Expanding Horizons

Underground

MEYCO

OCTOBER 2011

Tunnels & tunnelling INTERNATIONAL

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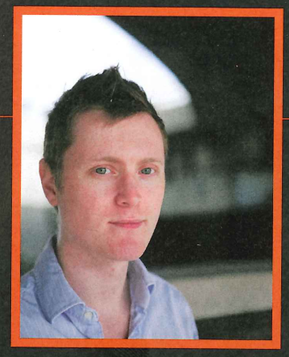
Western Europe
A station floated under a station, a tunnel to rival Gotthard and a self help consortium

Precast segments
Precision tolerance measurement, handling procedures and the joy of gaskets

Stare down the ages

The century old Tottenham Court Road Station gets a major revamp



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I need a dollar

The tunnelling industry, which has shown its resilience during the global economic turmoil, could be under threat as Greece jeopardises the world's financial stability. Emerging economies, the main source of new work through the western recession, are reliant on a stable Euro filling their foreign exchange coffers to protect growth. If the situation in Greece is not resolved, a weakening or destabilisation of the Euro could have a domino effect on the newest tunnelling markets.

As I write, Athens is playing host to international inspectors who will soon rule on whether or not the European Union (EU), the International Monetary Fund (IMF) and the European Central Bank – together known as Troika – will grant Greece an EUR 8bn (USD 10.9bn) bailout to save it from bankruptcy next month.

In a brilliant flow chart published by the BBC (www.bbc.co.uk/news/business-14977728) it is clear that regardless of the actions of Troika, or the austerity demands, Greece is set for a very grim future. The only question that remains is whether the rest of the eurozone will be brought down with it.

The euro was created in 1999 under the Maastricht Treaty. Clear criteria were set out for each country to meet before it was eligible to join. In short, they were: control of inflation rates; an annual deficit of less than three per cent; a debt of less than 60 per cent GDP; and control over long term interest rates.

When Greece joined the euro in 2001 the criteria were seemingly thrown out the window. It had a national debt of 117 per cent, a government deficit of more than three per cent, high unemployment and high inflation.

Investors warned at the time that allowing Greece to join the euro would send out the wrong signal to the financial markets suggesting that weaker economies may be allowed to join without fulfilling the Maastricht criteria, and would diminish confidence in the men controlling it. Greece backed it. Then Prime Minister Costas Simitis said: "We all know that our inclusion in the European Monetary Union ensures for us a greater stability."

The investors were right. This initial flouting of the rules prompted the EU to throw the whole book away in an effort to regain control over the currency. When the financial crisis struck at the end of the decade the EU changed the rules on bailouts (which were not allowed under the Maastricht Treaty) to have greater intervention powers. There is still no way of exiting the euro without leaving the EU altogether.

Outside of Europe the popularity of the euro as a national reserve currency has been growing since its launch. Encouraged by a weakening and less reliable US dollar and Japanese yen, it quickly replaced the old deutsche mark as the second most popular Foreign Exchange (Forex) Reserve.

Forex reserves are a vital tool for countries to stabilise their economies in the global market. In rapidly developing markets, where tunnellers are weathering the recession, these reserves build confidence for foreign investors, helping control inflation and exchange rates. And the euro is playing a key role.

According to IMF figures, in 1999, 71 per cent of reserves globally were in US dollars and just 18 per cent in euros. By the end of last year the euro accounted for 26 per cent, taking much of its growth from the US dollar, which fell to 64 per cent.

In emerging economies the popularity of the euro has grown more rapidly than in advanced economies. In 2010 almost a third of Forex reserves in new markets were euros. While each country holds its Forex make up as a closely guarded secret, it is likely that two of the most significant tunnelling markets will be affected. It is thought China holds some 10 per cent of its reserve in euros. And India is thought to have 25 per cent of its reserve in euros.

The eurozone turmoil will pose challenges for developing markets over the coming months. According to leading economists, loss of faith in the euro would lead to a global meltdown and the resilience of the tunnelling industry will be truly tested.

