APRIL 2011

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As the waters recede

The awesome power unleashed upon the east coast of Japan last month is a stark reminder of the challenge engineers face trying to tame 'mother nature'. Even the most sophisticated warning systems and robust construction could not save the lives of the tens of thousands that perished in the earthquake and resulting tsunami on 11 and 12 March.

Earthquakes are a way of life in Japan. Major earthquakes occur every couple of weeks and minor tremors can be detected daily. But as Professor Osamu Kiyomiya of Waseda University, Tokyo writes on page 12, the 9.0 magnitude earthquake went beyond seismologists' forecasts and past anything engineers had prepared for.

The statistics rolling out of universities and research laboratories observing this quake all over the world have made clear the power that mega earthquakes unleash and the challenge engineers have to overcome. The 11 March quake is the fourth largest recorded since 1900 and was caused when the Pacific tectonic plate dived under the North American plate, shifting eastern Japan towards North America by about 4m. The quake also shifted the earth's axis by some 150mm, shortened the day by 1.6 microseconds, and sank Japan downward by about 1m. As Japan's eastern coastline sunk, the tsunami's waves rolled in. The 10m waves breached sea walls up and down the coastline.

The damage to underground infrastructure is not yet known. But it will be there. Earthquakes occur many kilometres below the surface but it is in the last tens of metres that they are at their most destructive. As the shock waves pass from the hard rock into weaker ground they are amplified. Cut and cover tunnels and utility infrastructure near the surface will be the worst affected. In his comment article Prof Kiyomiya details the damage caused to underground infrastructure from previous earthquakes of a lower magnitude. This list is an indicator or what might be waiting for engineers when they begin to assess the damage.

Despite the obvious devastation and the lack of preparedness for an earthquake of this magnitude, Japan is still a success story. The early warning systems gave people a few extra seconds to react before the deadly shock waves shook the county. Many of the buildings behaved exactly as they should, swaying from side to side. It is standard in Japan to construct buildings for horizontal loading as well as vertical loading. The tsunami warning system gave coastal towns and cities nearly 20 minutes to evacuate. There is no telling how great the death toll may have been if those measures had not been in place.

The recovery will be slow. As the wreckage clears, the task of rebuilding will begin. Japan is a wealthy country and will rebuild its towns and cities to better withstand earthquakes and tsunamis. They are less reliant on foreign assistance than some of the other countries lying in seismically active regions. The charity RedR usually sends response teams to regions hit by natural disasters to help with the immediate rescue, short-term shelters and then the eventual rebuild. RedR has not had to do so for Japan. But the next disaster may not hit a developed country like Japan, and RedR may be called upon, and so *T&TI* has become a supporter of RedR and has pledged 10 per cent of future revenue from every individual subscription to the charity.

Jon Young

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On the cover:

T&TI visits Brighton pipejack project for the Sussex sewer upgrade

In the supplement

Breakthrough at Niagara for 14.4m 'Big Becky'.

Gotthard excavation is finished

ITALY

Excavation of the Gotthard Base Tunnel was completed earlier last month.

Five months on from the final breakthrough of the eastern drive, workers finished excavating the last metres of the west tube between Faido and Sedrun.

Breakthrough into the Sedrun section on 23 March by the Faido-launched TBM marked the end of excavations on the world's longest transport tunnel, a continuous bore of over 57km.

Construction on this section of Gotthard began in 2001 in the south at Bodio. Preparatory work began in 1996, which included access tunnels and two 800m-deep shafts at Sedrun.

Contractor AlpTransit said that 56 per cent of the overall project was excavated by TBM, with the remaining 44 per cent by drill-and-blast. The full network totalled 152km of excavation.

"With the end of excavation under the Gotthard, a further important milestone has been reached in the construction of the world's longest railway tunnel," said Renzo Simoni, CEO of AlpTransit Gotthard.

AlpTransit said that it would present the tunnel in operating condition to Swiss Federal Railways in May 2016 following tunnel lining operations and systems installation.

Funding boost for HCM MRT

VIETNAM

The Asian Development Bank (ADB) and Government of Vietnam signed a USD 540M loan deal this week to fund construction of the MRT Line 2 in Ho Chi Minh City.

The 11.3km MRT Line 2 will run along 9.3km of tunnels and 2km of elevated track stretching from Ben Thanh in the centre to Tham Luong, out past Tan Son Nhat International Airport.

Ayumi Konshi, ADB directory for Vietnam said, "The project will have clear indirect poverty reduction impacts and will not only significantly reduce traffic congestion and accidents but also substantially reduce greenhouse gas emissions, making Vietnam one of the leading countries in the region to address climate change mitigation through low carbon transport modes."

Readying for Sochi

RUSSIA

SK Most subsidiary OJSC Bamtonnelstroy completed a 4.5km stretch of tunnel on the Sochi project this month. The project was part of the infrastructure vision for the Sochi 2014 Winter Olympics.

The 6.2m Robbins Double Shield TBM encountered difficult ground, advancing with average rates of 100-120m per week.

The 6.2m TBM achieved high rates despite difficult conditions. The alignments ran through mixed ground including massive to completely fractured limestone with clay seams. Some sedimentary rock including sandstone and siltstone was encountered, along with fault zones consisting of breccias and conglomerates.

"In May 2010, the machine was stopped after encountering a significant fault zone consisting of broken rock and running soft ground," said Robbins.

"Field service personnel and crew successfully freed the machine by excavating a bypass tunnel around the TBM, freeing the cutterhead. Following the restart, a combination of continuous probe drilling and ground treatment with cement silicate and foam kept the machine moving forward."

A 10m TBM was still excavating the parallel 4.6km main railway tunnel, 762m into the drive as *T&TI* went to press, and a 13.2m diameter road tunnel was also under construction. A continuous conveyor system was used on the main tunnel for efficient muck removal.

Over 20 road and rail tunnels stretching for 40km are under construction for the Sochi Games. Project owner DCRC-Sochi, a subsidiary of Russian Railways, hopes to complete all rail and road infrastructure by June 2013.

News in brief

Breakthrough at Niagara
The 14.4m diameter hard rock TBM mining Canada's Niagara Tunnel completed an initial breakthrough on 1 March. The Robbins main beam machine entered a pre-existing grout tunnel excavated using drill and blast. The TBM will continue boring another 300m up to the intake structure and make a final breakthrough in mid-April.

Tunnel widening recommended for I-70
The Colorado Department of Transportation (CDOT) recommended widening the eastbound bore of the I-70 Twin Tunnels to the Colorado Transportation Commission. This expansion would allow for a third lane beginning at the east Idaho Springs Interchange to the base of Floyd Hill.

David threatened by rail tunnel

ITALY

An architect pronounced as an expert in underground construction, Fernando de Simone of Parma, has called for a new underground home to be constructed for Michelangelo's statue of David, to avoid claimed likely damaged from new rail tunnel construction work in Florence due to start this summer.

The fact that the statue is in a perilous state has been known for a long time. The picture here shows a scanning image produced in 2008 to illustrate areas of high likely stress in the statue, confirming weak spots, especially in the 'tree trunk' supporting the right leg of David. The statue already has many tiny cracks in its marble structure allegedly due to both the low quality of the original marble used by Michelangelo and the footsteps of the many visitors.

The image is part of work on Scan and Solve computer software developed by Vadim Shapiro of the University of Wisconsin-Madison and Igor Tsukanov of Florida International University's Spatial Automation Laboratory for the US National Science Foundation.

The tunnelling work in question consists of a tunnel approximately 6.4km long, and a new underground station in Florence at Firenze Santa Maria Novella allowing the existing station to become a through link instead of a head-stop, with high-speed routes to Rome and Milan. The new station and tunnel will go under the existing station and will house a new link between the new Bologna-Florence high-speed line and the existing Florence-Rome Direttissima line. The planned tunnel alignment was about 600m from the statue of David at its home in the Accademia Gallery.

It has not been reported how much damage moving the statue might cause. One art critic, Vittorio Sgarbi, has called for the tunnel excavation to be halted saying, "Our heritage should come before anything else," as reported in the *London Daily Telegraph*.

Blogger David King of New York *(on Getting from here to there)* commented, "There are many more places to put David than there are to put trains that connect to the station."

What do you think? Should infrastructure construction be stopped by items of heritage? Is the claimed vibration damage due to tunnelling possible? What are the alternatives? Contact the news editor: Alex.Conacher@tunnelsandtunnelling.com.

FCC wins Bucharest metro

ROMANIA

FCC has been awarded a EUR 267M (USD 370.65) contract to construct section one of the Bucharest Metro Line 5 in Bucharest, Romania. It was awarded the contract as a JV comprising Astaldi, as well as local companies AB Construct and ACM Delta.

Romania's national metro company Metrorex awarded the contract, which included two parallel 5.7m diameter tunnels 4.85km in length and a third 260m tunnel connecting lines one and five.

The European Investment Bank and the Romanian Government have agreed to fund the project. Work has been scheduled to begin in the second half of 2011.

Other bidders for the project included a Turkish-Russian-Italian consortium of Dogus, Gulermak, Moskovsky Metrostroy and Salini and an Austrian-Romanian JV of Strabag and Straco.

FCC already employed over 500 people in Romania at the time of the award on projects including the Bucharest north bypass.

SKB nuclear permit request

SWEDEN

Swedish Nuclear Fuel and Waste Management Company (SKB) submitted a construction permit application to Swedish authorities this month for a final disposal facility for nuclear waste.

The request was to build an encapsulation facility at Oskarshamn in southern Sweden and an underground repository at Osthammar, some 450km to the north. Waste would be transported to the latter by sea once encapsulation is completed.

Posiva said, "The application is based on 30 years of research and development on the final disposal of spent nuclear fuel in metal canisters deep in the bedrock (the KBS-3 method). Posiva has adopted the same final disposal solution and cooperates closely with SKB in various areas of final disposal technology."

More information on this will be available at WTC Helsinki and in chapter eight of the Finnish Tunnelling Association's upcoming book: Rock - sound of countless opportunities, released at same.

News in brief

Seattle anti-tunnel group short on signatures
A group calling itself SCAT (Seattle Citizens Against the Tunnel) has failed to secure enough signatures to qualify for the ballot its Initiative 101 opposing the tunnel replacement for the Alaskan Way Viaduct. SCAT will have 20 days after the final report is issued in late March to collect enough valid signatures to qualify for the ballot.

Queens TBMs launched for East Side Access
A ceremony was held 18 March dedicating the slurry TBMs constructing four tunnels for a total of 3.2km in Queens, for the East Side Access. Herrenknecht supplied the machines to the Granite/Traylor/Frontier JV building this section of the East Side Access project.

Breakthrough set for A Luoi tunnel

VIETNAM

Vietnamese construction firm Cavico announced that it will have completed excavation work on the A Luoi hydropower project headrace tunnel in the second week of April.

Cavico was awarded the contract for underground works and an access road in 2007. Cavico excavated using NATM and blasting on the 6.5m, 11.7-km headrace tunnel and secondary tunnels.

Cavico worked on the project on the A Sap River, Thua Thien Hye Province for client Central Hydropower Joint Stock Company.

"We are pleased to prepare for the final breakthrough on the A Luoi Hydropower project," said Hung Manh Tran, executive vice president of Cavico. "Our efficient, highly skilled team is working diligently to excavate the final meters of this complex project."

When finished the plant will have a 170MW capacity.

Above: Excavation on the A Luoi hydropower project will completed in April

Song Giang holes through

VIETNAM

Cavico announced this month that it had broken through to adit sub-tunnel number two, and so completed excavation of a 138ft (42m) high surge shaft for the USD 50M Song Giang 2 Hydropower project.

Cavico had excavated 4367 feet (1331.1m) of 8ft (2.44m) tunnels for the project as T&TI went to press. The Vietnamese engineering, design and construction firm was awarded the contract to excavate the surge shaft, two sub-tunnels and headrace tunnel in January 2009. Excavation distance totalled 2.8 miles (4.51km).

"This breakthrough represents months of dedicated work on the Song Giang 2 project and is a very important milestone for Cavico," said Hung Manh Tran, executive vice president of Cavico.

"This marks Cavico's fifth tunnel breakthrough in the past three months, and we are excited by the strong progress our teams are making at Song Giang 2."

Located on the Song Giang River near Nha Trang City, Khanh Hoa Province, Vietnam, the plant will provide 141MKWh annually to address the electricity shortage in the country.

Cavico expected the plant to generate USD 10M in revenue.

Lyon Metro wraps up

FRANCE

The TBM excavating the Lyon metro Line B extension broke through into the future site of Oullins Station early this month. This milestone ended the 1.4km Gerland to Oullins run, of which 972m were bored by the TBM.

French contracting JV Sytral engineered the excavation of 70,000m3 of material and the laying of 536 segmented rings. The Rhone-traversing drive took five months to complete.

The tunnel began a three-week shutdown following breakthrough for technicians to check its condition and move it across the station. When this has been completed, the TBM will excavate the remaining 300 meters to Orsel Street over approximately 10 weeks where it will then be dismantled.

"This is a milestone and a highlight for the teams who have worked on the project and will carry on with it until completion," said Sytral.

News in brief

Promotion at Indal WRTL
i-TunneL promoted Steve Ebbrell to operations manager, responsible for all tunnel activity with in the UK for Indal WRTL.

Prague metro TBMs named by local children
Patients of the Paediatric Surgery in the Motol Faculty Hospital, Prague have named the two TBMs tasked with excavating Line A of the Prague metro. The children named the 6m EPBMs Tonda and Adela in the presence of Mayor Bohuslav Svoboda.

Crossrail station style on show

GREAT BRITAIN

A full-scale mock-up of a Crossrail underground station was revealed to invitees at the Leighton Buzzard Technology Centre of Vinci Construction UK this month.

Constructed within a tubular wooden form, the 'station' will help inform on final design decisions for the new route's station platforms, says Crossrail, including materials, CCTV camera positions, signage, passenger movements, lighting, acoustics and general aesthetics. It will help decisions about whether any design modifications need to be made before main construction of the stations begins.

The mock-up's interior dimensions are 20m in length, 10m in width, and a ceiling height 5m above the platform-edge doors. The layout includes part of one platform and a cross-passage as an entrance and egress measuring four metres. Mirrors at each edge of the mock-up give the visual impression a full platform length.

Where appropriate actual finishes have been replicated without the expense of using traditional materials by using film-set design techniques, says Crossrail. A sprayed concrete lining is portrayed using sprayed expanded foam on wallpaper. Crossrail area director general William (Bill) Tucker explained to *T&TI* that a choice of two real concrete flooring materials have been used, and will be tested at Victoria Station before a decision is made. Station design implementation is the responsibility of Julian Robinson, Crossrail head of stations.

Further trials of platform surface materials will be undertaken at Victoria London Underground station later this year. The stations are being designed to last for the next century, says Crossrail.

One decision that has already been changed as a result of the mock-up is to place 'next train' information displays above the platform edge doors rather than in conventional signs hanging over the 250m-long platform. The platform length will accommodate future trains 240m long as well as current plans for 200m-long trains.

Above: Bill Tucker (left) and Julian Robinson inspect the mock-up

New underground stations for Crossrail are due to be built along the central section of the route at Paddington, Bond Street, Tottenham Court Road, Farringdon (adjacent to the *T&TI* editorial offices), Liverpool Street, Whitechapel and Canary Wharf.

Of particular importance in the design trials is the improvement of access and services for passengers with restricted mobility, or those with visual or hearing impediments.

Once the station design and testing work has been completed, Crossrail hoped to retain a section of the mock-up for public display in London so that Londoners would be able to experience something of what travelling on Crossrail will be like.

News in brief

Blanka bill explained

Prague City Hall published a list of extra costs for the Blanka tunnel last month. Estimates increased by USD 513.7M, including USD 86.6M associated with extraordinary events and measures ordered by the State Mining Administration. A spokesman could not comment on other costs due to having 'no information about the prices of construction items'.

LRT tunnel could ease Edmonton traffic

A city report last month proposed a USD 305M Light Rail Transit (LRT) tunnel to ease traffic flow on a major arterial road in Edmonton, Canada.

XRL river tunnel completes

Left: One of the four NFM Technologies TBMs used

GREAT BRITAIN

Construction of China's first underwater railway tunnel was completed last month in south China. The tunnel, part of the high-speed rail link between Hong Kong and Guangzhou, will allow trains to pass the Pearl River estuary faster than any other underwater crossing.

The Shiziyang Tunnel crosses the Pearl River estuary in south China's Guangdong Province with a length of 10.8 kilometers. It is designed for trains travelling at 350km per hour. Construction started on the tunnel in November 2007 and was driven by four NFM Technologies TBMs at depths of up to 60m.

The 10.8-kilometer tunnel is a key part of a 142-kilometer high-speed rail link that connects Guangzhou, the capital of China's southern economic powerhouse Guangdong, with the city of Shenzhen and then on to Hong Kong. The Express Rail Link or XRL is divided into two sections, the Guangshen section with four to six stations, and the Hong Kong section, with one station. Service was due to commence in 2010, but is now scheduled to begin in 2011 while construction of the Hong Kong section is expected to begin in 2010. Service on the Hong Kong section is scheduled to open in 2016.

Aurecon merges with Hong Kong consultancy firm

HONG KONG

Aurecon announced this week that it has merged with Hong Kong independent engineering consultancy firm Daniel Chan and Associates.

Aurecon said the merger will enhance its capacity to service large infrastructure projects in the region, and that it added a range of design and engineering expertise.

"This merger is part of Aurecon's strategy to develop across all aspects of building design. We see great opportunity in Asia, servicing clients in-country and in supporting overseas initiatives in Africa, Australia and New Zealand," said Charlie Miller, Aurecon general manager for Asia.

Daniel Chan, managing director of Daniel Chan and Associates said, "Our expertise in sustainable design is highly respected in Hong Kong and China and we look forward to sharing this with Aurecon's client base. We have a dedicated team of LEED AP and BEAM Pro Accredited Professionals with extensive experience in sustainable design."

Herrenknecht receives honour

GERMANY

Martin Herrenknecht was appointed as an honorary senator of the Karlsruhe Institute of Technology (KIT) this month. In the ceremony, Herrenknecht was presented the award by Eberhard Umbach and Horst Hippler of KIT for his past work on the development of tunnelling technology and general support of engineering.

"In his capacity as an engineer, Dr. Martin Herrenknecht has made a decisive contribution toward the development of tunnelling technology with his company playing a leading international role in this area," said Hippler.

This was the Herrenknecht CEO's second honour from KIT. He was awarded the 1st Karlsruhe Innovation Award for Construction Endeavours in 2002.

Above: Left to right: Herrenknecht and Hippler

The KIT was founded in 2009 as an amalgamation of the University of Karlsruhe (TH) and the Karlsruhe Research Center. Dr. Martin Herrenknecht was the first person to be appointed as a senator since the union. Herrenknecht said it has supported KIT for many years.

Keith Meeks joins Mosen

GREAT BRITAIN

Tunnel safety and fire engineering company Mosen has appointed Keith Meeks as technical director.

With the appointment of Meeks, Mosen said it had added to its specialist knowledge in fire life safety, tunnel ventilation design, high-speed rail aerodynamics and tunnel ventilation computer modelling.

Fathi Tarada, managing director of Mosen, said, "Keith's appointment is a milestone to Mosen's development as an internationally renowned consultancy in tunnel safety and fire engineering. Our clients will appreciate the depth of his expertise and his commitment to project delivery.

"His skills and expertise have been employed on major projects from Sydney Harbour Tunnel in Australia to Copenhagen Metro in Denmark and from Attiko Metro in Greece to Holmesdale, Bell Common and Hatfield Tunnels UK," said Mosen. "He was a past presenter on the British Tunnelling Society course covering tunnel ventilation and life safety systems."

Meeks has 30 years experience as a charteredengineer.

News in brief

Invitation to tender for health and safety consultancy
Deadline 21 April for health and safety consultancy services in the 2,700m Rive Gauche du Paillon tunnel and 430m Malraux tunnel at Nice, France. Contact: Communaute urbaine Nice Cote d'Azur, tel: +33 489981000, fax +33 489981033, e-mail: dao@nicecotedazur.org

Invitation to tender for Swiss projects
Tender for projects in Switzerland for construction and equipment engineering services for the section between Sciaffusa Sud and Herblingen interchanges on N04/06, including Fasenstaub II and Schonenberg tunnels and for the safety tunnel for Fasenstaub I tunnel. Contract duration 1 July 2011 – 31 December 2014. Deadline 22 April. Contact ASTRA, Winterthur, bid N04/06 SH Sud - Herblingen, AP EES, Winterthur, tel +41 522344711, e-mail: winterthur@astra.admin.ch

Tender for Norway electrical installations...
Open invitation to tender for upgrading of electrical installations in Fv37 Tinnsjo tunnels Jonjiljo (760 m) and Prestura (1,370m) in Norway. Contract includes supply and installation of impulse ventilators, lights, ventilation and safety, traffic control and monitoring, and radio. Register interest at www.doffin.no. Deadline 13 May. Further information, specs and docs from Jolanta Kroczak at Statens vegvesen Region south in Arendal, tel +47 90542558, e-mail jolank@vegvesen.no to whom tenders or requests to participate must be sent.

