch of Herrenknecht AG
For whatever reason you're tunnelling MSD - your reliable partner for special tunnelling equipment.
www.msd-dresden.de



What's on

2013

ISARC/WMC 2013
11-15 August 2013
Montreal, Quebec, Canada
The 30th International Symposium on Automation and Robotics in Construction, Minig & Petroleum Industries (ISARC) is being held in conjuction with the 23rd World Mining Congress (WMC). Both conferences will sponsor a joint trade show.
www.isarc2013.org
www.wmc-expo2013.org

18th ICSMGE
2-6 September 2013
Paris, France
The 18th International Conference on Soil Mechanics and Geotechnical Engineering (ICSMGE) will have a new format with the first two days devoted to plenary sessions and the following days devoted to discussion of papers and workshops from the committees.
www.issmge2013.org

The 15th International Symposium on Aerodynamics, Ventilation & Fire in Tunnels
18-20 September 2013
Barcelona, Spain
The Symposium, celebrating its 40th year, is focused towards knowledge transfer on aerodynamics, ventilation and fire in tunnels.
www.bhrconferences.com

Bauma Africa
18-21 September 2013
Johannesburgh, Africa
The massive construction show holds its first event in the African continent, focusing on all sectors and facets of the construction industry.
www.bauma-africa.com

SITCE 2013
7-10 October 2013
Singapore
The inaugural SITCE is a platform for urban land transport professionals worldwide to meet and discuss ways to shift the transport focus to people. The biennial SITCE is one of the first initiatives by the UITP Centre for Transport Excellence for the Asia-Pacific region.
www.sitce.org

ExpoTunnel
17-19 October 2013
Bologna, Italy
The newly-established exhibition will also host the Italian Tunnelling Society congress entitled "Tunnelling and Underground Space for European Development."
www.expotunnel.it

Stuva Conference
27-29 November 2013
Stuttgart, Germany
The bi-annual conferency of the Stuva organisation heads to Stuttgart.

2014

CONEXPO
4-8 March 2014
Las Vegas, USA
Held every three years, the exposition showcases the latest construction equipment, products, services and technologies. The show will be held at the Las Vegas convention centre.
www.conexpoconagg.com

Eurasia Rail
6-8 March 2014
Istanbul, Turkey
The 4th International Rolling Stock, Infrastructure and Logistics Expo features a tunnel construction section. By 2023, Turkey's Ministry of Transport is planning to build more than 11,00 km of rail track. International pavilions are on show from Poland, France, Germany, Russian Federation, Czech Republic, the United Kingdom and Republic of China.
www.eurasiarail.eu

ISTSS
12-14 March 2014
Marseille, France
The 6th International Symposium on Tunnel Safety and Security will discuss current practice and emerging trends and research in the field of tunnel safety and security.
www.istss.se

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

World Tunnel Congress
9-15 May 2014
Iguassu Falls, Brazil
The show includes WTC and the 40th ITA General Assembley.
www.wtc2014.com.br

IAEG XII Congress
15-19 September 2014
Turin, Italy
The International Association for Engineering Geology and the Environment celebrates its 50th anniversary at this conference, which offers a series of topics and sessions on four main themes: environment, processes, issues and approaches. With case studies for engineering geology forming a particular highlight.
www.*aeg2014.com*

British Tunnelling Society

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

Thames Tideway Tunnels
19 September 2013
After more than two years of public consultation on Thames Water's proposals, the development consent application was submitted to the Planning Inspectorate on 28 February. The presentation will include background on the sewage problems and the proposed solution; an update on the project development and design for tender; progress on the development consent application; an outline of the technical challenges faced; the proposed delivery route for the construction; and the latest situation on procurement.

London Underground turns 150
23 October 2013
A special presentation in honour of the 150th anniversary of LU operations.

National grid cable tunnels
21 November 2013
A report on the project, which comprises 33km of 3m and 4m diameter tunnels across London. John Trounson, National Grid Stephen Meadowcroft, Costain.

Contact us

Jon Young

Editorial

Editor
Jon Young
Tel: +44 20 7406 6622
jyoung@tunnelsonline.info

Alex Conacher

Deputy Editor
Alex Conacher
Tel: +44 20 7406 6616
aconacher@tunnelsonline.info

Americas Editor
Nicole Robinson
Tel: +1 612 940 2780
nrobinson@tunnelsonline.info

Nicole Robinson

Regular Contributors
Maurice Jones, Adrian Greenman, Bernadette Ballantyne, Partick Reynolds, Rhian Owen

Production

Jim Moore

Design/Editorial Production
David Cooper

Production Controller
Loraine Lee
Tel: +44 20 8269 7799
Fax: +44 20 8269 7840
llee@progressivemediagroup.com

Technical Illustrator
Nick Stenning

Sales

Head of Sales
Jim Moore
Tel: +44 20 7406 6584
jmoore@tunnelsonline.info

European Sales
Randolf Krings
Tel: +49 611 5324 416
Fax: +49 611 5324 519
t&t@emcmedia.de

Classified & Recruitment
Tom Willard
Tel: +44 20 7406 6599
twillard@tunnelsonline.info

Head Office

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

Tel: +44 20 7406 6622
Fax: +44 20 7936 6813

www.tunnelsonline.info
editor@tunnelsonline.info

Subscriptions & Reprints

Subscription prices for 12 (24) months:
Mailed anywhere in Europe €262.50 (€459), USA & Canada $258 ($258), UK £110 (£188), Rest of the world $316 ($553).
Send subscription and back issue queries to *Tunnels* Customer Services:
cs@progressivemediagroup.com

Tel: +44 (0) 845 073 9607 (local rate)
Fax: +44 (0) 208 269 7277
subscriptions@progressivemediagroup.com
Tunnels Subscriptions,
World Market Intelligence,
Progressive House, 2 Maidstone Road,
Foots Cray, Sidcup, DA14 5HZ.
Subscribe online at *www.buythatmag.com*

Tunnels is printed at Stephens & George Print Group, Merthyr Tydfil.