Jon Young

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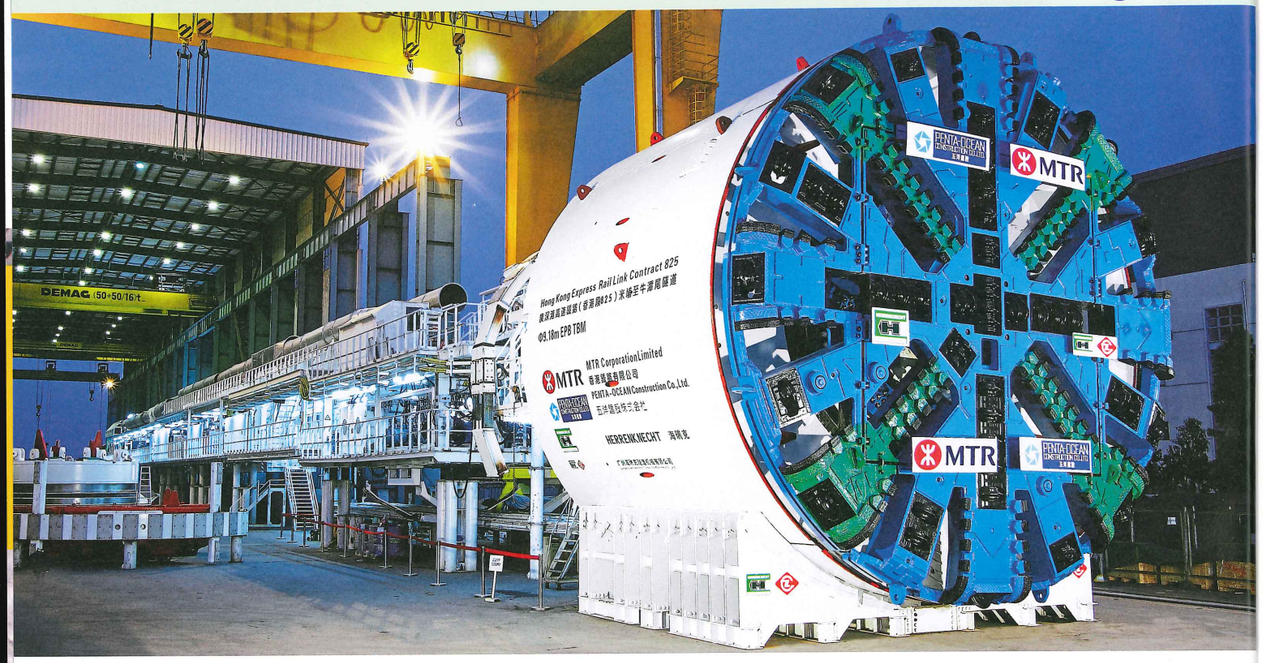
On the cover:

Tottenham Court Road Station's extensive upgrade works after a century of operation

In the supplement:

Eight TBMs being built to bore Toronto's subway and light rail



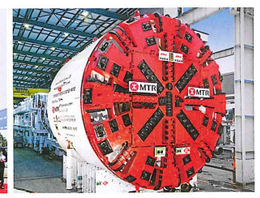
LAUNCHING OF FIRST DRILLING GIANT FOR XRL HONG KONG SECTION.

When the "Guangzhou-Shenzhen-Hong Kong Express Rail Link" (XRL) has been put into operation, this will reduce travel time by 40 million hours annually. The present travel time of 100 minutes will then be reduced to about 50 minutes. This involves building 140 kilometers of new high speed route between the metropolis of the Pearl River delta from Kowloon to Shenzen and Guangzhou.

Herrenknecht is manufacturing a total of six large tunnel boring machines (Ø 9.18m – 13.17m) for the Express Rail Link: one Mixshield for the Shenzhen section, four Mixshields and one EPB Shield for the Hong Kong section to excavate a total of 25.8 kilometers of tunnel. The first drilling giant for the Hong Kong section was put into operation at a ceremony on August 10, 2011. The Herrenknecht EPB Shield S-620 was given the name "Zhao-jun". This is the name of a beauty known from ancient China and it stands for "communication and connection". It was chosen from among 33,500 proposals in a public competition which was organized by the client MTR Corporation. The Herrenknecht Mixshield S-550 (Ø 13.17m) is already working underground for the XRL in Shenzen.

SHENZHEN AND HONG KONG | CHINA

PROJECT DATA	CONTRACTOR
S-620, S- 550, S-623, S-624, S-630, S-631 **1x EPB, 5x Mixshields** Diameter: 1x 9,180mm, 2x 9,250mm, 2x 9,900mm, 1x 13,170mm Installed power: 1x 2,800kW, 1x 4,200kW, 4x 3,150kW Tunnel lengths: a total of 25.8km	S-550, S-623, S-624: China Railway 15th Bureau S-620: Penta Ocean Construction Co. Ltd. S-630, S-631: Dragages Hong Kong Ltd., Bouygues Construction



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Second Avenue breaks through

USA

The TBM excavating Phase One of the Second Avenue Subway in New York made a breakthrough last month into an existing tunnel at Lexington Avenue/63rd Street station.