...and assorted systems
Tenders are also invited for delivery and installation of the managing, regulating and monitoring systems for the upgraded Tinnsjo installations. Access details as above.

Strabag enters big three

SWITZERLAND

Strabag has acquired Brunner Erben and Astrada, doubling its annual revenue in Switzerland to around EUR 615M (USD 862.7M). With the move it became the third largest construction company in the country.

All involved parties agreed not to release the terms and conditions of the acquisition, in which Strabag has taken ownership of all Brunner Erben and Astrada employees and brands.

"These acquisitions illustrate our strong commitment to the Swiss market and our determination to be a leading player in each of our key countries," said Hans Peter Haselsteiner, CEO of Strabag.

Above: Hans Peter Haselsteiner, CEO of Strabag

"Through these acquisitions, we will nearly double our output volume in Switzerland and are enhancing our presence in Zurich and Bern, two very important regional markets. We are determined to continue to expand our market presence from this level in order to operate nationally across all of Switzerland."

Approval from the Swiss Competition Commission was still pending as *T&TI* went to press.

Valemus Australia sold to Lend Lease

AUSTRALIA

The sale of a 100 per cent stake of Valemus Australia. Bilfinger Berger subsidiary Valemus Australia to Australian construction group and parent company of Abigroup, Baulderstone and Conneq: Lend Lease, was finalised last month. The agreement to transfer all Valemus shares to Lend Lease was signed in at the end of 2010 (reported in *T&TI* February p.13).

The sale price was around AUD 1.07bn (USD 1.08bn). Bilfinger Berger said it resulted in a net profit of approximately AUD 970M (USD 974.6M).

Steve McCann, CEO and managing director of Lend Lease said, "It presents the opportunity for Lend Lease to take a leading position in the engineering and construction market at an attractive price."

Bilfinger Berger said, "With the sale of Valemus Australia, we have completed a major step in the re-dimensioning of its construction business."

The firm added, "The net cash inflow from the sale together with existing leverage potential give the Group considerable financial scope to invest in the further expansion of its services activities."

Lend Lease has acquired a secured future revenue of AUD 5bn (USD 4.96bn) and over 150 standing contracts.

Arup opens Adelaide office

AUSTRALIA

Arup opened a new office in Adelaide last month. The engineering firm said the office was a response to continued infrastructure growth in South Australia.

"South Australia is currently experiencing a boom in infrastructure investment with a record total of AUD 80bn (USD 79.06bn) worth of major developments occurring or planned for the State," said Patrick Conlon, minister for infrastructure and transport, who attended the opening function.

"Investment spending by South Australia's private sector is at an all time high, according to the latest ABS statistics – growth in South Australia's private new capital expenditure over 2010 was 17.9 per cent, the highest in the country and more than three times the national figure".

John Haese, Arup's Adelaide office leader said, "It's an important time for all of us, as the Government and industry looks to revitalise rail and transport networks and implement the 30 year plan including increased focus on transit oriented developments."

News in brief

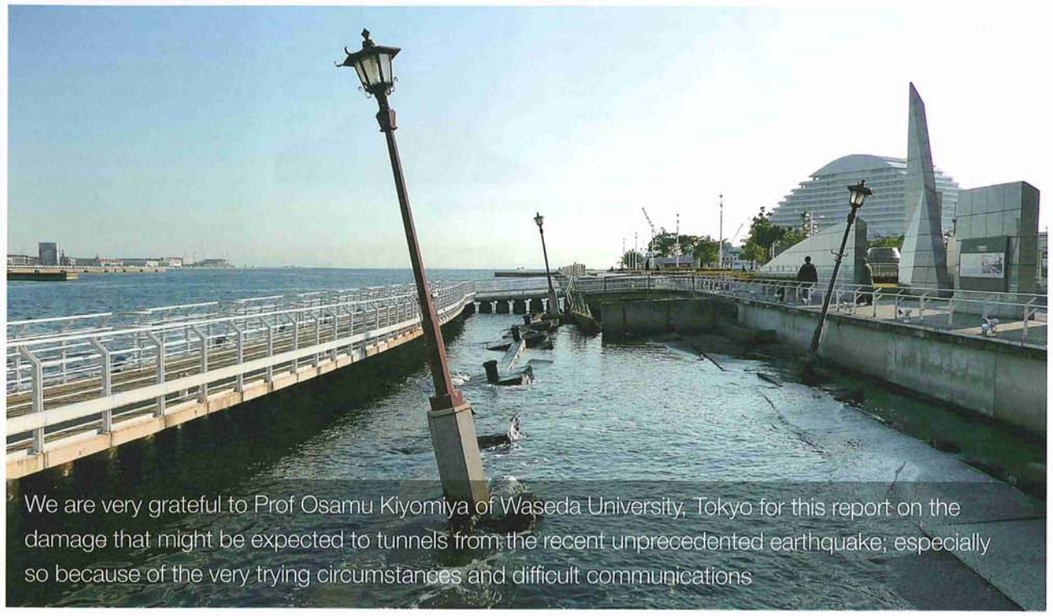
Albania road tunnel contract award
Greek firm Aktor was awarded a EUR 58.6M (USD 82.9M) contract for the single-tube, 2-3km long Tirana-Elbasan tunnel in Albania. Construction will begin in April lasting 18 months. The tunnel was for European Transport Corridor VIII. Tel +30 210 81840-00, e-mail info@aktor.gr. For more details contact Jeta Rustemi, Ministry of Public Works and Transport, tel +355 42 380 833, e-mail jeta.rustemi@mpptt.gov.al

Open invitation to tender for Bosnian hydropower
Tender for construction of additional spillway in open air and tunnel for control of flood discharges in the storage of Bocac HEPP, and establishment of facilities technical monitoring system. Financed partly by EIB loan, value EUR 103M (USD 145.7M). Contract duration 18 months. Deadline for tender 27 May. Further information from Milan Bejat at ERS. Tel: +387 51343-924, e-mail: mbejat@ers.ba

Polish canal tunnel contract award
Award of contract, value EUR 4.45M to Wuprinz for construction of canal tunnel and associated works. Contact +48 616565770, fax +48 618425686, e-mail tp@wuprinz.pl. Further project information from Maciej Pospieszny at PK in Wronki, tel +48 67254-5655, fax -0645, e-mail m.pospieszny@pk-wronki.pl

Invitation to tender for inspection services
Tender for architectural, construction, engineering and inspection services of Oberau dual-tube tunnel project. The 2.9 km tunnel will be NATM-driven in soft ground and rock on B2 road. Contract duration 55 months. Deadline 12 April. For more details, tel: +49 8954552-444, e-mail: vergabe@abdsb.bayern.de

Earthquake and tsunami damage to tunnels in Japan



We are very grateful to Prof Osamu Kiyomiya of Waseda University, Tokyo for this report on the damage that might be expected to tunnels from the recent unprecedented earthquake; especially so because of the very trying circumstances and difficult communications

Since tunnels are surrounded by stable ground, their acceleration and displacement during seismic activity are smaller than those of other structures such as buildings and bridges. Seismic design for tunnels was not carried out before a two decades ago.

Kanto earthquake (Mg. 7.9 1923)

The Kanto earthquake caused severe damage to tunnels. Some 93 railway tunnels that were located within a 120-km radius of the epicentre had severe damage. Some 25 tunnels required complete reconstruction.

Izu-Ohshima-Kinkai (Mg. 7.0, 1978)

This also resulted in large damage to mountain tunnels. These tunnels are crossed by active faults, and damage to the tunnels was caused by ground movement. At Izu-Ohshima Kinkai the maximum displacement gap was 1.2m. To deal with ground movements, the tunnel lining was removed and the bore was re-excavated to maintain the constructed dimensions and gauge.

Damage of the tunnels due to earthquakes were reported in past, but these damages were considered to be unusual cases, therefore seismic design and countermeasures were ignored.

Hyougoken-nanbu (Mg. 7.2, 1995)

Hyougoken-nanbu (Kobe or Great Hanshin) earthquake also caused severe damage to mountain tunnels and metro tunnels in the city. Centre columns of the metro tunnel collapsed, resulting in the failure of the ceiling slab and 2.5m of ground settlement above the tunnel. Many diagonal cracks were also observed on the walls in the transverse direction. Damage was judged, from the damage pattern, to be caused by the shearing force of the earthquake. This was first case of damage to a reinforced-concrete box-type tunnel.

A new design method was applied to tunnels constructed after this earthquake. Now two levels of earthquake are defined, namely:

- Level 1 earthquake movement, determined for an earthquake on a 1-in-75-year period; and,
- Level 2 earthquake movement, determined for an active fault predicted for a future earthquake in a period of once every 500-1000 years.

Potential damage for the two level earthquake movements is calculated by non-linear numerical analysis. In the conventional method, allowable stress and inertia forces were used. New-build tunnels are designed by this concept, and many existing tunnels have been reinforced to cope with insufficient strength using various methods such as steel-plate cladding, steel bar insertion and so on.

Nigataken-chuetsu earthquake (Mg. 6.8, 2004)

Nigataken-chuetsu earthquake caused a running Shinkansen train (Bullet Train) to derail and some mountain tunnels to sustain severe damage. Some 24 railway tunnels were seriously damaged and five tunnels required lining repair and reinforcement. The heavily damaged tunnels were concentrated in an area within a 10km radius from the epicentre. Concrete linings broke and fell onto the track. The damaged locations were restored through rock bolting, sprayed concrete and reinforcement using precast segments after old concrete removal by breakers. The repair work took two months to complete. An investigation was carried out to discover the cause of the collapse of the concrete lining. Beside very strong earthquake motion there were two causes for the collapse. The first was the ambient ground was Neogene mudstone and therefore relatively soft. The second cause was a void that was observed at back of the lining construction work.

Causes of tunnel damage during an earthquake are summarised as follows:

1. Poor geological conditions,
2. Shallow tunnel,
3. Sliding of an earthquake fault crossing the tunnel aligment,
4. Structural defects in the tunnel lining,
5. Poor shear capacity of the concrete structural elements.

11 March 2011

Off the Pacific coast of Tohoku, an earthquake was detected on 11 March on an extremely large scale. Its Mg was 9.0 and maximum acceleration on the ground was about 3000Gal. The duration was over two minutes. This earthquake generated a huge tsunami with waves around 20m high (values are tentative). Details of damage to tunnels are not yet available, but many tunnels will be found to be destroyed in future investigation. We will report the damage of the tunnels as soon as possible to the world.

Water invasion from a tunnel entrance creates a serious hazard for people who stay in underground structures and below-surface accommodation. Where ground level is lower than sea level, risk of flood and water invasion is potentially very high, but on the other hand, tsunamis also rush far inland and to the higher ground. Fortunately water invasion to tunnels due to the tsunami has not yet been reported. However many bored and immersed tunnels have been constructed along the coastline, especially in or near cities.

Counter measures are adopted for tsunami waves. These counter measures are the same as for flood by storm surge. Entrances to subway stations are protected by waterstop barriers. Waterstop gates and waterproof walls are also installed around station entrances. These countermeasures can also be applied to tunnel portals and ventilation ducts. Once water suddenly starts flowing in, even with a water depth of 200mm, the doors become held fast by water pressure, making it impossible to escape and impossible to climb the tunnel stairs. When a long tunnel crosses under a river, the water-gate is installed further inside the tunnel. However, this style is a special case.

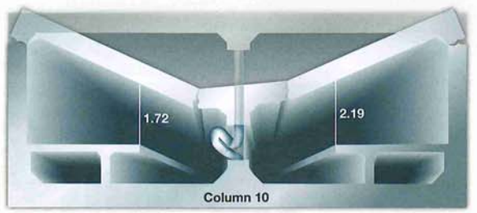
In Japan, the flood-protection banks, breakwaters and the water-gates have been arranged where tsunamis are predicted to strike according to historical records and numerical simulations. Various countermeasures, including evacuation routes, alarm systems, hazard maps and evacuation towers have been prepared. However, the tsunami on 12 March 2011 attacked the shoreline with waves in excess of 20m, dealing enormous damage.

Even though various countermeasures were arranged for tsunamis, the damage was past imagination, and beyond engineering judgment. Seismologists never imagined such a strong earthquake. The worst possible scenario had happened. We now have to consider the possible reoccurrence of such a strong tsunami, and countermeasure to protect underground structures in the cities.

Table 1: No. of damaged tunnels by earthquakes in Japan

Name	Mg	Severe damage	Medium damage	Small damage	Comment
Kanto	7.9	25	12	56	Railway
Izu-Ohshima-Kinkai	7.0	2	4	3	Railway
Hyougoken-nanbu	7.2	12	-	18	All
Niigata-Chuetsu	6.8	11	14	24	All
Niigata-Chuetsu-oki	6.8	4	1	1	All

Below: **Outline of metro section structural collapse in Kobe earthquake**



Tsunamis

A tsunami is a large ocean wave that is usually caused by sudden motion of seabed due to an earthquake. This motion invariably occurs at a place where two geotectonic plates collide, in this case beneath the Pacific Ocean. The moving wave begins travelling out from where the earthquake has occurred (the epicenter). Water rushes landwards to flood the shoreline, lowered even more by ground movement. Japan has been hit by a lot of strong tsunamis and many lives have been lost. Tsunamis have high speeds of up to 3-8m/s and have a wave period longer than that of normal ocean waves. In the past, wave heights have been recorded at up to 20-30m.

Seismic units

This is not intended to be a comprehensive explanation of units used to measure earthquake properties, as the relationships can be mathematically complicated and require further study for those interested.

Units of total earthquake force

Local magnitude (Richter) scale of total earthquake intensity (range 0-10 Mg, Mw)

JMA (Japan Meterological Agency) Shindo scale of seismic intensity (range 0-7) depicting degree of shaking at a particular location)

Other scales (out of many) include:

Moment Magnitude Scale (total magnitude of earthquake)

Modified Mercalli Intensity Scale

European Microseismic Scale (EMS)

Units of acceleration of ground movement or PGA = Peak Ground Acceleration

Gal = Galileo unit OR Gall = cm/s2

World Tunnel Congress the Scandinavian way

With the 37th World Tunnel Congress (WTC) almost upon us, *T&TI* presents its preview to the show and explores the wider Scandinavian region, Alex Conacher interviews the presidents of the Swedish, Finnish and Norwegian tunnelling societies

Housed in the magnificent congress and concert palace Finlandia Hall, the show will run from 20 to 26 May, following the main theme: 'underground spaces in the service of a sustainable society'.

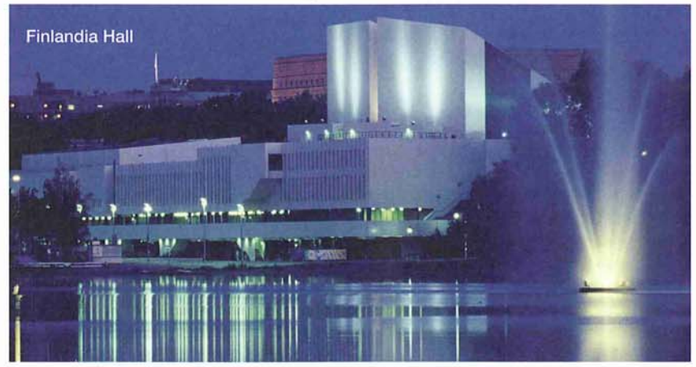
The Finnish Tunnelling Association (FTA) boasts an impressive range of presentations for the show. Not all have been confirmed as *T&TI* goes to press. The deadline for the registration fee is the end of March, but the remarkable acceptance list of 153 oral and 81 poster presentations should ensure that this WTC really has something for everyone.

Keynote speakers have been named, with mayor of Helsinki Pekka Sauri speaking on the importance of underground spaces in the urban environment, Timo Alkas of Posiva presenting on the disposal of spent nuclear fuel and Professor Hakan Stille of the Royal Institute of Technology of Finland.

The Muir-Wood lecture, held in memory of the death of Sir Alan Muir-Wood, first and honourary president of the ITA, will kick off the talks. It will be presented by Robert Mair, professor at Cambridge University, with the topic: tunnelling in urban areas and effects on infrastructure – advances in research and practice.

Besides the conference, the FTA has arranged a series of technical site visits for the more hands-on attendees. These include:

- The energy and multi-utility tunnel network of Helsinki.
- The Itakeskus underground swimming centre.
- The Viikinmaki underground wastewater treatment plant.
- West Metro Project.
- KEHU – City Service tunnel for delivery vehicles.
- Underground coal storage and district



Finlandia Hall

Underground spaces in the service of a sustainable society

List of presentation sub-themes:

- Planning the usage of subterranean spaces
- New dimensions of rock engineering/construction
- Investigation and data management
- Design and architecture
- Excavation methods and equipment
- Service and maintenance
- Municipal services
- Wastewater
- Waste processing
- Fresh water tunnels
- Energy distribution and stockpiling
- Operational technologies
- Conditions
- Equipment
- Facilities
- Safety and security
- Monitoring
- Traffic and logistics
- Rail
- Road
- Communication
- Multipurpose
- New innovations
- Geologic disposal of nuclear waste
- Concepts
- Proposals
- Projects
- Renewable energy
- Hydropower
- Geothermal power
- Project management
- Administration
- Finance
- Quality and risk management
- Environmental impact assessment
- Lifecycle management
- Contractual relationships

Above: Glycol de-icer created an ideal environment for concrete-eating microbes at the Helsinki airport link project

cooling.
- Ring Rail Line Keharata.
- Parking and service tunnels for Finlandia Hall and new Music Centre, Helsinki.
- The underground research hall of VTT Technical Research Centre of Finland.

The city of Helsinki is itself a bright spot in the Scandinavian tunnelling industry. The airport transit link currently under construction (see page 19) and the recently agreed expansion to the metro stand amongst many other projects in the Nordic region.

"Work is available and on the increase," says Pekka Sarkka, president of the Finnish Tunnelling Association (FTA). "There's good competition between the companies. The industry was not really affected by the global depression. Maybe work isn't as widespread as in an outright boom–but it isn't low at all."

Social program

Get together

Sunday 22 May, around 18:00-20:00

Venue: Hesperia-park, next to the Finlandia Hall

Complimentary to participants

Helsinki City Reception

Monday 23 May, at 19:00-

Venue: City Hall

Complimentary to participants

Reception hosted by the Lord Mayor of Helsinki.

Congress Banquet

Wednesday 25 May, at 19:00-

Fee: EUR 100 (USD 139.66)

Dresscode: Business casual

Venue: Dipoli, with return bus tranfer from Finlandia Hall

Vital information

Airport

Helsinki-Vantaa Airport is 19km from the centre of Helsinki and can be reached by car in 25 minutes. You can also take a taxi, the Finnair airport bus or Bus 615 to the Central Railway Station. A taxi to city centre costs approximately EUR 30 (USD 41.9).

Climate

Average daytime temperature for Helsinki in May is between 15 and 20 degrees Celsius.

Time zone

Time in Finland is GMT+2. Daylight Saving Time (DST) is in effect during the summer as in the rest of the European Union. Finland is always one hour ahead of Central European Time (CET) and two hours ahead of time in the UK and Ireland.

Currency and credit cards

The Finnish currency unit is the euro, divided into 100 cents. Major credit cards are accepted in hotels, restaurants, larger shops, and department stores. Visa Electron is also accepted in many shops and department stores.

Banks

Finnish banks are open on weekdays from 09.00 am to 16.30. ATMs for cash withdrawal are fairly widespread and marked by the sign OTTO.

Electricity network

The electric current in Finland is 220 V (230 V), 50 Hz. The country uses the two-pin plug system, used throughout Europe. Adapters are available in airport shops.

Trends

"Without speculating on why, Swedish companies used to win contracts for hydroelectricity jobs all over the world and now not so much," says Bengt Ljung, chairman of the Swedish Mining and Tunnelling Group.

As for back home, the majority of work in Sweden is around Stockholm, with impressive projects like the SEK 16bn (USD 2.49bn) Citybanan, which involves many of the large firms in Sweden, such as Sandvik, ABB and others. The Citybanan will improve the traffic situation in central Stockholm.

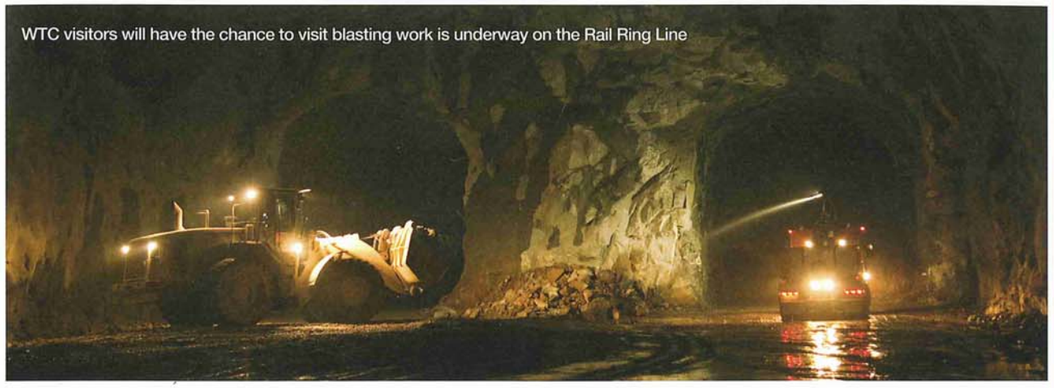
"In Finland, rail traffic accounts for the majority of tunnelling work," says Sarkka. "And almost 100 per cent excavated with drill and blast."