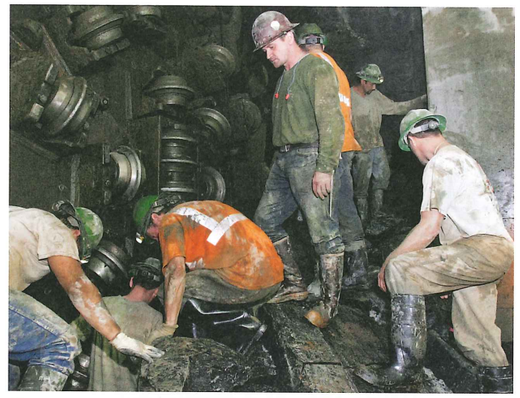
This is the TBM's second pass from 96th Street along Second Avenue having completed the 6.7m diameter western bore in March. The 7,793ft (2.4km) eastern bore started shortly after in April.

A joint venture of Skanska, Schiavone and Shea (S3 Tunnel Constructors) has been working on the twin tunnel project since 2007.

S3 elected to use one TBM for both bores to save space in the launch box and to avoid the logistics of doubling the electricity, water, ventilation and other services required.

The JV used a reconditioned open-face main beam gripper machine with 44 cutters, 17in in diameter, from Shea's fleet—a decision that saved time in a tight schedule. Working with Herrenknecht, it took roughly five to six months to refurbish and rebuild the machine.

Advance rate was initially predicted at 50ft (15.2m) per day but in reality approximately 40ft (12.2m) per day was achieved. Risk to existing buildings and infrastructure above meant the contractor had to carry out more probing than originally planned.



Above: Breakthrough at Second Avenue (photo courtesy of MTA)

Herrenknecht chosen to supply London Thames Tunnel TBMs

GREAT BRITAIN

Herrenknecht will manufacture the final two Crossrail TBMs, the project announced last month. The 7.08m diameter slurry machines will bore the Thames Tunnel portion of the project. The slurry setup was chosen over EPB, used on the remainder of Crossrail, due to the chalk conditions through the Thames Tunnel alignment.

Herrenknecht was earlier this year selected by contractors to supply the six EPBMs to excavate the rest of Crossrail, primarily through London Clay. The Thames Tunnel contracting JV comprises Hochtief and J Murphy & Sons.

The Thames Tunnel TBMs will be launched from the Plumstead portal in late 2012 and drive a 2.6km twin-bore westwards. Portal construction was underway as *T&TI* went to press.

Central Subway to proceed

USA

The San Francisco Municipal Transportation Agency (SFMTA) announced initial notice to proceed (NTP) on 13 September for the Central Subway's largest construction contract, worth USD 233.5M.

The SFMTA last month moved forward with the first of three NTP authorisations for the tunnelling contract, awarded in June to a joint venture of SA Healy and Barnard. This allows the contractor to proceed with ordering the two TBMs that will be used to construct the 1.7-mile (2.7km) twin bore tunnels for the underground portion of the Central Subway Project.

The contract had three distinct NTP authorisations: NTP One (USD 35M) authorised procurement of the 6.4m diameter TBMs, NTP Two (USD 36M) authorised construction of the tunnel launch box and contractor's work area and NTP Three (USD 163M) authorised the start of tunnelling, which includes construction of approximately 8,240ft-long (2,512m) segmental lined twin-bored guideway tunnels.

Tunnelling not desired for offspring

***T&TI* online poll: Would you raise your child to be a tunneller?**

News in brief

Airport Link trust for fallen tunnel colleague
The Airport Link team last month launched a campaign to financially help the family of a tunneller struck by a beam and killed. Hundreds of the man's co-workers will donate a days pay. The Thiess John Holland JV said it would also contribute to the trust. Work was halted for a tribute day.

Indy Deep Rock contract awarded to Aecom
Aecom announced last month that it was awarded the USD 25M contract from the City of Indianapolis to provide construction management services for the USD 280M Deep Rock Tunnel Connection and dewatering pump station in Indianapolis. The main tunnel is approximately 12,680m long and 5.5m in diameter at a depth of 70m.