He explains that the flat profile and good rock of Finland—recent glaciation has stripped the land of much of its soil—allows for shallow, flat tunnels, in contrast to the steep, fjord-bypasses of Norway. It also allows for the construction of lots of access tunnels, which compensates for the slower rate of excavation associated with drill and blast.

There is a very clear focus in Norway towards developing infrastructure, especially road tunnels, according to Eivind Groev, president of the Norwegian Tunnelling Society (NFF). A scattered population in a country that presents many challenges to cohesive infrastructure is a priority for a government responsible for reaching rural areas.

"There is an upcoming project—a 20km rail tunnel south of Oslo that is currently being discussed," says Groev. "We are deciding whether to use TBM or drill-and-blast. If TBM is the decision, it will be the first use since the early 90s."

The prevalence of drill-and-blast is a result of the need for road tunnels, which do not necessarily need a circular bore-section, making TBM use obviously inefficient.



WTC visitors will have the chance to visit blasting work is underway on the Rail Ring Line

Challenges

The Ring Rail Line in Helsinki has experienced a unique problem under the Helsinki-Vantaa Airport runway. The glycol de-icer used to protect the planes has seeped through the bedrock and supports the growth of concrete eating microbes. Sarkka anticipates that this has resulted in a half-year delay on the project.

The Helsinki Metro western extension has been similarly delayed, though in its case by permit issues, rather than voracious, chemically enhanced, tunnel-destroying microorganisms.

Norwegian tunnelling has been almost without incident in the past decade, according to Groev.

The last major incident occurred in the late 90s with the accidental draining, by tunnel works for the Romerike project, of several small lakes on parkland east of Oslo and damage to houses. This caused political tension with the resulting public protest, but as Groev points out: "Lessons are always learned from such situations." Water inflow to the tunnel reached 3000 litres per minute and was eventually stopped with Rhocal-Gil, which was followed by concrete when the potentially poisonous sealant was banned in Norway in 1997.

The Stockholm Citybanan has problems relating to delicate and valuable buildings along the alignment. "The path of the tunnel requires that we blast under a small island covered in 17th Century churches, it is effectively an island-museum – there is a need to be very careful," says Ljung.

Future

In the past, notably the '60s, '70s and '80s, Norway was heavily involved in tunnelling for hydroelectric projects, the fruits of which provide for the majority of Norway's power requirements today.

"In future I think hydroelectricity will become more of a focus again," says Groev. "We are exporting and importing with Europe depending on the season. In the next 20 years we will be getting back in to hydropower."

In Finland, Posiva has been responsible for research into the permanent storage of nuclear waste material underground. The Onkalo project has driven down to a depth of 420m to perform a suitability study and ascertain the nature of the bedrock. This will also enable the testing of a final disposal scenario under real world limitations.

"The nuclear storage project in Finland, the first of its kind in the world, has been the focus of a lot of research for 30 years now," says Sarkka. "I cannot foresee any obvious problems with it because of this level of work and investigation."

These and many other quirks of the Scandinavian tunnelling industry, and wider, will be presented at WTC Helsinki. Pekka Sarkka and the FTA invite you to join them as they work eagerly towards a bright future for the tunnelling industry!

The spouse program

The traditional for the ladies/non-tunnellers agenda has not been overlooked for WTC Helsinki. The spouse program offers alternative distractions for accompanying persons who, for whatever reason, cannot see the attraction of a juicy program of all things tunnelling.

Opening ceremony

Monday 23 May at 9:00-

Helsinki City Reception

Monday 23 May at 19:00-

Helsinki City tour

Monday, May 23 at 13:00-16:00

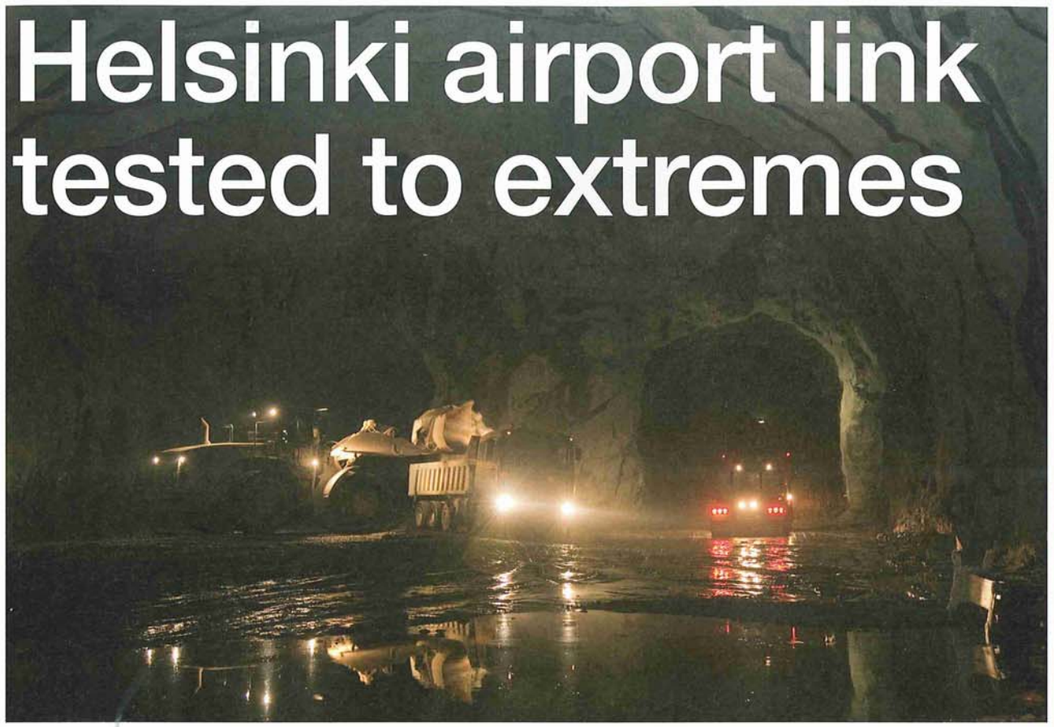
Sightseeing tour of Helsinki followed by a walk to Market Square in the South Harbour and then further sights including the magnificent Temppeliaukio Church, carved into solid rock. Tour starts and finishes at Finlandia Hall.

Design and shopping tour

Tuesday 24 May at 10:00-15:00

A visit to the Arabia museum and gallery – including the Arabia outlet shop – will be followed by a guided tour of the Design Museum. A light lunch at Kappeli, a traditional restaurant situated in the heart of the Esplanade will be digested over a stroll to the Marimekko shop including an introduction to Marimekko design. Tour starts at Finlandia Hall and finishes at Marimekko in the Esplanade.

Helsinki airport link tested to extremes



The construction of the 18-km long Ring Rail Line began in May 2009. An 8-km twin tunnel under Helsinki-Vantaa International Airport is under construction. It requires the excavation of about 1,500,000 cubic metres of rock. So far 80 per cent of this work has been completed in five separate contracts. The Ring Rail Line project is being conducted under the direction of the Finnish Transport Agency. Cooperation partners are the City of Vantaa and Finavia Corporation. Traffic will start in 2014, Merja Vilska, spokesman for the Ring Rail project reports

The Ring Rail Line is an important rail loop for the Helsinki metropolitan area, that will reduce road traffic and will promote the EU's climate policy objectives. It is also a 30 minutes rail link to Helsinki-Vantaa International Airport. Construction began in 2009 with three access tunnels.

Twin tunnel under the airport

The Ring Rail Line tunnel will have twin single-track tubes, with connecting tunnels as well as shafts and access tunnels leading to the surface. The tubes will be divided into fire sections and will have connecting corridors between them. Access tunnels will be located at regular intervals

Technical and safety facilities will be located in stations and connecting tunnels. Pumping stations and collector basins will be built at stations and the lowest points in the tunnel.

Owing to Finland's cold winters, each mouth of the tunnel will have to be insulated to prevent freezing. Insulation will be installed over a distance of about 2,500 metres.

The tunnel is being excavated by drill-and-blast. Finnish bedrock is very hard and it is not possible to use a tunnel boring machine for this purpose.

Tunnel excavation

Tunnelling in hard Finnish bedrock is a chain of different work stages that is repeated from one blast to the next. The time needed to get ready to blast takes a single shift or an entire day, depending on the nature of the rock. In part of the Ring Rail Line tunnel the rock is highly fractured. This significantly increases the amount of time needed for reinforcing and slows down work. Reinforcing includes shotcreting, bolting and injection. Before this can be done loose rock must be scaled from the ceiling and walls of the tunnel mechanically.

"In Finland a new railway line is usually built through the middle of forests. The Ring Rail Line is an exception, since it runs through residential and business areas practically the whole way," says Maija Salonen, project manager of the Ring Rail project.

Above: **The twin tunnels are being cut by drill and blast**

Strict environmental regulations must be observed in excavation work for the Ring Rail Line. The contractor is responsible for controlling environmental noise and vibration.

"In the environmental study maximum permissible vibration levels are set for buildings with different types of foundations, along with noise ceilings. Before work starts inspections are conducted to determine the condition of buildings in areas that may be affected as well as any existing damage. Inspections generally cover 100 metres on either side of the line. If necessary, equipment that is sensitive to vibration is insulated. Air control for Helsinki-Vantaa International Airport is located near the tunnel under the airport and is full of sensitive equipment, which must not be damaged by vibration," Salonen explains.

Gauges installed in buildings will measure vibration caused by blasting. Sensors will measure swaying, amplitude, frequency ranges and the duration of blasts. Results will reach the site office over the Internet within seconds after each blast. A cap has also been placed on the amount of explosives that can be used at any one time. The limits that have been set by authorities must not be exceeded, but if results show that this has happened, the amount of explosives will be reduced.

After the contract has been completed, final inspections will be conducted to determine whether buildings have suffered any damage. The contractor is liable for the cost of repairs.

The Ring Rail Line's permit under the Water Act requires that water used in the blasting process or dripping inside the tunnel must be removed from the tunnel. Once solids such as drilling grit have been allowed to settle, water can be pumped to ditches or the sewer or rainwater network after pH neutralisation (originally pH 9) and oil separation. Water pumped from the tunnel must not cause silting or corrosion at outlet points. The condition of pipes and ditches above and below outlet points will be monitored. The permit does not set limits on nitrogen or nitrates.

Groundwater and surface water will also be monitored during different stages of work.

Right: **Water in the tunnel will be pumped to ditches or into the sewer network after pH neutralisation**

Scope of work

Supervisor Esa Kiiski from construction management consult Ahmainsinoorit says, "Time schedules are tight and rock conditions vary. Rock is crushed. Blasting vibrations, especially adjacent to Finnair headquarters and other challenging environmental issues exist near ground water areas. The nearby Paijanne tunnel brings household water to whole capital area."

The scope of work consists of:

- Open cut and shafts: 150,000m³,
- Rock excavation, underground: 1.5Mm³ (sections < 60m²), railway tunnels 2 x 8km, two railway stations 250,000m³ volume and 280m long
- Sprayed concrete: 18,000m³ unreinforced + 36,000 m³ steel-fiber reinforced,
- Rock bolting: Hot-dip galvanized rock bolts, 3 – 6m totalling 500km (120,000 pieces) and CT-bolts 28,000 pieces
- Continuous test drilling (MWD)
- Pregrouting if needed. Pregrouting pressure 5MPa, 18 – 28 holes, 24m / hole. Cement is microcement Rheocem 650 or Cementa 20.

Drilling by computer

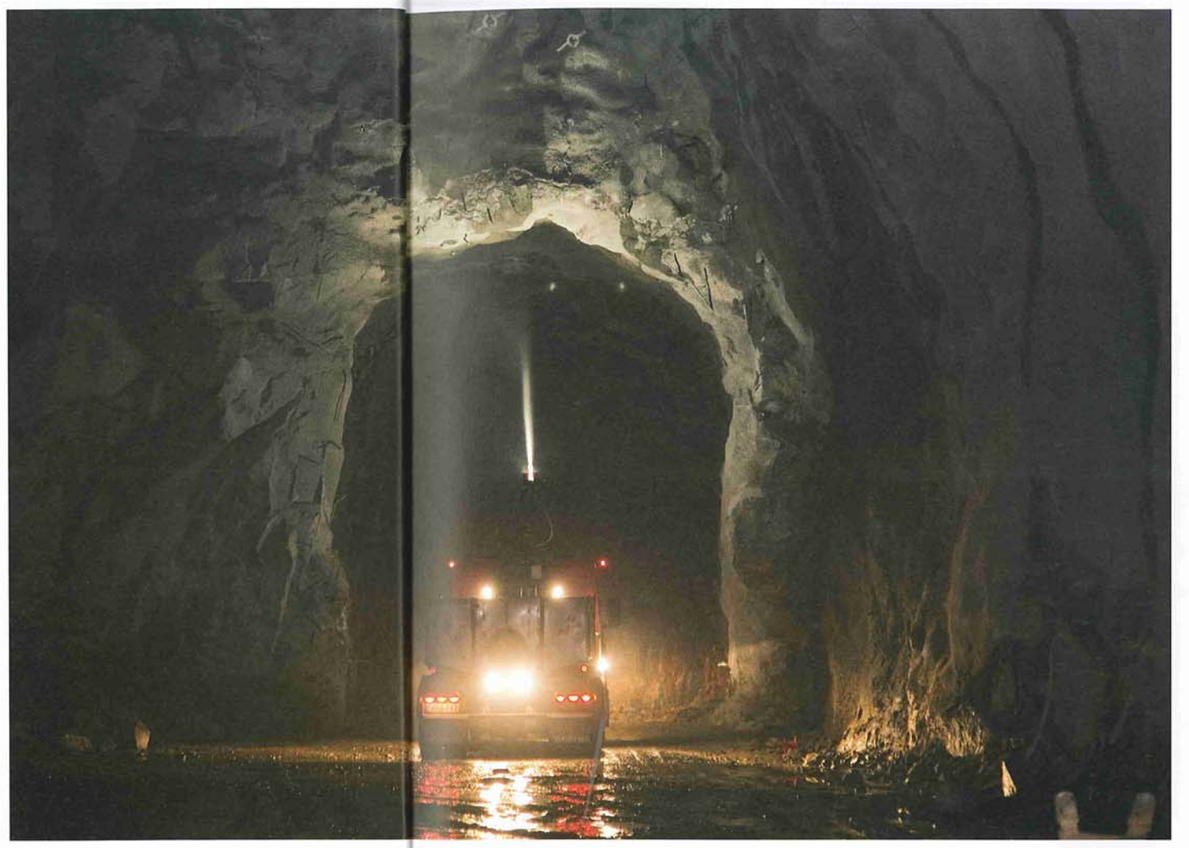
A computer-based Atlas Copco Advanced Boom Control (ABC Total) is in use for the Ring Rail tunnel project to help with the demanding conditions. Computer placed drill holes lead to a longer advance, an accurate excavated tunnel profile and minimun damage to the surrounding rock. The result is significant savings in the costs of blasting, mucking reinforcement.

Tunnel Manager by Atlas Copco as well, is a support software for planning, administration and evaluation of the drilling operation. It is a Windows-based support program, that runs on a regular stand-alone office PC. In the beginning of drilling work, the Ring Rail project provided drawings and standard information to prepare detailed construction plans, such as tunnel profiles, drill patterns, tunnel alignment tables and charts defining the position and alignment of the laser beam. The plans are prepared on a PC and transferred to the drilling rig on a disk. Actual data collected during drilling can be recorded on a disk transferred back to the office PC and analysed. This way the accurate data is always available.

Equipment used in drilling, blasting, and tunnelling (4 work sites)

230 people working in shifts 06-14, 14-22, 22-06, sat and sun 06-18.

- **Drilling jumbo:** AC WL3 or XL3 (4 pcs), AC L2C (2) and Sandvik DT 1130 I, Axera 08 or Axera 11 (5)
- **Charging mobile:** Normet Charmec LC 905 BEA (or similar 5 pcs)
- **Spraying mobile:** Normet Spraymec 9110 WPC or 7110 WPC (5)
- **Grouting platform:** AC Craelius (4)
- **Loaders:** CAT 980 H (or similar 6)
- **Hauling:** 20 - 30 trucks (short distances 2-8 km)



Rock study

The rock excavated in the Ring Rail Line project has been studied, and possibilities to use crushed rock in railway and road structures have been evaluated. About 1.5M cubic metres of rock is being excavated to build the 8-km twin tunnel. Economically feasible uses have been sought for the rock that will be left over after the project. Crushed rock is either used to build the railway bed and for ballast or is hauled off and screened. The best solution for the project is to use as much crushed rock as possible in substructures or embankments, so that aggregates will not have to be transported to the site from elsewhere.

Excavated rock is crushed and used in substructure layers, provided it meets quality requirements. Rock that is left over is placed in embankments or crushed and used in construction elsewhere.

Any aggregates that are used in substructure layers must meet technical requirements that have been set to ensure a service life of 100 years. In the case of crushed rock the main criterion is degradation. This causes permanent transformations that can result in settling as well as an increase in reversible deformations and water retention capacity, leading to higher frost susceptibility. Strength requirements are set in order to minimise degradation.

Fire safety tested in Switzerland

To test fire safety, Poyry Infra conducted simulations in Switzerland in late 2008 and early 2009 according to the existing solution (VE2A1), which called for the Viinikkala, Aviapolis and Airport stations to be designed and for space to be reserved for a station with two halls in Ruskeasanta, along with a shaft to remove smoke and balance pressure, an access tunnel and connecting tunnels to the station and the twin tubes.

For the fire simulation an aerodynamic simulation was first conducted using a model based on the geometry of the tunnel in stage one of the Ring Rail Line project together with information on train traffic and climate conditions. This defined the aerodynamic starting point and then the fire simulation was carried out using a 3D programme. A train fire was simulated according to the most critical scenario and location and a maximum fire load of 40MW. The test assumed exhaust fans operating at 58m³/s at a pressure of 900Pa.

The location that was chosen for modelling is the deepest part of the tunnel section, which lies between the Viinikkala and Aviapolis stations and is ten metres below sea level. Fires were simulated for two different cases in which a train was running from west to east.

In the first case the fire was in the rear of the train and exhaust fans blew from the direction of Vainikkala towards Aviapolis. Rescue personnel approached from the direction of Vainikkala.

In the second case the fire was in the front of the train and exhaust fans blew from the direction of Aviapolis towards Vainikkala. Rescue personnel approached from the direction of Aviapolis.

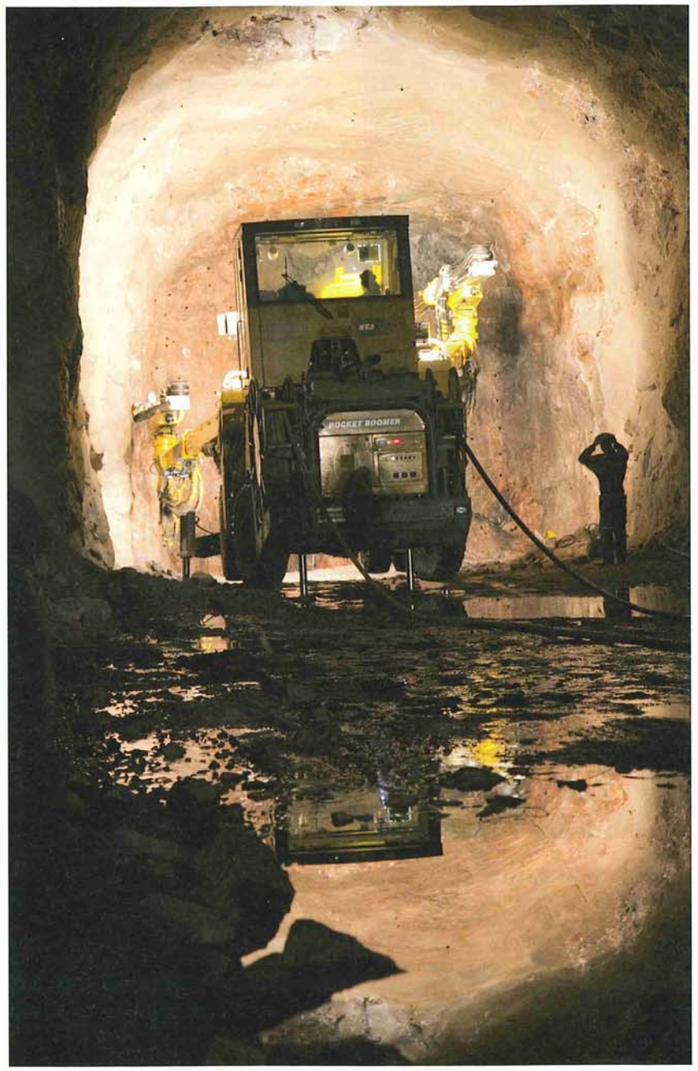
The simulation assumed that a train was stopped in the deepest part of the tunnel when fire broke out and that passengers immediately got off on the safe side and proceeded through the connecting tunnel to the other tube or via an exit shaft before stations' smoke doors closed six minutes after the fire started. The windows on the train broke after five minutes, causing the burning process to accelerate. The exhaust fans turned on one minute after the smoke curtains closed (seven minutes) and reached full strength one minute later (eight minutes). The fire reached full strength in 20 minutes. The total duration of the simulated fire was 30 minutes.

The simulation showed that in both cases the temperature in the tunnel on the side approached by rescue personnel did not exceed 70 degrees C at a height of two metres, although combustion gases at the crown of the tunnel in this location could rise to a temperature between 140 degrees C and 200 degrees C. Further away, temperatures fell to less than 100 degrees C at the crown of the tunnel. Smoke no longer flowed towards the exhaust fans 10-12 minutes after the fire started. Smoke was blown in the other direction at a rate of about 3.5m/s. This exceeds the required rate of 3m/s.

According to the simulation the exhaust fans are strong enough to blow smoke from the railway tunnel in both scenarios, and conditions in the tunnel did not become too dangerous for passengers getting off on the safe side within six minutes or for rescue personnel arriving within about ten minutes to put out the fire.

Effect of cold also simulated

The effect of freezing temperatures on the Ring Rail Line tunnel was also simulated by Poyry Infra in Switzerland. Simulations were based on different station solutions, the geometry of the Ring Rail Line, station



Left: Drill and blasting work is restricted by noise and vibration limitations

plans, and information on local weather conditions and train traffic. The effects of changing baseline information and engineering solutions on the temperature in the tunnel were also studied. The results can be utilised in planning insulation and other measures aimed at controlling heat in the tunnel.

Ways to reduce cold were tested by keeping pressure-balancing shafts closed at the sites reserved for future stations. This reduces the natural air flow resulting from differences in air pressure between the mouth of the tunnel and the pressure-balancing shaft ('chimney effect'). Keeping shafts closed did not affect the aerodynamic results (air flow speed, pressure) for the Aviapolis and Airport stations significantly, so other ways to reduce cold were studied.

Different measures and structural solutions can be applied to reduce cold in the Ring Rail Tunnel according to what risks are considered acceptable. A risk-free solution, which means insulating structures so as to eliminate problems altogether, even in the coldest winters, would result in very high construction costs. Other options involve saving money during construction and using it later on to improve the effectiveness of temperature monitoring and maintenance measures. The solution that has been adopted for the Ring Rail Line lies somewhere in between. The tunnel and shafts will be insulated in areas where risks are unacceptable, and cold will also be reduced by building heat transfer tunnels between the tubes at both ends of the tunnel. Areas that remain susceptible to cold will be monitored closely and necessary maintenance measures will be carried out promptly.

Microbe population in the tunnel

A microbe population was found during tunnelling under the eastern runway at Helsinki-Vantaa Airport in summer 2010. The population consists of normal soil bacteria whose growth has been stimulated by glycol and other substances that have seeped into the ground from the runway. Glycol is used to de-ice aircraft.

In February 2011 VTT Technical Research Centre of Finland completed a study concerning the effects of glycol seepage on concrete and steel structures. The study showed that seepage will reduce the service life of tunnel structures.

When glycol breaks down, it forms acidic by-products and carbon dioxide, which have a corrosive effect on the tunnel and its walls as well as structures extending into the bedrock. When bacteria nourished by glycol seep into the tunnel and come in contact with oxygen, this speeds up their growth. The resulting glycol breakdown products form a harmful chemical environment for steel and concrete materials.

Research indicates that in the case of the Ring Rail Line tunnel the chemical environment would cause steel and concrete materials to deteriorate. Deterioration would be rapid, and an acceptable service life (50-100 years) could not be achieved with ordinary solutions.

The Finnish Transport Agency has arranged a planning of alternative solutions and has selected seven planning offices for this purpose.

In operation in 2014

The Ring Rail Line will cost EUR 605M (USD 854M), divided as follows: Finnish Transport Agency EUR 389M (USD 549M), City of Vantaa EUR 186M (USD 263M) and Finavia Corporation EUR 30M (USD 42M). The project will receive EUR 18M (USD 25M) of TEN-T support from the EU. The line will go into operation in 2014.

Fehmarn tunnel favoured

In a competition over which world class structure to build, the immersed tube tunnel option has won over its bridge rival for the fixed link to be built across the Fehmarn channel between Denmark and Germany. Report by Patrick Reynolds

Only two months ago, though a long time after it had to start to fight for its chances against the alternative of a bridge for a coast-to-coast link over the Fehmarn channel between Denmark and Germany, the tunnel option won political backing as the favourite. No small feat considering it would mean building the world's longest immersed tube tunnel – a 17.6km long structure, slightly shorter than in earlier design studies.

On 1 February, Danish politicians gave the state-owned developer of the EUR 5.1bn (USD 7.24bn) project, Femern, the sign-off needed to support its preferred option and move forward with design work for the road and rail link, and have construction underway by 2014 and the tunnel open by 2020, later than previously expected due to longer time needed for environmental investigations and the approval process.

But first, and though Denmark is funding the development of the project to cross the 19km-wide, relatively shallow but busy shipping channel, the approval of German authorities will be needed, environmental approvals gained and an act of parliament obtained to give legal permission for the new bi-national connection to be established.

Geotechnical investigations in the channel continue and studies are expected to finish next year, which is also when the Environmental Impact Assessment (EIA) is to be submitted and an application made to the German authorities. The construction bill for the Fehmarn tunnel is to be submitted to the Danish parliament (Folketinget) in 2013 – which is around the time the verdict from the German authorities is expected.

The countries signed a treaty in 2008 to build the link, which their respective Governments ratified it in 2009.

Rival designs

Choosing between the bridge and tunnel options for the Fehmarn crossing has been no simple task to carry a four-lane motorway (dual 2-lane) and two-track electrified railway. Early on the initial studies and outline analyses tipped in favour of the cable stayed bridge but the relative advantage seen at that point was not secure enough to eliminate the immersed tube alternative. The tunnel survived into a further round of studies and design refinement, this time by consortia of consultants working on parallel, independent tracks. Competing, in effect.

Either means of building the link would, however, see the chosen structure step onto the podium of world-class rankings. To pass over the shipping lanes, the cable-stayed bridge would have required the largest spans built, and the immersed tube would be among the world's longest – even with a ventilation island about mid-point, though the need for that aspect of the tunnel could possibly be designed out.

Then, late last year, after the additional studies, designs and site investigations, the client announced its preferred option was the tunnel.

Financially, it was seen as a close run race. Unlike before, it was the tunnel that had the edge in construction budget terms. However, the tunnel was assessed to be more expensive to maintain and operate. The payback periods for the toll-fee projects are about the same – 30 years. The client says that, from an overall financial perspective, there is no difference between the bridge and tunnel.

However, the tunnel is expected to present fewer risks in both the construction and operational phases. While the tunnel would be an extremely long structure, it wouldn't call for the boundaries of technology to be pushed to the same degree as required to build the cable-stayed bridge. The tunnel was judged as likely to cause less long-term impact than the bridge, and also it would be safer for ship traffic in the channel.

After recently receiving backing of Danish politicians for the tunnel option, Femern chief executive, Leo Larsen, says: "We welcome the political support for our recommendation that the future link be designed as an immersed tunnel. The decision means that Femern has reached an important milestone in the planning of the fixed link.

"As our conceptual design projects are based on an extremely thorough, technical foundation we can now focus on ensuring that the authorities approve the project.

Left: **Tunnel portal at German coast**

Danish hub

Denmark is becoming an increasingly important transport and economic hub in northern Europe thanks to the series of major infrastructure projects built in the last two decades and the Fehmarn crossing to come.

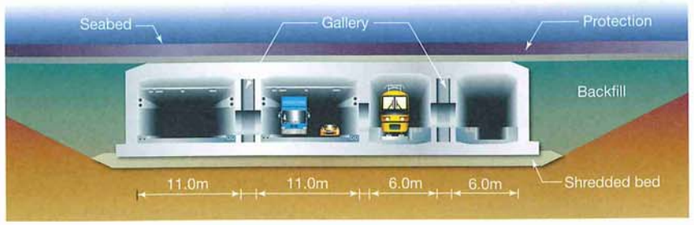
First, the Storebelt (Great Belt) project joined the peninsular and island parts of the country with a combined road and rail link, then the Oresund Crossing established a fixed link for road and rail over the relatively short expanse of water between Copenhagen and Malmo, Sweden, and with the Fehmarn link the road and rail network will be plugged more into the main part of Continental Europe.

Already the Copenhagen-Malmo axis is blooming economically, and metro links in each city have been improved. In the Danish capital yet more investment is taking place with tunnelling set to start in 2012 for the 15.5km long Cityringen addition to the network. Last year, Malmo opened a new rail link.

Next, the Fehmarn link, says the client, will cut travelling times between mainland Europe and Scandinavia, allowing high-speed train services to operate between main cities and creating a new, and important, growth area in northern Europe. The key axis is foreseen to be Hamburg with Copenhagen/Malmo.

The date for the link to open has shifted over time. Early studies thought 2015 might be possible, and then in the initial stages of the tunnel squaring off against the bridge the timetable was for construction to start in 2013 and the link to open in 2018. Following the lengthy competitive analyses,

Below left: **Tunnel portal at Danish coast**
Below right: **Location of the Fehmarn Tunnel project to link Denmark and Germany**



Above: **An immersed tube tunnel for road and rail travel below Fehmarn channel**

the latest revised schedule sees construction start a year later than planned and the link to open to two years later.

Fehmarn tunnel concepts

As the variety of bridge design variations were assessed to give the competitive best chance against a tunnel, and included suspension as well as cable stayed structures, so too was there a refinement process undertaken for the tube options.

The client has had a separate team working with a different consultant JV on the bridge option. Early cost estimates, given in 2008, the year before the twin track design studies got underway put the budget for the bridge option at EUR 4.5bn (USD 6.4bn), or about 18 per cent less than that for tunnel cost of EUR 5.5bn (USD 7.8bn).

The work was done by a client team working with a JV of consultant – Ramboll Danmark with Arup and Tunnel Engineering Consultant (TEC), which were supported by subconsultants – WTM Engineers, HTG Ingenieurburo fur Bauwesen, Wilkinson Eyre Architects, Schonherr Landskab and Oriental Consultants.

Left: **Seabed geology has been investigated to help rival bridge and tunnel designs**

The immersed tube design has been favoured over a bored tunnel solution since the early days of examining the possibilities for a fixed link across the Fehmarn channel. Even as far back as the feasibility study completed in the late 1990s the immersed tube was viewed as the more robust alternative.

However, the possibility of bored tube was not ruled out in the most recent studies despite the focus being on an immersed tube, for which the majority of design variations were examined – more than 10, or almost double that for a bored tunnel. They were compared on a range of parameters, such as robustness, environment, safety layouts, ventilation, time to build, risks, cost, constructability and connecting into the road and rail networks ashore.

For the immersed tube, during the design assessment stage the indicative size of the immersed tube tunnel was gauged as needing to be about 40m wide by 9m high to hold a two cells for rail lines and two for road traffic, all side-by-side.

There was also examination of how, and whether, to eliminate the ventilation island in the middle of the channel. The ventilation design and use of space inside the tunnels were, therefore, crucial aspects to help reach a conclusion on what might be possible, and to recommend.

Immersed tube - selected

Femern recommended an immersed tube tunnel design that is 17.6km long – approximately 900m shorter than envisaged in earlier studies thanks in part to a revised alignment and also the design of shore areas to match those for the rival bridge design.

The tunnel will be about 43m below the channel at its deepest point. Fehmarn tunnel will be the deepest immersed tube carrying both road and rail traffic. The tunnel will be formed of dozens of precast concrete elements that will be floated out and placed into excavated trenches in the seabed along a mostly straight alignment.

Excavation of about 15.5Mm³ of seabed – about a quarter less than previously thought – will be dredged to form the trench to hold the immersed tube tunnel. Once backfilled and covered, the tunnel will also be covered with a 1.2m thick stone layer for protection against shipping and anchors.

When looking at constructability, a key consideration was to find yards not too far away that could cast elements that are at least 200m long and weigh about 70,000 tonne.

In the elected design, the immersed tube elements are notably longer than in the 1999 feasibility study – 217m versus 150m-175m, or at least almost a quarter longer – though they are of the same order of size in height and width, albeit a little shorter and thinner, at 8.9m and 42.2m, respectively. At about 73,500 tonne, the elements are about 8 per cent heavier.

An element has four cells and these run its length; when the tunnel is complete the cells form continuous passages for road and rail traffic from coast to coast. In the fehmarn design the two road cells are each 11m wide and the pair of rail cells are 6m wide – a little wider and narrower, respectively, than previously considered in the earlier concepts. The cells are all 5.2m high within elements that have an overall 8.9m element height.

The figures are for standard elements because the Fehmarn also calls for special elements to be inserted at 1.8km intervals. There will be 10 special elements in addition to the 79 standard elements.

The special tunnels were conceived to take advantage of the length of the tunnel to concentrate the M&E equipment requiring space and maintenance at these dedicated areas, located at regular intervals. The special elements are wider than standard elements, adding a further 2.7m to the overall width, and they are deeper too – by 4.2m to accommodate a number of additional cells below the road and rail cell decks from access to the technical rooms. The special cells also provide space for recesses beyond the emergency lane in the road cells where service and rescue vehicles can park without disrupting traffic.

Eventually, the construction work will be undertaken through a design and build contract. Preliminary calculations suggest it will take 6.5 years to build the tunnel.

Copenhagen cut

Detailed planning is underway for major excavations and tunnelling works on the Cityringen metro line in Copenhagen. Report by Patrick Reynolds

The JV of Salini Tecnimont and Seli is heavily into planning for the large scale TBM tunnelling works and deep box station excavations needed for Cityringen, the latest addition to Copenhagen's metro network. Known as Copenhagen Metro Team (CMT), the JV was formally awarded the contract to build the 15.5km long loop of twin tubes through the heart of the Danish capital, along with 17 new stations.

The client, Metroselskabet, recommended the award in late November 2010, pending approval by its owner, and the EUR 1.7bn (USD 2.38bn) contract was confirmed in January. At the same time, Ansaldo was awarded the separate contract by the client for the control systems and driverless trains, which are to commence services in 2018.

Procurement was a long process for this major project, starting in 2009. In early planning the loop was split into two tunnel packages (North, South) for the bid process, and it was not determined until later whether to also allow offers to undertake the entire works. Closer to the bid phase the option was taken, which created a wider mix of possibilities to weigh from the range of JVs on the tender shortlist – three groups, eventually, one having dropped out.

While a single infrastructure contract to build the whole metro line was eventually chosen by the client, offering at least economies of scale, Metroselskabet noted when the contract award was recommended, late last year, that the build cost for the entire scheme was still higher than it had initially expected. However, it added that negotiations have chopped the extent of the increased cost and also that the low interest rate environment has helped to offset the impact and so keep the overall cost within budget limits.

Extra money did not have to be found for the underground transport project, which is budgeted, in entirety, at DKR 21.3bn (USD 4bn).

As planning and programming are being advanced and refined, the construction schedule currently envisages that tunnel boring will start around the middle of 2012. Seli will perform the TBM drives, and the other members of the JV will undertake construction of the deep box stations.

A JV of Cowi, Arup and Systra worked with Metroselskabet in the project development phase to prepare the civil design to the tender stage. The client is now working with the consultants' consortium to develop the construction management (CM) organisation for the build phase of the project. The CM organisation will include a management team and part of the supervision team from Metroselskabet supported by staff seconded from the consortium.

Above: **Map of Copenhagen's existing metro lines and next to be built – the 15.5km long Cityringen 'loop'**

Project preparations

Copenhagen's metro operates two driverless train services, M1 and M2, on a Y-shaped network. The lines are a combination of surface and tunnel sections, the underground parts running at the centre of the 'Y' and running through the middle of the city.

By building the entirely underground Cityringen loop on top of the 'Y', Metroselskabet will add significant capacity to the expanding metro network, for which Copenhagen Municipality provided funding for branch lines and construction of stub tunnels as part of the forthcoming tunnelling works.

The M3 and M4 train services are introduced with driverless trains running every 200 seconds and 100 seconds respectively. It will take about 24 minutes to travel the circle line on an M3 train, and the services on Cityringen are to operate around-the-clock.

Studies for Cityringen began in 2003, funding was agreed in late 2005, legislation passed in June 2007 – although further approval would be needed – and initial design work started in 2008. The preparations overlapped with the development of the 'Y'-shaped initial network, built over 2002-7 in three phases.

Site investigation along the alignment was extensive where the tunnelling conditions are relatively favourable, and there is previous experience with large TBM drives for the early metro construction. Archaeological investigations were also undertaken along the route.

Geology is glacial moraine over limestone (half the alignment) with groundwater pretty close to the surface. In the northwest quadrant, near Norrebro, there were extra surveys performed at the thicker sand beds – meltwater deposit – between layers of Clay Till – moraine – in the area. In Norrebro the limestone is at a depth of 30m-35m.

The internal tunnel diameter was not specified from the outset to be the same as the existing metro – 4.9m i.d. – but in the end this is also to be the size of the Cityringen tubes. The shields are to bore at depths of 15m to more than 30m, possibly 35m according to the pre-contract award outline design but the vertical alignment will be settled with the contractor.

The box stations will have standard lengths of 62m and be excavated to varying depths, averaging 18-19m, though some being up to about 28.5m, and with platform 13m below ground surface.

Tunnelling work also calls for construction of four crossovers, the stub tunnels, and also five shafts – 15 fewer than in initial plans.

Procurement

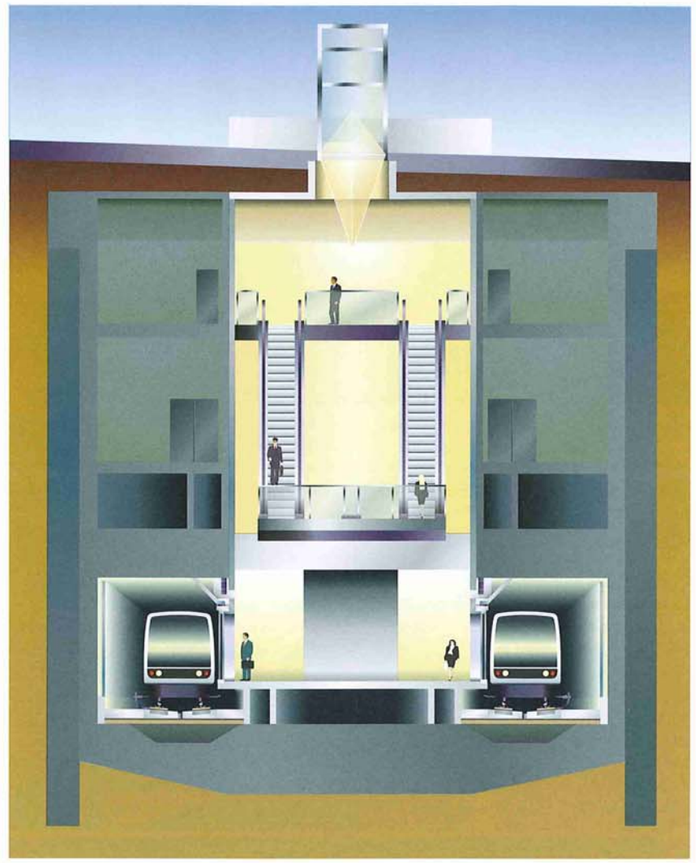
Metroselskabet began preparations to start procurement of the main construction contracts in 2009. The preliminary steps involved the prequalification process and drawing up a shortlist of JVs approved to bid. Tender documents were issued in late 2009.

Early planning had envisaged contract award by mid-2010 but bids were only submitted in May. The line remains on schedule to be opened in 2018.

A two-stage bid evaluation process was followed, with the initial price coming in a bid-opening ceremony, followed by a period of technical evaluation and then negotiations, until September.

Rival bidders for the tunnel works were the following JVs: MT Hogaard with Hochtief, Ed Zublin and E Pihl & Son, and Alpine Bau with FCC Construccion. Early in the procurement process the prequalified JV of Bilfinger Berger, Per Aarsleff and Vinci pulled out.

Salini said in mid-2010, after bid opening, that it had made the lowest offer for the two lots combined, followed by those offers from JVs led by MT Hogaard and Alpine, respectively. It added that the JV was in second place for one of the individual packages – the South contract. Contract award had been expected to be made about September last year but the bid evaluation process took another couple of months, to November.



Above: **Cityringen will have 17 box stations excavated underground**

Salini commented on the client having visited its tunnelling works on the Line B1 metro project in Rome, which is ahead of schedule, it reports, and also noted the recent B2 award. Seli is also working on the project. They said that the Danish client was able to see their approach to minimising impact on the city's inhabitants, and using local workforce and companies where possible.

Following the extensive procurement period and negotiations, Metroselskabet noted that the building costs for Cityringen came in approximately DKR 3bn (USD 560M) higher than expected in its early planning work.

Henning Christophersen, chairman of the board of Metroselskabet, said late last year at the results announcement of bid competition: 'The price of the construction has risen, but we are satisfied that we can finance the budget ourselves through savings on interest expenses, which means that our owners will not have to find new funding for the project. The overall financial situation is thus unchanged.'

But, as Metroselskabet further noted, the negotiations had managed to reduce the costs from even higher levels over the early budget estimate. It managed to cut the price by around DKR 4bn (USD 750M)

Henrik Plougmann Olsen, chief executive, said they succeeded in reducing the price while dealing with the tenderers' reservations.

The proposed award of the tunnelling and underground construction contract to the Salini-led JV was announced on 24 November 2010, and then, following approval by Metroselskabet's owners, it was signed on 7 January 2011.

Construction phase

Cityringen is an extremely complex project since the Danish capital is at sea level,

Above: **Cityringen tunnelling and station works are being done under a single contract**

groundwater levels are high and large numbers and volumes of excavations are required. And, not least, environmental regulations for groundwater protection are extremely important.

The JV has four EPBMs are to be used to bore the twin tubes for Cityringen, which is about the same number as the estimate (4-5) given by the client in early planning work prior to commencement of the procurement phase. Metroselskabet expected there would either be EPBM or slurry shields, or a combination, used on the project.

The first of the 5.78m diameter shields is to be launched around the end of the third quarter, or early in the fourth quarter of 2012, around 20 months or so after contract signing.

Aside from the work sites at the stations, the main construction sites for the project are at Norrebro Park, Oster Sogade (near Trianglen station), and the Control and Maintenance Centre, Tommergraven area, in the north and south of the project.

An additional construction site, notes Metroselskabet, is for cover and cover construction at Sonder Boulevard. It is needed because the intended sprayed concrete bifurcations will not be used to form the tunnel junctions due to difficulty of employing the method in a hazardous working environment that will result from dealing with a known ground contamination having been found to extend into the main aquifer in the area.

With the Salini-led JV responsible for detailed design under the contract, the coming months will see the focus on establishing and refining plans for the optimum solutions in construction and cost across the job. Time will be needed to settle the designs as well as have the details and proposals approved by the client.

As such, the finishing locations of the TBMs, for example, are to be determined later, and the split of the drives between the machines to cover the 31km total length of the parallel tubes has also to be decided.

So, too, is the question of concrete segment production. While the design parameters of the segments is known – 300mm thick to form 1.4m long rings (5+1) – it has yet to be finalised which companies will supply the moulds and manufacture the segments. Comparatively, the existing metro tunnels have 275mm thick segments, and also six-part rings.

What is determined, though, is that Seli will perform the tunnelling activities for the JV and also supply the main boring and back-up equipment. Seli has noted that the EPBMs and auxiliary equipment is valued at approximately EUR 40M (USD 56M). The company added further that with the award its acquired backlog of projects has risen to EUR 800M (USD 1.12bn).

One change in station design, notes Metroselskabet, will also mean that the tough construction work to carve out a station cavern at the base of a slimmer-than-standard box structure for Marmorkirken station is no longer to be done. The station, named after the adjacent old church of the same popularised name, meaning 'The Marble Church', has had its layout and construction method changed to stack the tracks within a slightly deeper box structure instead of trying to keep them at the same elevation. The station name has also changed, from Frederiks Kirke, the official name of the church.

Tunnel excavation is to be completed by around mid-2016, which will then see 2013-15 as the peak period of TBM excavation below Copenhagen.

Left: **Early preparations underway for the construction site at Norrebro, in the northwest of the city**

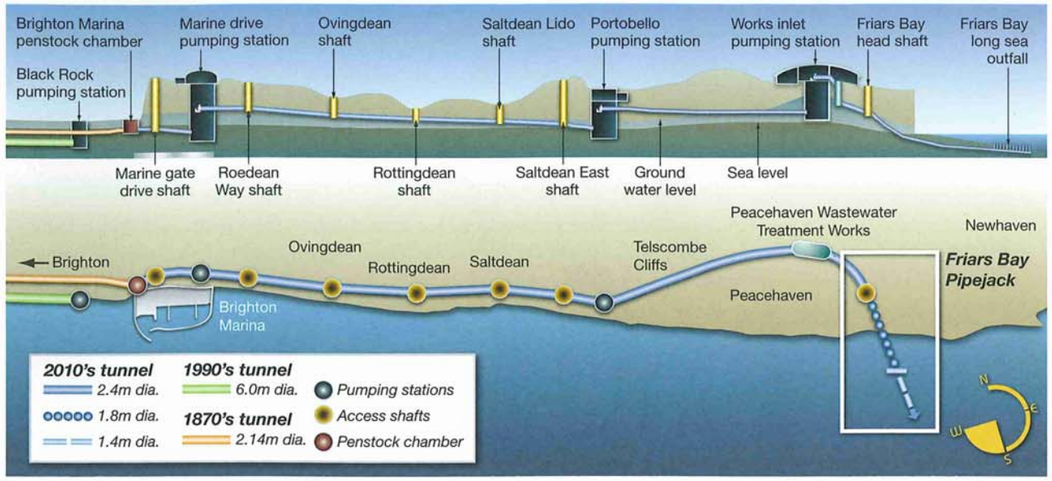
Hard treatment for unforgiving chalk drive

Climbing down the steep cliff-side steps, past the flint layers, of which there are many, each indicating some great, apocalyptic extinction event, it becomes clear just how deeply and how steeply the pipe must descend. Alex Conacher explores the Joseph Gallagher worksite near Brighton, one of the most ambitious jacking projects ever undertaken in Britain

The Cleaner Seas for Sussex project will affect a quarter of a million people on the south coast. Started in the early 1990s as a response to threats of hefty pollution fines for Britain from the EU, it will supplement the old Brighton sewerage system designed by Sir John Hawkshore more than a hundred years ago. It has been severely delayed by environmental factors but the GBP 300M (USD 480M) project is finally nearing completion. Contractor 4Delivery—a JV of Costain, United Utilities and MWH—is undertaking the work for client, Southern Water.

A crucial part of the vision: the linking of the main sewerage works to a long sea outfall at the eastern end of the project is being undertaken at Friars Bay near Peacehaven. This 34-week contract was awarded to Joseph Gallagher. It is valued at around GBP 2.7M (USD 4.4M) but includes the pipe itself, supplied by Costain, which would cost an additional GBP 800,000 (USD 1.3M).

This part of the project will enable treated sewage to be pumped from the treatment plant, down the 1.8m diameter pipe,



Above: **The pipejack connects the main wastewater works with the long sea outfall**
Previous page: **Breakthrough of the TBM into the promenade shaft**

manufactured by FP McCann, to the 2.5km long sea outfall and then into the sea.

The project

At nearly 1000m in length, the drive is one of the longest in the country. Because of the geography, however, things are made a little more complicated. The drive shaft is located close to the top of the cliffs by the nearby village of Peacehaven, while the section of the long sea outfall that joins onto the end of the tunnel begins some 690m out to sea and around 45m below the start of the drive. According to Ben Green of Southern Water, the floating installation of the outfall broke every harbour procedure ever written.

The drive would be unusual due to its length alone, but to also have a vertical curve with an arc radius of 600m and to be launched at a downward grade of 1:10, the proposal is all the more challenging and impressive.

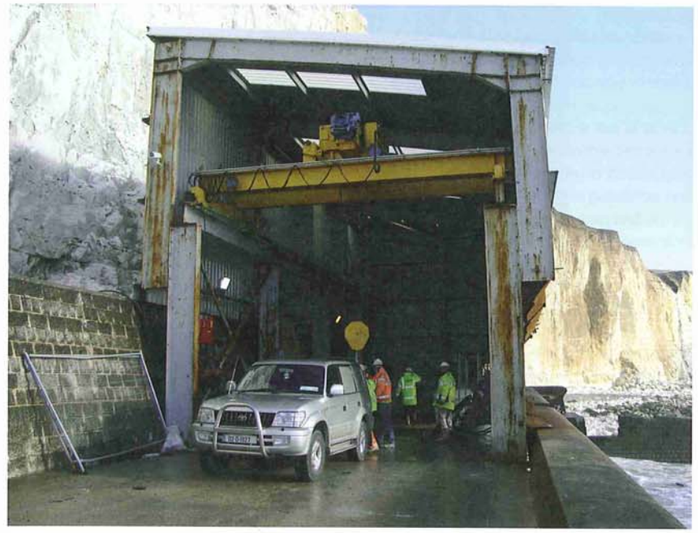
"The drive has been challenging and unusual, like working two projects at once," says Martin Brookes, the TBM operator on site. "The grade is so unforgiving that water must not get in. Normally I'd look out the window [at the shaft]—but here? The machine's capable of flooding after 20m into the drive, and we wouldn't even see it. This job's all about picking stuff up along the way, making modifications and adapting—that's what's important."

At the time of *T&TI*'s visit, the Uncle Mole Super supplied by Iseki had already tunnelled approximately 150m. This is where the choice of equipment comes in to help. As the first drive in Great Britain, or even Western Europe, that has made use of fibre optic machine control in microtunnelling, a massive and reliable data capacity is on hand. This means that many more cameras and detectors can be deployed in the tunnel to monitor the progress and condition of the TBM. According to Paul Wilkinson, the general manager for Iseki Microtunnelling in the UK, the fibre optic technology being used was developed for military communications. Its use here is an example of, as he puts it, "Engineering out the risk."

Originally intended to be two drives, one from the first shaft at the top of the cliff to the second shaft at the bottom of the cliff, where the machine would be inspected and refitted, no matter the condition of the cutterhead, and then sent a second drive under the sea to the outfall and reception chamber, to await marine recovery.

Now, however, the second shaft will act purely as an inspection and repair access point. The project will be treated as a single drive. This decision was made due to the extreme weather conditions experienced at the shed covering the second shaft. The change is cost neutral, as the site does not require relocation.

Left: **The drive shaft in the main worksite at the top of the cliffs**



Above: **The promenade shaft awaiting arrival of the TBM, exposed to the elements at the bottom of the cliffs**

"Weather conditions have delayed works by around two weeks," says Graeme Monteith, contracts director at Joseph Gallagher. "We have had high winds coinciding with spring tides and due to the unusually cold weather and despite draining the system and lagging pumps the slurry tank pipes have frozen overnight, as well as the site being shut down due to heavy snow fall."

The high winds associated with extreme sea states is the main reason for not relocating the worksite to the second shaft at breakthrough—the high storm tides batter halfway up the cliffs and have in the past ripped the cladding from the shed.

Breakthrough at the second shaft has been achieved since *T&TI* visited the site. According to Dickie Dexter, tunnelling director at Joseph Gallagher, the breakthrough was, "Spot on, in line and level, on 3 February." He adds, "The machine has performed well in the chalk with only minimal wear and tear on the teeth—approx 20 per cent—but as a precaution we will refurbish the teeth for the 690m section out to sea. The chalk is not ground to a paste and the machine dealt with multiple bands of flints on its way down through the cliff to the lower shaft."

The machine holed through the cast concrete entry wall, which has an aperture fitted with a rubber 'sphincter'. Mirroring this on the opposing wall is an exit seal. As *T&TI* went to press, the refurbishment was underway in the second shaft. Monteith adds, "Interestingly the specially designed lubricant provided a complete cut off of any water pressure in the annulus allowing for a dry reception."

Treating chalk as rock

Apart from the long drive length, the steep grade, the sharp bend, the howling winds, crushing waves and the groundwater pressure—equivalent to being underneath 40m of water—through the cliffs, there is another risk to the drive. The Uncle Mole Super is a hard rock variant of the regular Uncle Mole. Despite often being treated as a soil, the chalk is hard and self-arching. This makes it appropriate for the use of a rock capable tunnelling system, though the use of a head loaded with roller discs is generally not used in chalk due to the fear that the roller cutters will not turn and develop flat spots.

Monteith suggested that as this machine has been designed in Japan where chalk or its equivalent is not present, it is possible that this has allowed the designers to take a fresh view and not be influenced by perceived wisdom or urban myths that exist around tool choices in chalk.

"Loaded with a mixture of specially designed tungsten insert protected roller cutters and rippers the TBM has shown itself capable of advance rates of up-to 160mm /min," says Monteith. "With the slurry machine, rather than an EPBM fitted with conventional rippers, less work is done by the cutters themselves, meaning less wear. The cutter head design proved to be very successful indeed with only around 20 per cent wear being evidenced on the discs following inspection at the promenade shaft."

Six jacking stations will be employed along the drive, but that is just a formality, according to Monteith. "We're putting six in, but we don't expect to use that many, if any at all. Costain, using Joseph Gallagher's specialist labour has completed a 450m drive in these conditions on the same contract without using a single one and we have just completed 300m with jacking loads of around 200t out of an installed capacity of 1,200t."

The TBM and all site equipment is connected to the national grid, no generators are used to power the works. The site draws approximately 1MVA of power.

Below: **Paul Wilkinson of Iseki next to the electronics clean room**

Gyroscope

"The gyroscopic system is situated in the machine and measures many variations every second so it can plot where it is moving all the time," says Dexter. "It continually feeds this information back to a PC screen in the driver's cabin so he can constantly see position and alignment of the machine compared to the theoretical. The information is plotted against the known alignment for the tunnel, which in our case involved a vertical curve—not something attempted often anywhere, microtunnels mostly being straight and occasionally incorporating a horizontal curve.

"The gyro works by interacting with the constant rotation of the earth to know the bearing it is on all the time, and uses this to compare with [the direction] required as well as inclination.

It has the advantage of not needing a laser in the shaft bottom but it needs constant reminding exactly where it really is as small distance errors creep in with time and that can make a large difference on a curve.

The Joseph Gallagher site engineers involved with the project check it every two days, about 25m, and we have the European supply company attend site about every 10 days for a secondary check. They bring with them high-accuracy gyro theodolite to make the job easier."

Lubricant

Mudtech provided most of the construction chemicals. A 'super lubricant' called SeaJack was used during tunnelling. It is designed to be resistant to the dehydrating effects of salt water. The lubricant has performed extremely well having provided a total cut-off of ground water in the annulus and achieving extremely low jacking loads on the first part of the drive. There is every indication, according to Monteith, that if the current conditions prevail the full 1,000m of the jack could be installed just using the main jacking station within the drive shaft.

Slurry separation plant

"The key to successful slurry tunnelling in chalk revolves around the tunnelling system being able to firstly mine the ground effectively, and then separate the excavated material from the slurry quickly and efficiently, returning the slurry to as close to clean water as possible, re-using the slurry reservoir without having to dispose of slurry," says Monteith. "If any one part of the process is going to cause issues in terms of cost and delay then in chalk it is the separation plant. It is for this reason that I chose to combine the state-of-the-art plant designed by Manvers Engineering in one package, hiring the plant and operator from Barhale Construction and obtaining the expertise in separation plant chemicals from Mudtech. Utilising the specially formulated 'Chalk Floc' to dose a single Baioni 47L Centrifuge this plant is capable of supporting up-to six pipes or 15m of advance per shift."

Removal of spoil

Vast amounts of sodden chalk cake the site and, when asked about it, site workers all reply with the same: 'it gets everywhere'. The high water content is the real issue however. When loaded onto trucks, the transportation vibration causes the water to rise to the top of the load and slosh around, representing a severe risk to the driver and other road users if the trucks have to break or swerve suddenly. This was a costly problem, as trucks could only be loaded halfway, causing massive inefficiencies. The solution was found in 'DryAdd' a super-absorbent that can retain water up to 400 times its own weight and, when added to spoil in a measure of 0.5-1 per cent of the total load, means that full truck loads can be taken from the site. "It's a good investment – an GBP 40 (USD 65) bag saves about GBP 250 (USD 400) in transport costs," says Monteith.

Recovery

The Cleaner Seas for Sussex specialist offshore contractor, Land and Marine Engineering, which used to be part of Costain, will handle the recovery of the TBM as part of a GBP 10M (USD 16M) overall contract. A reception pit has been dug with dimensions of roughly 13.5m x 8m x 8m and filled with a granular material—a sea-dredged ballast gathered by a small dredging unit from a designated area near the Isle of Wight. The TBM will push clear of the tunnel, into the pit at which point certain vital electrical components will be removed from the machine.

The TBM's watertight doors will shut, and a positive air pressure will be applied inside the mole, then the cleared tunnel will be flooded and the ballast removed from the semi-buoyant TBM. "The current proposal is then for a surface support vessel to assist divers in attaching floatation tanks to bring the TBM to the surface," says Robert Blakebrough, project manager at Costain. "This operation has been done before, but is by no means common. We are currently applying for permission to operate the undersea drive on a 24-hour shift, whether we get this or not will decide the number of months until the recovery operation can go ahead."

After recovery, the Uncle Mole Super will be sent off to excavate the Prague sewer in the Czech Republic, and then the Riyadh sewer in Saudi Arabia.

Below: Graeme Monteith (left) and Robert Blakebrough explored the site with *T&TI*

Changing the drill

Changing construction economics in China has led to jumbos being adopted over hand-held drills for part of the Chang Hong Lin rail tunnel. Report by Patrick Reynolds

A combination of labour and energy costs plus relatively slower advance rates has led to a shift in excavation method from traditional hand-held drills to jumbos on part of the Chang Hong Lin tunnel, a key element of the Chongqing to Lichuan, or 'Yu Li' link in China's expanding high-speed rail network.

The 13.3km long, twin-track rail tunnel is being excavated through slate and clastics, and the contractor for the portal and adit one is Department One of the Tunnelling Bureau. The tubes are being constructed with 110m² cross sections (10m high by 13m wide) and the depth of cover reaches up to 420m along the tunnel alignment through the mountain foothills. The adit is 2km long and was completed early last year.

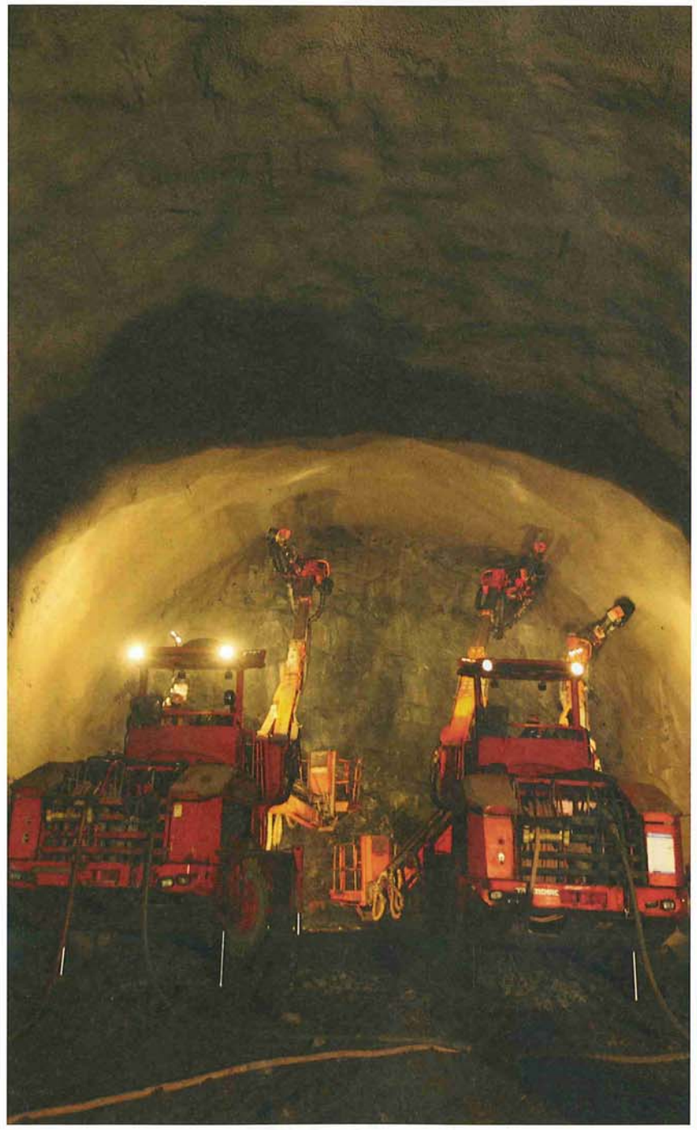
By the end of 2010 the contractor had advanced more than 4km into the rail tunnel using two Sandvik, 3-boom Axera T11 jumbos for full-face excavation.

Tunnelling challenge

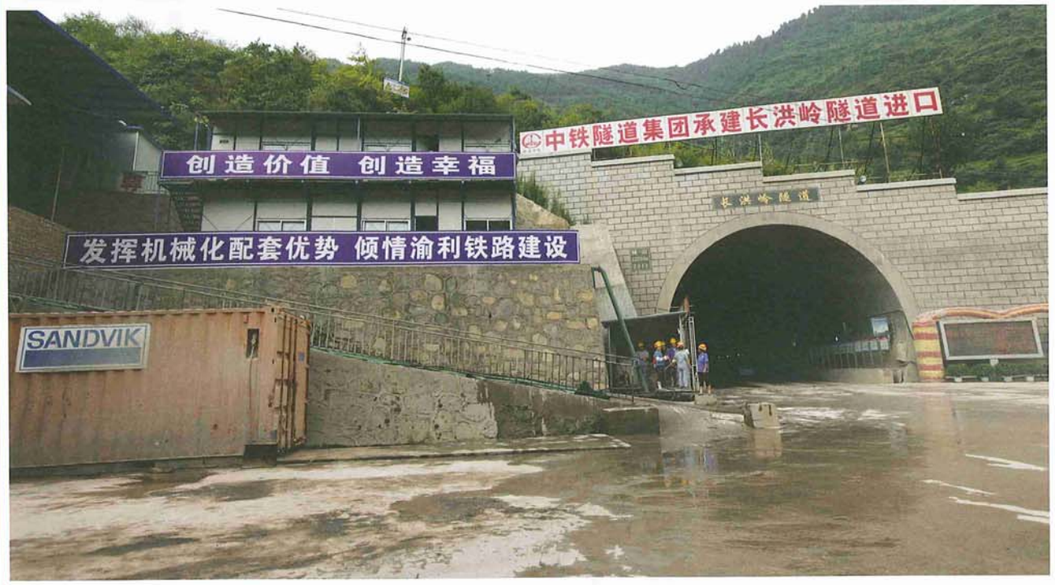
Local hand-held drills were used to commence excavation of adit one, which is located approximately 2km along the tunnel alignment. The excavation method for the 80m² tunnel was based on traditionally low labour costs, and the contractor employed up to 22 drills supported by six stationary air compressors.

However, the cost advantage began to erode as labour costs were rising and also from the increase in energy costs for the works; as the face advanced, extra compressors were needed to deliver sufficient air supply. Then there was also the concern of penetration rates being less than the using jumbos – 0.7m per minute versus almost three times that rate for jumbos.

Based on evaluations, the total excavation time using the hand-held drills was also established to be longer than using jumbos. Sandvik says higher availability rates were also noted for the jumbos. It was decided to switch. The hand-held drills were taken off the job early last year.



Above: A pair of Sandvik Axera jumbos are working side-by-side to excavate part of Chang Hong Lin tunnel



For the main running tunnel, the jumbos have been working shoulder-to-shoulder to drill a total of 140 x 48mm diameter holes to a standard depth of 3.7m, and taking on average two hours to do so. About an hour is then spent to set charges and undertake the blasting, then approximately three hours spent in spoil removal.

The works then proceed to scaling, and then up to four hours is allocated for bolting. The bolts are placed about 1m apart, and shotcrete is also applied. To take the total cycle time up to the 14.5 hours allowed the final tasks are screening and surveying.

The contractor is working around the clock and the average blast rate is approximately 1.85 per day. The contractor has excavated more than 4km.

Above: **The Chang Hong Lin rail tunnel passes through sedimentary rock, and hand-held drills lost out to jumbos as works progressed**

Below: **Location map of the Chang Hong Lin tunnel on the Chongqing – Lichuan 'Yu Li' rail line in China**

Growing network

By the end of 2012 the Chinese high-speed rail network is expected to have expanded to cover a total distance of 13,000km – the world's largest. The strategic plan for the country's network, being developed by the Ministry of Railways, will have four high-speed lines running east-west and the same number north-south.

China has more than 40 high-speed rail projects under construction.

The 224km long Chongqing to Lichuan or 'Yu Li' link will tie-in to the yet-to-be constructed Huhanrang line, which will extend from Wuhan, Nanjing and Shanghai. The travel time between Chongqing and Shanghai will, then, be reduced dramatically – by approximately 80 per cent - from up to 42 hours to only about eight hours.

While capital investment in the high-speed network to save time and money at the larger, regional and national, scales in future, there is also a focus on economics in the nearer term and at the smaller scale for construction needs. The heating economy and comparative costs of excavation methods are also bringing fresh focus on construction economics, and changes to how things can – and possibly will – be done.

Singapore sting

TBM firms on new metro projects in Singapore are being asked to provide performance bonds direct to the client that can be called on in the event of a dispute during construction, regardless of who is at fault. John McKenna reports

It is that old guy-meets-gal scenario: contractor bids for job, contractor wins job, contractor negotiates with TBM manufacturer, and a deal is done. In most tunnelling projects, the relationship between those involved in delivering the scheme is hierarchical, with the client at the top. They in turn have a direct contractual relationship with the main contractor, who in turn has contractual relationships with its subcontractors, including its TBM supplier.

If a machine gets stuck in the ground, it is down to the contractor and TBM supplier to find a way to get it moving again. But what happens if and when the relationship between contractor and supplier breaks down, be it over a payment dispute or a blame-game regarding a fault with the machine?

Singapore's Land Transport Authority (LTA) is currently procuring contractors for the third stage of its Downtown Line Three metro system, with TBMs on the second stage due to be launched in the summer and construction on the first stage nearing completion.

The company was tired of having to step in to resolve disputes between contractors and TBM suppliers, and so looked for a way of having leverage over both parties, says LTA deputy director for contracts on Downtown Line Two Sandee Heng.

"In recent years we have had problems with tunnelling contractors putting up claims for extra payment and refusing to do anything, and in the meantime the TBM is stuck in the ground," says Heng.

"Because the tunnelling is done by the subcontractor, the client has no power to tell them to order spare parts or do something to get the tunnelling going."

Heng says that in seeking to resolve this issue and give the LTA greater control over its projects, she looked at the LTA's existing relationships with subcontractors in other areas.

"In other civil engineering works – for example an underground station – you always have a warranty for water proofing, for piling works, given by our contractors," she says.

"So I thought if we can have this for other areas, we can have this for tunnelling. In addition to the warranty, the TBM manufacturer also has to put up a performance bond. It's SGD 1M (USD 785,000) per drive. It is an on-demand bond that the LTA can call on. Obviously if they comply we will not call on it."

With one recent dispute between a contractor and its TBM supplier allegedly leaving the machine stuck in the ground for six months, it is understandable that the LTA has sought a way to get things moving again.

However, it is understood that delays caused by disputes are far from the only reason that the deed and performance bond have been introduced.

A key concern behind the scenes at the LTA is the quality of contractors its heavily price-focussed procurement process may attract, although this is not admitted publicly.

On Downtown Line Two and other recent metro projects the LTA awarded the contracts on a 70/30 split between price and experience respectively. This focussing of the competition resulted in greatly reduced tender prices - on one contract the winning tender was more than SGD 200M (USD 150M approx.) cheaper than the closest competitor – and on Downtown Line Three and further metro schemes, contracts will be awarded on an 80/20 split, almost guaranteeing the lowest bidder the contract.

The concern is that contractors without the technical ability to successfully deliver the projects may end up winning jobs, and the LTA views a direct contractual link with the TBM supplier as a way of safeguarding the future of the project.

This attempt at safeguarding can also be seen in the new contractual requirement in LTA's tunnelling schemes that the TBM manufacturer has a full-time representative working with the contractor's team.

Robbins TBM Singapore country manager Pierre-Alain Scherwey – whose firm is bidding for packages on stage three of the Downtown Line – welcomes this requirement.

"This is something that we like to propose on all projects," says Scherwey.

"One specialist from the TBM manufacturer on the job site is a very good thing for the contractor if he has any questions about the machine, the parts or anything else. They can be answered quicker as the contractor can speak face to face with the supplier. The contractor saves money if the TBM goes fast and completes the tunnel ahead of schedule. However, this is significant money for the contractor to pay as our man is an expert, so often they prefer to manage by themselves."

The requirement for a TBM firm employee onsite can also help ensure proper treatment of the machine during the project, which is of concern for the manufacturer if there is a buy-back option on the TBM. On Downtown Line Two the early signs are that the increased financial and on-site involvement of TBM suppliers are helping guarantee the LTA technical excellence on their projects.

"So far the main benefit has come at the design stage on the specification of the machine," says LTA project manager Simon Hoblyn.

"What we tended to see was the machine manufacturers playing a bigger role in the final design as they didn't want any corner-cutting by the contractor."

Dowtown Line will be the fifth MRT line in Singapore. When fully completed, the line will be about 42km long with 34 stations.

Stage one of the Downtown Line is targeted for completion in 2013, while stage two is targeted for 2015 and stage three is targeted for 2017.

As construction on stage one nears an end and stage three is still in planning, stage two is preparing for its peak later this year. Downtown Line Two is 16.6km with 12 stations and one depot. The project is fully underground and is split into 10 main civil contracts between seven contractors and three TBM manufacturers. Shafts are currently being built and tunnelling is due to begin early summer.

The contractors are: GS E&C, SK E&C, McConnell Dowell, Alpine, Sembawang E&C, STEC, Ssang Yong.

There are 19 TBM drives on the project, and each one carries with it a SGD1M performance bond for the TBM supplier. Herrenknecht machines are on 10 of the drives – four slurry TBMs and six EPBs. Kawasaki slurry TBMs are on five of the drives, and Hitachi EPBs are on the remaining four drives.

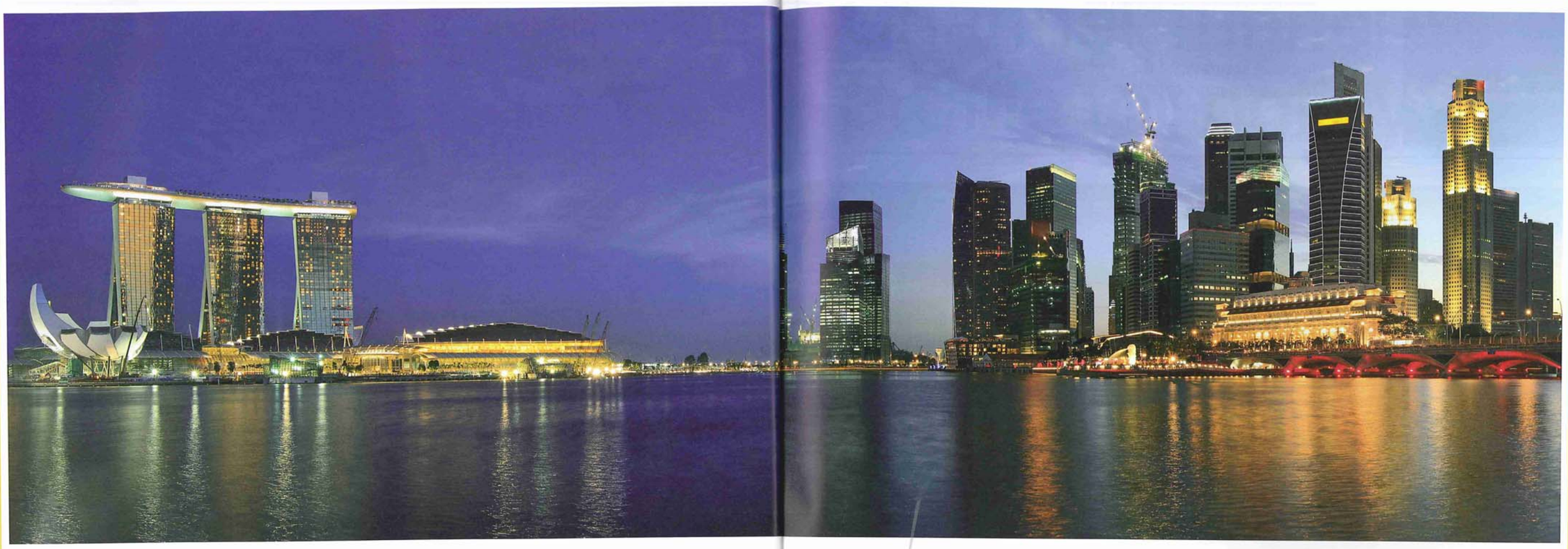
At SGD 10M (USD 7.85M), Herrenknecht's exposure to performance bonds on Downtown Line Two is significant, especially when you consider that on-demand performance bonds require no justification by the holder (LTA) for drawing on them.

Herrenknecht declined to comment. Scherwey says the financial risk is one that firms have to be willing to take.

"It is not an unacceptable demand and I can see it from the client's point of view – the way to get companies involved is to get money involved," says Scherwey.

"However, it would have to be a very big problem for the LTA to call on the bond – I don't see that the LTA has an interest in harming the TBM manufacturers. I hope contractors will be fair enough and LTA will be fair enough. The question to ask is what is the relationship between the bond and problems onsite such as delays? They can't just claim SGD 2M (USD 1.58M) for minor things."

Or can they? The strict definition of an on-demand bond is that the bondholder (in



this case the LTA) does not need to give any justification for calling the bond.

Berwin Leighton Paisner Associate Iain Suttie says: "As you will appreciate, the purpose of an on demand bond from a sub-contractor in favour of the client is to allow the employer certain and ready access to cash for use on the project in the event of some default. The bond demand should be conclusive in itself and not require the client to prove in detail that a loss has been incurred as a result of the sub-contractor's default."

The TBM manufacturer's performance bond would typically be supplied to the LTA by a bank with whom the TBM supplier has an account. The bond essentially guarantees that the TBM supplier has a certain level of cash in its bank account that can be accessed immediately by the bondholder, i.e. the LTA.

While Suttie says that the additional risk that comes with supplying a bond should be priced at tender stage by the TBM firm, Hill Hofstetter partner Jim Sharkey warns that a call on a bond can still have a sizeable impact on firm's financial health.

"On demand performance bonds are great for the party that's got them, but they are clearly not very popular with firms," says Sharkey.

"Their credit lines can be buggered up by an on-demand performance bond [if it is called on] and they have no ability to argue against this."

Heng tries to reassure TBM firms that the LTA will only call on the performance bond as a last resort and will be discriminating.

"We work very closely with the project, so when we have a problem we know who is at fault, whether it is the contractor or the TBM manufacturer," says Heng. "We will not just penalise the TBM firms."

Engineering consultant Nigel Legge says he is doubtful that anything in tunnelling could ever be as clear cut as Heng says.

"I'm not sure it's so simple in reality – determining causality and responsibility are typically complex and obfuscation is the norm," says Legge.

"If providing a TBM warranty is what clients require then contractors and manufacturers will have to comply. Contractually and legally though this could have significant 'can of worms' potential."

This 'can of worms' potential was illustrated by a case in the Singapore courts late last year in a dispute between a property developer and its contractor over the dveloper's calling of a performance bond.

Under Singapore law there are only two arguments TBM manufacturers can fall back on to delay or even stop a calling on an on-demand performance bond: one is fraud, the other is 'unconsionability'. While an argument of fraud asserts deliberate dishonesty on the part of bondholder in calling the bond, 'unconscionability' merely implies unfairness.

In the case of contractor Gammon versus developer JBE Properties, the Singapore High Court Judge said Gammon had shown 'a strong *prima facie* case of unconscionability' when arguing for a deferring of the bond.

JBE had called on the bond to rectify defects in a property Gammon had built for it after the contractor had failed to do so. While Gammon acknowledged that the defects existed, it argued that the calling of a SGD 2.2M (USD 1.74M) bond for what were minor cladding defects was unconscionable as it was wholly disproportionate to the value of the works – it equated to more than 25 per cent of the original contract value. Gammon also alleged that the awarding of the rectification works to a rival contractor was a 'sham', with the letter of award being a one page document that included no details about the scope of the work.

The judge granted Gammon an Interim Injunction which deferred the calling of the bond until further notice, and ordered Gammon to complete the rectification works in six months.

JBE appealed against the judgement, and the result of the appeal offers even more hope to TBM manufacturers worried about the lack of justification needed for the calling of an on-demand performance bond.

The Singapore Court of Appeal made some observations on whether the bond was, in fact, and on-demand performance bond, or whether it was actually an 'indemnity performance bond' – that is one where the bank is only liable to pay out the performance bond on upon proof of breach by Gammon and loss by JBE.

On the facts, the Court of Appeal was of the view that Clause One of the bond was the crucial determining factor as to its nature. Clause One stated that the Bank was obliged to indemnify JBE only against 'all losses, damages, costs, expenses or [sic] otherwise sustained by [JBE]' as a result of Gammon's breach of the Building Contract. This meant that the Bank's obligation under the bond was limited to indemnifying JBE against actual losses sustained by it due to Gammon's breach of the Building Contract.

Since the payment obligation of the Bank was so limited, the Court of Appeal concluded that the Bond had the character of a true indemnity performance bond. Following from its ruling that the Bond should be construed as a true indemnity performance bond, the Court of Appeal held that JBE was not entitled to call on the bond unless it proved that it had suffered actual loss at the date of its call on the bond as a result of Gammon's breach of the Building Contract. The Court of Appeal found that JBE had failed to do so and upheld the granting of the Interim Injunction accordingly.

Allen & Gledhill partner Ho Chien Mien, who represented Gammon, says in a recently published paper on the case that any client that intends to obtain an on-demand performance bond from its contractor should look at the wording of their contracts closely.

"[They] should ensure that the terms of the performance bond do not suggest or contain provisions which indicate that the issuing bank of the performance bond is only obliged to indemnify the developer against losses, damages, costs, expenses 'sustained by' the developer as a result of a breach of the contractor's obligation under a building contract," says Chien Mien.

"Further, a [client] demanding payment on an on-demand bond should also ensure that it is properly able to justify such a call, even if only on a rough and ready basis."

While on-demand performance bonds may make TBM manufacturers uncomfortable, they should take solace from the fact that Singaporean law offers greater protection to issuers of such bonds than many other countries' legal systems. Indeed, it appears it would be very difficult, given the legal precedents, for any bond to be truly 'on-demand'.

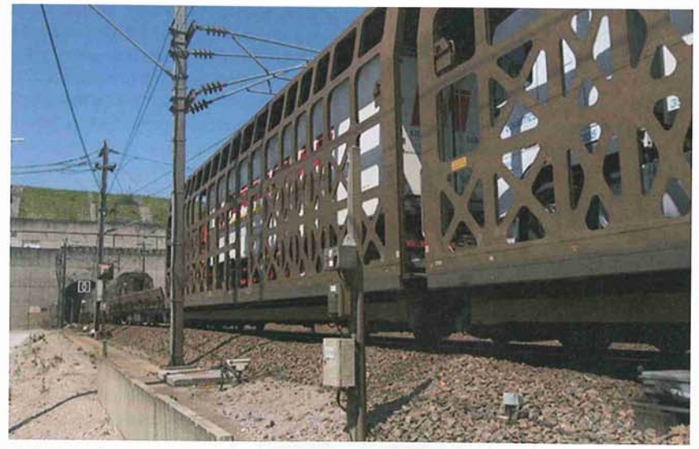
Channel Tunnel risk profile for policy

This article is based on a the presentation by Richard Clifton to the 2nd Annual Fire Protection and Safety in Tunnels Conference held in Milan, Italy, in October 2010. The presentation was entitled 'Case Study: An exploration of Channel Tunnel design and operation, factoring in risk profile, to assess key safety policies'. Richard Clifton is chairman and head of the UK delegation to the Channel Tunnel Safety Authority within the Office of Rail Regulation, UK

The presentation covered the basic characteristics of the Channel Tunnel, its risk profile and safety problems, the tunnel safety systems, the history of fire and other safety incidents with consequent measures taken, and arrangements for future operation, including new/additional train services and new rolling stock.

As most readers will know, the Channel Tunnel includes three main bores under the English Channel; two as unidirectional running tunnels of 7.6m id each and 30m apart, and a smaller service tunnel of 4.8-m diameter, usually positioned between the other two. The overall tunnel complex is approximately 50km long between portals, of which 37.5km is around 40m below the bed of the English Channel. Other major underground structures include cross-passages between the three bores, piston pressure relief ducts between the two running tunnels in an arch profile over the service tunnel, and three crossover chambers, fitted with normally closed sliding doors, for switching trains between running tunnels if necessary. The cross passages are all equipped with fire-resistant doors. The piston relief ducts are equipped with dampers that, in normal operation, only open when the air pressure increases sufficiently due to train movements.

For most of their length the three bores lie in a bed of chalk marl with sets of portals at Castle Hill, Folkestone on the English side near Cheriton terminal, and at Coquelles on the French side near Sangatte and Calais. There are three main pump stations in the tunnel.



Above: **Freight shuttle train entering a portal**

Train services

Currently the usual running tunnel traffic consists of Eurostar high-speed passenger trains running between London and the cities of Paris, Lille and Brussels, and specially designed shuttle trains running between Folkestone (Cheriton terminal) and Calais. The latter can either form tourist trains of transferrable one or two decks, depending on the heights of the vehicles, including coaches, or heavy-goods vehicles wagons with an open structure, together with a driver 'club car'. In the central service tunnel special trackless rubber-tyre bi-directional service vehicles (STSS) run to facilitate maintenance requirements, or fire & rescue vehicles for routine patrols and emergency requirements.

In addition to these most well-known trains there are also standard freight trains (locomotives plus freight wagons, container flat cars, etc), and works trains.

Le Shuttle trains run on looped track at both terminals to change direction. For operational purposes the running tunnels are split into six zones or 'intervals'; three in each direction. The ends of these intervals approximate to the Holywell shafts below the cliffs in England, the UK crossover chamber, the 'French' crossover chamber, and the French portal and crossover to the inland side of the larger Sangatte shaft. The pumps stations are located one within each interval length.

Risk profile

Tunnels are generally safe unless there is a

Above: **Major fire damage to the concrete lining of the running tunnel with spalling from and behind the steel reinforcement**

fire, and many of Europe's worst transport accidents have been tunnel fires. Other risks to be included in the overall profile for the Channel Tunnel cover threats to people (users and staff), national security (using the tunnel as passage), and to the fabric and equipment of the tunnel. These risks include:

- People being trapped underground in trains for long periods, perhaps resulting in panic (second only to fire).
- Conventional railway risks such as collision, derailment, signals passed at 'danger' (SPADS), and broken rails.
- 'Normal' industrial health and safety risks such as hazardous vehicle movements, and in maintenance facilities, construction work, offices and shops.
- Degradation of the infrastructure.
- 'Clandestines' (stowaways etc).
- Security threats requiring emergency response measures.

The worst transport accidents in Europe include several major fatal tunnel fires:

- Mont Blanc road tunnel – 24 March 1999 – 39 dead.
- Tauern road tunnel – 29 May 1999 – 12 dead.
- Kaprun ski access funicular rail tunnel (Gletscherbahn 2) – 11 November 2000 – 155 dead.
- Gotthard road tunnel – 26 October 2001 – 11 dead.
- Frejus road tunnel – 5 June 2005 – 2 dead.

Incidents outside of Europe have included the Daegu metro station fire in the Republic of Korea of 18 February 2003 in which 192 people died at Jungango Station.

These incidents have been the initiators of both individual and broader initiatives to achieve improved safety.

Safety systems

In the Channel Tunnel there is a wide range of safety measures installed or in action. The service tunnel is ventilated to a higher air pressure than the running tunnels to prevent leakage of any smoke or fumes from possible incidents in the running tunnels from entering the service tunnel. Thus the service tunnel can be regarded as a safe haven, rather than a rescue station.

At each end of the Tunnel fire brigade teams with paramedic expertise, termed FLOR (First Line of Response) are stationed, and use the previously mentioned STSS vehicles to travel the service tunnel. Whilst the FLOR crews usually stay within their 'own end' of the Channel Tunnel, in the event of a serious incident the emergency personnel in charge may declare that the bi-national emergency plan (BINAT) is in force. Under this the emergency teams have unrestricted access to all parts of the tunnel, irrespective of the sovereignty respected during normal operations. Thus UK and French emergency teams can, and have, co-operated to deal with serious incidents. BINAT is also a term used for the regular emergency exercises undertaken by both UK and French teams.

There are fire detection systems both in the tunnels and on the trains. Communications systems, including continuous monitoring, are installed throughout the tunnels. Train movements are monitored from two rail control centres (RCCs) at each terminal. Other protection and detection systems include automatic train protection signalling and binding brake detection.

The Shuttle trains employ tunnel-specific rolling stock with special safety design features, whilst there are specific safety rules for passenger rolling stock and tunnel operation. Emergency sidings are provided at both ends of the Channel Tunnel.

Incident history

Signing of the Treaty of Canterbury in 1986 allowed work to begin on excavating the Channel Tunnel under the UK-France agreement, including safety procedures and controls. From 1994 train services were progressively introduced including many trial runs to test systems operation, before fare-paying services commenced.

On 17 November 1996 there was a major fire starting from a truck in an HGV shuttle train that had to stop within the French section. The resultant damage to the equipment and tunnel lining required significant rebuilding during which this 'interval' of the tunnel had to be closed for a long period with trains, once permitted, being diverted through a crossover chamber. In addition to replacing railway and tunnel equipment the tunnel lining had to be repaired by applying steel-fibre-reinforced sprayed concrete. Concrete had heat spalled from the precast lining segments, exposing the steel reinforcement cage. Extreme damage occured for a length of about 50m, with severe damage over another 240m and more minor damage over another 190m. On 21 August 2006 there was second fire, but with less serious consequences.

On 11 September 2008 there was another serious fire, this time in the 'English action', with major consequences. Finally, considered serious for safety due to trains being stuck underground, there was a major series of incidents on 18 and 19 December 2009 affecting five passenger trains that broke down as a consequence of cold weather conditions.

Most of these incidents involve the HGV shuttles, a service that has been affected by three fires since the opening of the Channel Tunnel in 1994. The fire of 17 November 1996 resulted in safety procedures being changed, but the last fire, on 11 September 2008, is leading to more significant changes.

It should be pointed out that in all these incidents, evacuation procedures were effective, no one was killed, and there were no significant injuries to anyone. However, there has been extensive physical fire damage requiring repair, and major disruptions to normal services.

There have been no significant fires on any other type of train.

Investigations post-2008

As results of the September 2008 fire, safety systems have been re-examined in several respects. Firstly risk assessment was revised to determine if the system is acceptably safe. In particular there has been a re-examination of the design of the HGV shuttle train rolling stock.

Eurotunnel also launched the Salamander project action plan in consultation with the Channel Tunnels Safety Authority. This took place before receipt of the BEA-TT (French Bureau d'Enquetes sur les Accidents de Transport Terrestre) report on the fire, assisted by the UK Rail Accident Investigation Branch (RAIB).

Briefly, the three elements of the Salamander project are:

- Better systems of detection and loading procedures of vehicles.
- Early intervention by fire fighters.
- Reconsideration of fire suppression or control system in the tunnel or trains.

Other subjects for investigation include a current project to examine the feasibility of, and to build in a tunnel fire suppression system. Also, as a consequence of the fire, there has been a revision of the 'drive through' or 'stop and evacuate' procedures in the event of a fire on a train.

Considerations for future

Matters requiring attention for future use of the Channel Tunnel are currently focussed on the introduction of new passenger services. At the forefront of these are the requirements of the European Union Common Market 'Open Access' programme to allow more competition by allowing more operators through the Channel Tunnel.

The German state-owned operator Deutsche Bahn has been at the forefront of attempts to exploit the opportunity, although French organisations have objected on the basis of current Channel Tunnel safety rules on motive power construction.

These seem to be now approaching settlement, and it is likely that services to Amsterdam and northern Germany will be introduced at some stage.

At the end of 2009 Deutsche Bahn (DB) received permission to run German Intercity-Express (ICE) trains through the Channel Tunnel in the future. On 19 October 2010 Deutsche Bahn ran the first ICE train through the Channel Tunnel arriving in London St. Pancras station, after evacuation tests in the tunnel were a success.

Whatever new services are introduced it is a requirement that rolling stock is compatible with the safety rules for the tunnel, and operate with a service specification that is acceptably safe in terms of numbers of crew, training, knowledge of evacuation procedures etc.

In addition the introduction of new services will require attention to security requirements related to new operational centres, in addition to any modifications to meet with the overall international security situation.

Acknowledgements

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Current rolling stock

The initial rolling stock for passenger use was authorised prior to the Channel Tunnel opening in 1994. This was prior to the development of European Technical Specifications for Interoperability (TSIs) that could have been used as effective standards for design of rolling stock.

The safety considerations in case of fire have been based on certain scenarios relating to the occurrence of fire. A train could, with a fire on board or when affected by another, similar incident, run through to the emergency sidings at the end of the tunnel, or there could be a controlled halt with evacuation of occupants into the service tunnel through the nearest cross passage.

In some circumstances the train halt may have to be 'uncontrolled', perhaps necessitating a greater distance to the cross passage and the safety refuge of the service tunnel.

The preference from 1994 was for a train with a fire on board to travel through to the emergency siding, if it were possible. This procedure was on the basis of a train running capability of 30 minutes.

During the train's travel to the siding, passengers would move along the train to an unaffected part, and the fire isolated. If, however, evacuation were necessary, passengers would pass directly from the train into the service tunnel. If the train is damaged, or malfunctions, prevent further ravel, it can be split and the undamaged part driven out.

In accordance with these planned procedures, the specific safety rules introduced in 1994 stated that passenger trains were to have a 30-minute running capability at least.

The 400m-long passenger trains have a continuous through corridor to facilitate direct evacuation to the service tunnel. The construction of the carriages - and so the corridor - are smoke tight to prevent breathing difficulties in passengers until the short crossing to the cross-passage and safe haven.

The train has to have a traction system suitable for the tunnels, and be fitted with fire detection and suppression systems in the locomotives. In accordance with recovery procedures, the train would also need to be 'splittable'.

Rules revision

Following consultations with all interested parties in 2010 it has been proposed that the above rules be revised. This is in accordance with European Directive 2004/09 that requires safety standards be maintained or improved.

Above: **View through a freight shuttle club-car window to a cross passage – the escape route**

Some of the main provisions are as follows. The need for a 30-minutes running capability is maintained. Formations of train construction, other than the 400m-long standard train with corridor, will be allowed if a safe evacuation procedure can be demonstrated. The carriages and connecting corridor would still have to be smoke-tight, although a choice of technical solutions to achieve this will be allowed.

The principle of distributed power (see above with reference to French objections to DB trains by Siemens) is accepted, but fire detection and suppression systems will be required in each motor unit. The train 'splittability' requirement has been abandoned.

Overall outcome

The updated requirements for passenger rolling stock to pass through the tunnel will enable new passenger trains to be authorised, but meanwhile retaining safety standards. This will also facilitate new Channel Tunnel train services.

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Fire protection by spray

The concept of applying fire protection to a tunnel lining is gaining acceptance even though projects in which it has been used are not yet in great numbers. Successful recent use of BASF Meyco's Fireshield 1350 material on the massive Gotthard base rail tunnel seems destined to increase confidence in the method however.

Contractors employed Meyco Fireshield 1350 in the 15.9km-long Bodio section (southern portion) running tunnels of the Gotthard project, the longest railway tunnel in the world. Fireshield 1350 is a special fire protection mortar that can be applied by hand, as with other mortars, or by the same spraying methods used for sprayed concrete lining support.

The engineering consortium that designed the Bodio section, as well as the Faido and Sedrun sections, totalling about 38km in length, is the Engineering JV Gotthard Base Tunnel South comprising of Lombardi Engineering, Amberg Engineering and Poyry Infra, all of Switzerland.

In a similar way to Channel Tunnel safety procedures (see previous article), it is known that a potential train fire in the tunnel could cause damage to the structure, putting users at risk and resulting in the need for time-consuming and expensive rehabilitation to make the structure safe for operations again. The aim of fire protection is therefore to ensure tunnel availability during the event (fire) for the safety of individuals, and to promote availability after the event for cost effectiveness in returning the train services to full operation. The first requirement implies that the affected bore must be adequately structurally safe for 45 minutes, and the neighbouring bore for 90 minutes, so that users can be rescued safely.

The project owner, AlpTransit Gotthard, set up a fire protection task force in 2003 to indentify scenarios associated with a freight train fire and a passenger train fire (sizes of 250 MW and 40 MW respectively) and to develop damage and risk assessments for both. This was coupled with the assessment and recommendation of protective measures to meet the availability requirements described earlier.

The passive fire protection measures identified were:

- Addition of polypropylene fibres to the concrete mix to avoid heat spalling,
- Where these fibres were used, increase the concrete cover to protect reinforcement steel and to ensure no reduction in tensile strength due to increased temperature,
- Sacrificial fire protection layers to insulate the lining from the fire's heat.

Fireshield

The Fireshield 1350 fire protection mortar manufactured by BASF protects the concrete tunnel lining of the Bodio tunnel cut-and-cover section. This is near the southern portal in Switzerland Ticino canton, linking it with the Faido multi-functional station further north. The section comprises the two bores, each 400m long, and one cross-passage about 260m from the portal. Application of this special fire protection mortar was required since temperatures exceeding 300 degrees C lead to concrete spalling and crumbling, and when concrete is exposed to temperatures above 1000 degrees C it loses its load-bearing capacity altogether and the tunnel may collapse.

A minimum thickness of 31mm of Fireshield was required to meet fire protection requirements, applied direct to the structural concrete lining. The specification was increased to 35mm thickness to cater for application tolerances. To maximize a high-tensile bond strength between the Fireshield layer and the concrete lining, a fully-bonded design including stainless-steel fine-mesh reinforcement was chosen. Before application the concrete surface was hydromilled at 2000bar pressure by a robot to achieve the specified minimum roughness depth of 5mm. Stainless steel rockbolts were also used at a rate of five piece per square metre to hold the mesh and provide additional security against delamination.

The Fireshield 1350 was applied by similar robotic spray equipment to that used for sprayed concrete, with a total applications area of about 13 500 m2. The correct application thickness was aided by coloured markers on specially designed Fischer spaces, used with Fischer Nail Anchors to hold the mesh.

Above: **Spraying Fireshield through and onto the stainless steel mesh by remote spraying unit**

"Being covered with a layer of fire protection mortar the tunnel walls withstand temperatures of up to 1400 deg Celsius for a minimum of 90 minutes. This way we gain some precious time for firefighting," says Frank Clement, BASF expert for underground fire protection solutions.

A Meyco Suprema spraying unit and nozzle system were used by contractor Walo Bertschinger to apply a layer of a specified thickness onto the inner concrete lining of the tunnel.

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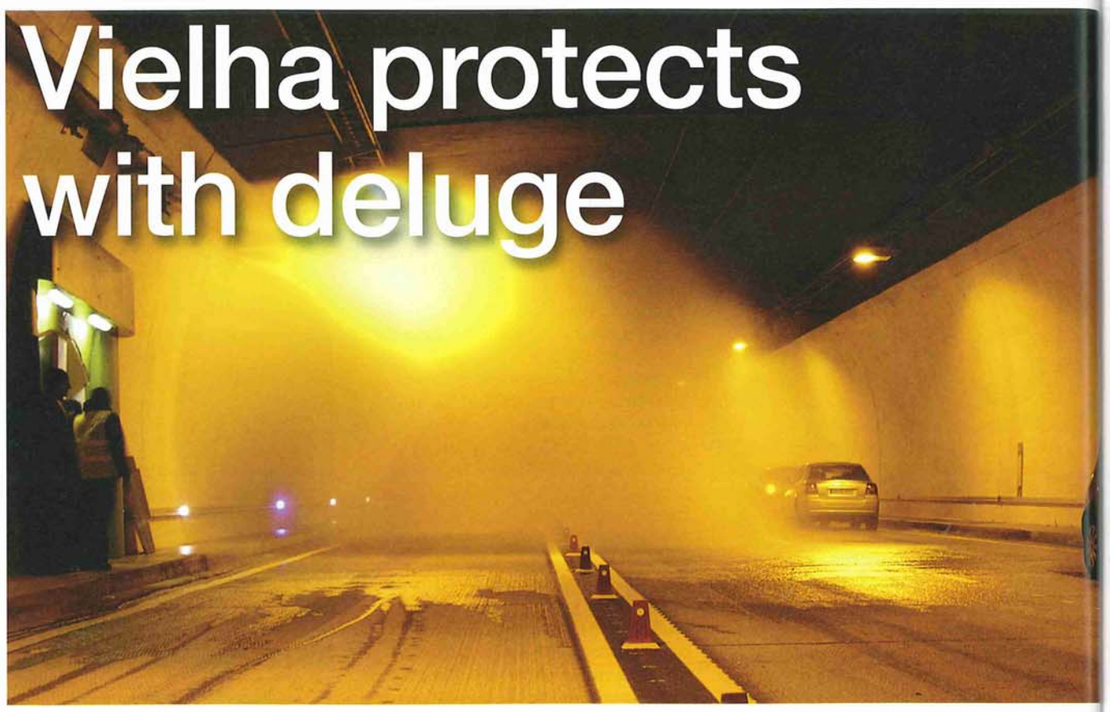
Vielha protects with deluge



Pedro Valcarcel, fire protection manager with Victaulic, describes a new type of fire protection installation in the new Vielha Tunnel bore in Spain

The new Vielha Tunnel

Completed at the end of 2009, the new Vielha Tunnel, formally named the Juan Carlos One tunnel, after the King of Spain, replaced the Alfonso XIII Tunnel, completed in 1948, which was listed as the world's longest until 1964. It is situated on the N-230 road connecting Vielha e Mijaran in the Pyrenees with the rest of Catalonia and France. Before the first tunnel was built the Val d'Aran could only be reached by roads over mountains more than 2000m high. Despite many programmes of improvements, including lengthening from 5133m to 5240m, it was decided that the structure and systems were no longer adequate for safety and increased traffic flows, and the 5230m-long, three-lane, reversible, tunnel was built, using the old tunnel as an escape route.

Although the tunnel had received a 'Very Poor' safety rating from European Tunnel Assessment Programme (EuroTAP) inspectors, or retesting in 2009 this was improved to 'Very Good'.

Besides the Victaulic fire protection systems other new safety systems include new lighting, Daetwyler fire-resistant cabling and Trox fire dampers.

In order to avoid misunderstandings when driving patterns are changed with the reversible 3-lane layout - especially during snowfall at the high altitude - special in-road lighting units are employed including 100 Advanced Light Rocon 2 DRM units from Lucebit Road. The lights are equipped with low-voltage halogen bulbs that are used instead of LED lighting to give heat dissipation from the units in freezing conditions.

The 80km of halogen-free Pyrofil Daetwyler cabling has 30-60 minutes of extended functional integrity in a fire to guarantee a reliable supply to safety systems including emergency lighting, surveillance, smoke and fire alarms and signalling systems.

The 5-km Vielha Tunnel was once identified by the European Commission as one of Europe's most unsafe tunnels. In 2002 the Spanish Government decided to make a major investment in safety with the rollout of a EUR 300M (USD 422.55M) improvement plan. The project involved the creation of a totally new tunnel close to the original site and the implementation of a new deluge fire safety system; the first of its kind in Spain.

Deluge systems are principally used in locations where the spread of fire can be very rapid or the consequences of fires can be devastating, such as in airport hangars, refineries, chemical plants and armaments factories.

The main advantages offered by the deluge system are its abilities to rapidly lower temperatures, to cut the advance of fires, and to protect structures against potential collapse. In Japan deluge systems have been used for the past four decades whilst in the United States there are six tunnels equipped with deluge systems. Other examples of similar European systems include the Mona Lisa Tunnel in Austria – a deluge system using mist – whilst elsewhere in Germany, France and

Left: Demonstrating the coverage of the Vielha Tunnel water deluge system to prevent the spread of fire

Italy feasibility studies are being undertaken.

Safety first

The Vielha Tunnel was the first deluge system to be implemented in Spain and one of the first in Europe. It received a EuroTAP ++ rating (excellent) and is a great example of how an installation should be carried out.

Now one of the safest tunnels in the world, it features evacuation galleries every 400m, safety recesses every 200m, semi-transverse ventilation, and a fire prevention network using water along the tunnel with hydrants and a deluge system with spray nozzles. Emergency beacons, cctv, smoke detection and automatic incident detection were also implemented.

During construction, to minimise the use of welding and reduce associated risks from toxic fumes and fire hazards, the specialist contractor Agbar Incendios and the main constructor UTE Tunel de Vielha proposed the use of grooved mechanical piping systems. The Spanish Government, with the support of Sener Engineering, accepted this proposal.

The high-altitude tunnel also posed some unusual challenges; not least its corrosive environment. Damage was reduced by using stainless steel for exposed pipe, and by burying ductile iron pipe.

The Victaulic FireLock fire protection system was selected because of its high quality and reliability. Advantages included a reduction of installation time of over 70 per cent. Victaulic stainless steel rigid and flexible couplings were also used for sections exposed to the elements, and all joints using Victaulic grooved mechanical couplings were made in accordance with the NFPA 13 standard (of the US National Fire Protection Agency) for the installation of sprinkler systems.

Deluge in action

The Vielha fire extinguishing system feeds nozzles (the equivalent of a 100m linear tunnel) from municipal reservoirs. There are two electrical pumps and one diesel, each capable of supplying 50 per cent of the total requirement, and pressure maintenance is ensured through a jockey pump.

There is a difference of more than 200m altitude between the North and South entrances, so to prevent pressure exceeding 16 bars there are a series of pressure reduction stations. Deluge valves also function as pressure reducing turn valves adjusted to around five bar, whilst hydrants and fire hose cabinets also act as valve pressure regulators.

The Vielha deluge system is equipped with a line of operation on detection and a line for extinction. The latter uses nozzles and is kept empty. Deluge valves are only opened in manual activation. When the deluge valves are opened, the water comes out of all the nozzles. Systems can be activated in situ at a manual 'pull station', or from the control centre.

At Vielha it was decided to use an electrically actuated deluge valve with pressure control. There is a deluge station positioned every 50m, so the total install involves over 100 independent systems.

A range of triple nozzles, made of stainless steel, are fitted every 5m in the tunnel to protect against any sort of fire. The pressure is maintained at five bar.

The semi-transverse ventilation system has vents on the ceiling and is reversible. The main objectives are to maintain air quality and guarantee control of smoke in the event of a fire.

The Vielha Tunnel is a very significant project that showcases the future of fire protection in Europe. It is not only a first; it is one of the safest installations of its kind there is.

Valves

The Victaulic water deluge system features its FireLock NXT Series 768-D deluge valve to supply the curtain of water when required. It has a straight-through body design that is claimed to provide superior flow and low pressure drop. The system utilises and open-type sprinkler, and pressurised water lines that fill when the fixed detection system is activated. Victaulic says that the FireLock NXT features a low differential clapper that has a direct-acting diaphragm to separate system water supplies from the deluge sprinkler systems, thus promoting reliability. The low differential, and latch and actuator design of the valve allows it to be self-resetting, eliminating the need to remove the cover plate.

Activation can be under manual control, as described above, or when the fixed release is tripped by heat from a fire. This action releases pressure from the supply lines to open a pneumatic actuator. The clapper then opens and allows water to enter the pipe lines, activating an electric alarm and/or water motor alarm, causing water to be distributed from all nozzles and sprinklers.

Above: Ground ends to Victaulic pipes avoid the use of welding during installation and are easily connected

The FireLock automatic device range also includes dry extinguisher system valves, and valves with double-interlocked pneumatic/electric activation.

The FireLockEZ Style 009H rigid coupling is designed as a lightweight, installation-ready unit for fast and simple operation, even with hand tools. It has no loose parts to drop, injure or lose, and it is shipped to the site intact. It is available in sizes DN32-DN100 (42.4-114.3 mm), and can be used in fire protection systems with pressures up to 2517 kPa.

The grooved end piping system provides a union at every joint to allow for easy and speedy routine system maintenance, including blanking off for system isolation, so that when one section is down the other can remain live. The 'flameless' installation also facilitates maintenance, such as damage replacement, by removing the need for cutting and welding permissions.

Victaulic also says that the integrity of properly installed grooved piping minimises the likelihood of leaks and ruptures associated with seismic stresses and movement. In tunnel operation, the joints' elastomeric gasket seal creates discontinuity in the piping system, cutting sound and vibration transmission through the piping from pumps etc, cutting background noise.

For more information on Victaulic's fire protection systems visit its website: www.victaulic.com

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Would Archimedes recognise it?

It's come to our notice at *T&TI* that some people think the auger screw conveyor found in earth-pressure-balance (EPB) TBMs, also known as EPBMs, is the same as Archimedes invented. Even though the great man is surely past worrying about patent disputes, the open-ended screw and ancillary equipment is actually a sophisticated assembly of hardware, in common with the rest of modern EPB TBMs. As such it is a suitable subject for the second in our series of 'How it works' features. Report by Maurice Jones

The Archimedes Screw, auger, and screw conveyors are not really the same thing, even if they look like it. The device found in modern EPB TBMs has been called all three, despite being in one of the most advanced forms, in particular that it performs more than one function.

Origins

Traditionally the Archimedes Screw, auger or screw conveyor have been used to move material from one place to another, including, sometimes, the extraction of material from a mass, such as with wood or soil augers and some piling rigs. The term 'Archimedes' or 'Archmedian Screw' is perhaps best restricted to devices performing the original function of lifting water for irrigation or drainage. A close fit between the auger flight and the carrying tube facilitates the transmission of water against gravity. In the transport of more solid masses this fit is not so crucial.

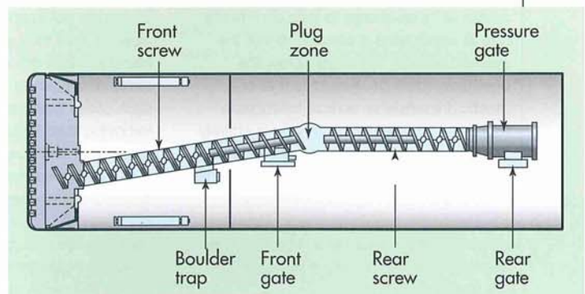
Auger screw conveyors are used widely in industries requiring bulk materials handling, using both tube or trough casing, for horizontal or inclined transfer, and even in rotary screw compressors. They are best applied to semi-solid materials or to fine particle solids that act in a similar way.

Augers have been used in underground construction for many years, including for, in addition to piling, site investigation and boring under surface obstructions - auger boring. With the addition of a steering device, augers with screw conveyors form the basis of one type of microtunnelling machine. The operation of such auger machines, up to around 1800mm diameter, is basically dry with limited groundwater capabilities, but developments in technology, particular of cutterheads, has increased their hard ground capabilities.

However, what we are concerned with now is their role in the so-called EPB TBM. This type of mechanised, full-face shield machine was developed after the slurry-shield machine and has the advantages that removal of excavated spoil is simpler, and that control of the face pressure is more immediate in that there is not the comparatively long time-lag associated with surface-sited slurry pumps adjusting to changes in face pressure, chiefly due to changes in groundwater pressures. The Mixshield or Benton'Air versions of slurry-shield design have minimised this problem however.

The EPB TBM needs the correct ground conditions to work properly, although the characteristics of the excavated material can be changed by the use of small quantities of bentonite slurry or other additives; principally polymers (see below). In this way EPB TBMs can be applied to a wide range of ground from the ideal soft material to, with right equipment specifications, hard inclusions.

Despite the frequent needs to 'improve' spoil by introducing additives, it is still a simpler process than slurry processing, at least in terms of the equipment required.



Above: Rotating double screws at different rates creates a sand plug, which aids pressure holding capacity

Using an EPB rather than slurry TBM eliminates all the slurry processing and separation plant required on the surface, and cuts out the major pumping lines for handling slurry to and from the TBM. However, such high-pressure pumping arrangements are better for handling more fluid ground and for high groundwater pressures. Standard EPB TBMs are limited to ground pressures of around 3-5 bar, but recent developments on sealing have lifted this to around 10 bar as in Robbins EPBMs being used in the Emisor Oriente drainage project in Mexico City.

Construction

As with other TBMs, EPB machines advance by cutting the ground at the face by rotary action of the chosen cutting elements under the pressure generated by the forward thrust of the TBM rams. The rotary action also mixes the excavated

solids with groundwater and any 'improver' introduced to the pressure chamber.

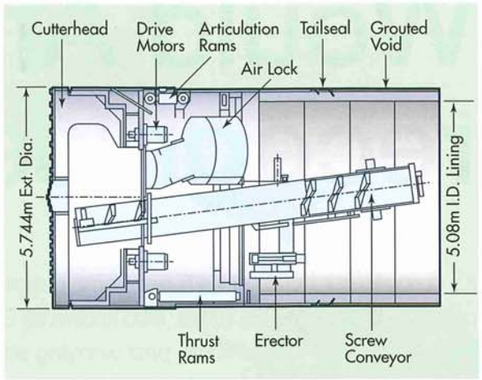
As well as removing this excavated soil from behind the cutterhead, the auger screw conveyor control must also cater for the need to maintain the required pressure at the face to balance the ground pressure. The speed and discharge rate - through a guillotine gate - of the auger screw is controlled to maintain correct pressure at the face, and match the spoil discharge to the advance rate of the shield. This balance, hence the term 'earth pressure balance', produced by conveyor control prevents over-excavation, and hence excessive loss of ground and consequent settlement. Since EPB TBMs were first developed, the screw conveyor has lengthened to facilitate balancing ground pressure with a more gradual reduction of the spoil pressure to discharge.

As indicated, the auger screw conveyor may be fitted with a guillotine gate or similar device at its discharge to help control the rate at which spoil is allowed to exit the system. Without the auger screw the operation could be likened to that of a mastic dispenser or vertical toothpaste tube in which the discharge rate is entirely dependent on the pressure applied on the material in front of the pressure plate. In the case of the TBM this would be likely to cause stability problems, particularly in mixed ground where the rate of advance might not be able to match the spoil discharge rate.

If large hard inclusions are anticipated, this will also require special attention to the design of the auger screw conveyor as well as the cutting tool and wear capabilities of the TBM cutterhead. If the conveyor tube is large enough, cobbles could be handled in the normal course of operation. Depending on power transmission requirements it may be possible to use an open-type 'ribbon screw' type of element without a central shaft, but the construction of the flights will need to be upgraded to handle the power transmission function without the central shaft.

For boulders and other larger hard inclusions, a stone or boulder trap will be installed near the start of the conveyor so that the boulder can drop out of the conveyor itself for removal.

In some cases the auger screw conveyor is split into two lengths as in the Robbins Mexico City machines already mentioned, better facilitating the transition from the TBM pressure chamber to discharge at atmospheric pressure. In this case the first section is inclined up to the guillotine gate and stone trap. This is of ribbon screw design at 900mm diameter and is capable of carrying boulders up to 600mm in diameter. The second section of a central shaft construction and runs across the top of the TBM back-up gantry. This length forms the transition between the high pressure of the face and the atmosphere. In this case discharge is to a series of belt conveyors.



Above: **Cutaway of an EPBM with major components. The amount of material removed is controlled by the speed of the auger conveyor (5) and the section of the opening by the drive unit**

Spoil handling

The ideal natural ground material for excavation by EPB TBM is a mixture of clay, silt and water, but this is found infrequently, requiring spoil improvement to achieve optimum performance (see below). Obviously soil improvement is unlikely to work on hard rock inclusions as may be found in made ground, glacial deposits and strata disturbed by ground movements. In such cases there must be facility for removing hard inclusions from the spoil for disposal or crushing.

In it's simplest form, the TBM auger, or screw conveyor, performs the initial mucking out function by extraction the spoil, usually as a paste, from the face pressure chamber of the TBM, and carrying it to its discharge end over a rail car or belt conveyor. In order to perform the function of counterbalancing ground pressure at the face, this action must be coupled to maintain this pressure but gradually reduce it until the discharge at atmospheric pressure is reached. This can be accomplished by reducing the screw drive speed to less that the optimum for spoil discharge. Similarly a 'plug' of moving spoil can be created within the screw conveyor to eliminate voids and form a seal against the higher pressure at one end of the conveyor. If two screw conveyors are used in tandem, this plug can be formed most easily between the two conveyors by running at different transmission rates.

Improving spoil

The handling of some difficult ground by EPBMs can be made possible or improved by the introduction of various materials to improve its characteristics. Whether foams, polymers or bentonite, these are injected in the TBM's mixing/pressure chamber between the cutterhead and bulkhead. It must be ensured that the chemical components are acceptable to the regulatory authorities and the controller of the spoil disposal site. In some jurisdictions even bentonite is considered a contaminant. The mechanisms of the exact effects of additives are too complex to detail here. Another subject for 'How it works', perhaps?

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Driving a life balance

Left: Simon Hoblyn

Simon Hoblyn has been working for Singapore's Land Transport Authority (LTA) since 2005 and is currently a senior project manager on Phase Two of the new Down Town Line (DTL). He manages tunnelling works on the northern half, overseeing seven slurry TBMs and two EPBs of 6.6m diameter.

"Work has reached the TBM mobilisation stage with a number of launch shafts bottoming out with the contractors preparing their sites for TBM delivery and assembly," says Hoblyn. "Typical current day-to-day activity includes working with our contractors to ensure their designs and working methods are compatible with Singapore and LTA's demanding requirements.

"Designs and methods carefully planned on paper can often not quite work in the real world requiring fine-tuning and adjustment on site. Management of these changes and adjustments keeps the job on track."

Although every project has unique challenges and experiences to offer, for Hoblyn, working for the LTA stands apart from past experiences.

"I have spent the majority of my working life with tunnelling contractors working in hands-on positions on projects in Europe, North Africa and the Far East. Working for LTA, the developer and project manager, has given me a view of tunnel project management that I would not have seen with a contractor.

"I have been involved in outlining concept design for the tunnels for a new railway, then packaging into contracts, procuring contractors, developing designs and specifications and now supervising construction of the tunnels and associated structures. Thanks to LTA's philosophy of proactive management I have been able to keep my hands-on approach through all these processes."

LTA has a 'transport masterplan' which will involve tunnelling continuing for the rest of the decade, according to Hoblyn. He has worked for LTA for six years and should see completion of DLT2 tunnelling in the next two.

"After that I'm not really sure [what I will do], I can't plan, personally, that far ahead.

"I am fortunate to be able to say I thoroughly enjoy my job. I have enjoyed tunnelling as a career since day one and I hope I will be able to say that for a good many years to come."

Working for so long, so far away from home does not bother the Englishman.

"I come from a small fishing village in Cornwall and went to school in Plymouth. I never managed to work on the Saltash Tunnel or Plymouth's Sewage Treatment Scheme so I have never worked at home and have taken working away from a home base as the norm throughout my career.

"Fortunately I enjoy travelling and have looked forward to the challenge of settling in to a new location or a new culture every few years. Of all the places I have worked though I can honestly say that Singapore has been the easiest to settle in to and maintain a sustainable work life balance.

"Stress is part of any job that requires the safe delivery of a quality product within a fixed schedule. The stress involved in tunnelling in an urban environment is amplified by the close proximity to sensitive structures and the general public. Stress is manageable though with a good life balance. For me that involves golf. The more stressed I get, it seems the worse my golf gets, but golf is only a game – isn't it?"

Hoblyn graduated with Mining Engineering from The Royal School of Mines of Imperial College in 1988 and was, as he puts it, 'enjoying a well-earned post university break' when his mother decided it was time for him to work for a living.

"This was at the time TML was gearing up for the Channel Tunnel. They had placed a number of double page advertisements in the local paper – I had not heard of *T&TI* at the time (*a terrible confession – ed.*) – looking for fitters, sparks and other industry trades from Devonport Dockyard which was sadly winding down. I'd obviously got under my mum's feet one too many times as she slapped the paper in my lap and insisted I write off on spec in case they needed engineers.

"Of course they did, and that was the end of my gap month. After a brief interview I started hanging plumb bobs, chasing lasers and dodging curses from lead miners and pit bosses. The craic was addictive though so when the Channel Tunnel was over I happily followed the work to Liverpool, Cumbria, Denmark, London, Taiwan, China, Singapore, Egypt and back to Singapore where I have been for the last nine years now."

No tunneller would dream of suggesting that they learned the job in the classroom. The unforeseen challenges and dangers of the trade only become apparent with years of experience.

"I could recount the nightshift on a job in London where following the opening of a club opposite the site we were left with the unusual challenge of coaxing down a transvestite who had climbed up the gantry crane – but stories like these tend to raise far too many concerns about health and safety to put in print. So I'll save the stories for the pub later.

"Living and travelling the world with my partner of 18 years, (who I met in Liverpool whilst working on MEPAS II) finally marrying her in 2009 in Singapore, ranks up there with the biggest achievements of my life.

"Work wise, completing the tunnelling on Singapore's Deep Sewer DTSS T-06 which involved 9.6km in extremely varied ground using an EPB was a challenge. Having been involved in DTL2 from concept design up to this point of preparing to start tunnelling feels like an achievement, however the most challenging part of the project is yet to come."

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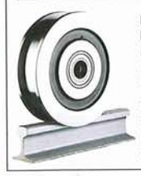

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21 - 26 MAY, 2011
WTC 2011 Helsinki - Underground spaces in the service of a sustainable society
The Finnish Tunnelling Association awaits you in Helsinki. A boom in tunnelling is currently underway in Finland. In this exciting environment WTC 2011 has been organised. General subtopics to include: planning the usage of subterranean spaces, municipal services, operational technologies, traffic and logistics, geologic disposal of nuclear waste, renewable energy, project management.
Website: www.wtc11.org
Booking / accomodation enquiries:
Tel: +358-9-5607500
Email: wtc11@congrex.fi

15 - 18 JUNE 2011
6th Annual meeting of chartered civil engineers in Opatija, Croatia
The specific seminar topics, all in the civil engineering sector, include tunnels in urban areas, geotechnics and project management. The opening session and round-table discussion should, say the organisers, show which projects should be started in this immediately before and after entering the European Union. For more information see www.hubtig.com.
Contact the secretariat, Ms Dada Papista. Tel: 00385 1 6130 062, email dada.paptista@hubtig.com

19 - 22 JUNE 2011
RETC 2011 - Rapid Excavation and Tunneling Conference and Exhibit, San Francisco, California
RETC is an international forum for the exchange and dissemination of developments and advances in underground construction.
For more information contact event organiser: RETC Exhibits, 8307 Shaffer Pkwy, Littleton, CO 80127, 303-948-4213, gury@smenet.org

22 - 23 JUNE 2011
Tunnel Design and Construction Asia, Sentosa, Singapore
Featuring best practices in geotechnical investigation, EPC contracting, project funding and risk management for Asia's tunnel infrastructure. The keynote speaker will be Heinz Ehrbar, chief construction engineer of AlpTransit Gotthard. Tel:+65 6722 9388
Email: enquiry@iqpc.com.sg

29 - 30 JUNE 2011
Underground Construction Conference and Exhibition, London
The eyes of the global tunnelling industry are swivelling towards the UK with some of the world's largest underground construction projects getting underway. Event includes: technical and design developments in underground construction, tunnel operation and maintenance, sustainable development and minimising the impact of underground works, a world wide tunnelling perspective, UK projects - today and the future, ground investigation, treatment and monitoring.
Tel: +44 (0) 207 973 6695
Email: g.stringer@hgluk.com
Website: 2011.tunnellingshow.com/

12 - 16 SEPTEMBER 2011
6th International Symposium on Sprayed Concrete, Tromso, Norway
Main themes will be design, construction and durability of wet-mix sprayed concrete in underground structures. The Norwegian Concrete Association is currently revising the Publication No. 7, Sprayed Concrete for Rock Support. This will be debated during the symposium. Contact: Siri Engen Email: siri engen@tekna.no Website: www.sprayedconcrete.no

14 - 15 SEPTEMBER 2011
IUT 2011, Sargans, Switzerland
Those involved in tunnelling will get together to exchange views and inform themselves about the latest trends and technologies. The traditional IUT Evening on the first day of the fair, being held in a VSH cavern, will be a highlight: here exhibitors and visitors will be able to exchange views against a relaxed background and experience an unforgettable evening. Contact: Deltacom
Projektmanagement +49 (0)40 35 72 32 - 0
info@deltacom-hamburg.de

19 - 23 SEPTEMBER 2011
Hydropower Africa 2011, Johannesburg, South Africa
Hydropower Africa 2011 is a niche meeting forum where comprehensive presentations, panel discussions and focused sessions will address the issues surrounding the financing and the implementation of hydropower projects in Africa. For further information, call: Nicolaas Loretz, Tel. +27 21 700 3555.

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition that is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site: Editor, 'Tunnels & Tunnelling International', Boundary House, 91-93 Charterhouse Street, London, EC1M 6HR, United Kingdom.
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Web: www.tunnelsandtunnelling.com

BRITISH TUNNELLING SOCIETY

21 APRIL 2011: **Harding Prize Competition**
The Competition is open to all aged 33 or under at the end of 2010. Entrants must submit an original paper relating to any aspect of tunnelling which they consider of interest to those in the tunnelling industry. The closing date for submission of papers is 28th February 2010.

19 MAY 2011: **BTS AGM + Limerick Immersed Tunnel**
The Limerick Tunnel will provide a new road crossing under the River Shannon. The tunnel comprises five 100m long immersed tunnel elements, a cut and cover tunnel and approach ramps on each bank.

29 JUNE 2011: **High Speed Railway Tunnels in Spain**
With the opening of the new Levante line, the Spanish High Speed Railway network has become the longest in the world. HSR lines with their demanding alignments require the design and construction of an unusually high number of tunnels, some of which are amongst the longest and more important in the world.
This presentation provides information of three good examples of the tunnels recently built in Spain: Guadarrama tunnel, Pajares tunnel and finally Atocha-Chamartan tunnel. This is an evening BTS Presentation being held at the "BTS Underground Conference 2011" on 29th to 30th June 2011. It is a 2 day conference being held in the Earls Court Exhibition Centre.

15 SEPTEMBER 2011:
Crossrail
Status update. Latest developments on this major London project.

20 OCTOBER 2011:
BTS / BGA Joint Event. Towards a Specification for the Ground - The use of Geotechnical Baseline Reports in the UK
Ground References Conditions. Working title details to follow.

17 NOVEMBER 2011:
Dulles Airport Rail Tunnel, Washington DC
Dulles Transit Partners is responsible for designing and constructing Phase 1 of the Dulles Corridor Metrorail Project. An 11.6 mile extension of the existing Washington Metro to Dulles International Airport. A central feature of the project is the Tysons Tunnel.
The Tysons Tunnel is a twin-bore, two-track tunnel running at 762m in length between portals. The central 534m is being constructed by SCL.

contacts

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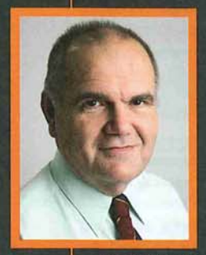

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