California tunnel receives local award
The San Francisco Section of the American Society of Civil Engineers recently honored the New Crystal Springs Bypass Tunnel with its Large Project of the Year award at its annual meeting last month.

World at a glance

A round up of the past month's milestones and challenges

CALIFORNIA, USA

The rehabilitation of the Cal Park Hill rail tunnel is Public Works Project of the Year according to the American Public Works Association (APWA). The tunnel was constructed in California in 1886 as a single-track rail tunnel and is now a combined rail, pedestrian, and bicycle facility. The category was historical restoration and preservation projects valued between USD 25M and USD 75M (see *T&TNA*, September 2010, page 25.

The award was presented at APWA's 2011 International Public Works Congress in Colorado on Monday. Jacobs was construction manager, Ghilotti Construction Company were managing contractors and Aecom was primary consultant. Works were carried out for the Marin County Department of Public Works.

VERACRUZ, MEXICO

Blasting and tunnel works last month commenced at Caballo Blanco gold project in Veracruz State, Mexico. Canadian contractor Goldgroup Mining said that the tunnel would be driven into the La Paila zone for better interpretation of the high-grade structures within the mineralised zone and also to extract large samples for testing.

Keith Piggott, Goldgroup president and CEO said, "This is another important milestone. Together with our diamond drilling program and advanced on-site column leach testing, this tunnel development is consistent with our schedule to commence production at Caballo Blanco in 2012."

BUENOS AIRES, ARGENTINA

Buenos Aires mayor Mauricio Macri last month urged a priority focus on public works projects that can prevent loss of life. A train-bus collision killed 11 people and injured over 200 more in Argentina's capital last month.

Macri argued the accident could have been prevented by the undergrounding of the Sarmiento rail line. The USD 1.2bn project to move the Sarmiento Line into an underground tunnel has been delayed for over a decade, despite hundreds of deaths every year from train collisions. In 2010, some 269 people were killed. Geodata was awarded the detailed design in 2010.

LONDON, GREAT BRITAIN

Contract notice was last month given seeking expressions of interest for major fit out of the new Crossrail tunnels. Work on the approximately GBP 400M (USD 625M) will start in 2014 after the two years of tunnelling have been completed.

Crossrail programme director Andy Mitchell said, "Such is the scale and complexity of the task it will take several years to complete the fit-out works with people working around the clock to complete the job."

A Crossrail spokesman added, "The new Crossrail tunnels will also require over 50 ventilation fans, 40km of walkways, 60 drainage pumps and 30km of fire mains, as well as lighting throughout the entire length.

"The fit-out works will be carried out within the entire tunnelled section of the Crossrail route between Royal Oak, Pudding Mill Lane and Plumstead Portals. It is envisaged that the selected contractor will start fit-out simultaneously from both Royal Oak and Plumstead portals."

The contract will be awarded in late 2012.

DURBAN, SOUTH AFRICA

A fire in a tunnel housing a 132kV cable left large parts of Durban without power last month. Investigators found evidence of homeless people seeking refuge in the tunnel, adjacent to the cable fire. The cost of repair works to the tunnel and cable are expected to run into millions of Rand and take over two months to complete. The tunnel was broken into twice despite engineers sealing the area with concrete slabs, reported an electrical department spokesman for the eThekwini Municipality.

RAWALPINDI, PAKISTAN

Muhammad Shahbaz Sharif, the chief minister of the Pakistani province of Punjab, last month approved construction of the Mareer Chowk tunnel project in Rawalpindi, Pakistan.

The project will put the congested Mareer Chowk junction underground and widen the railway crossing. The junction is a major road block on the main route between Rawalpindi and neighbouring city Islamabad. The PKR 360M (USD 4.1M) project is part of the 9.2km elevated expressway project from Mall Road to Faizabad Interchange.

The proposal to commence the tunnel project immediately was submitted by member of the national assembly Shakeel Awan and member of the provincial assembly Shehreyar Riaz.

XI'AN, CHINA

Northwest China's first metro line started moving in Xi'an, Shaanxi Province on Friday. Construction on the 20km-long metro, Xi'an Subway Line Two began five years ago. State news agency Xinhua said, "The plan was approved in September 2006 by the State Cultural Relics Bureau before China's top economic planner the National Development and Reform Commission submitted the ancient capital's proposal to build a metro system to the State Council."

It added that settlement was a great concern with many historical buildings above the alignment. "Tunnels were designed to be more than 12 meters deep underground to avoid cultural relics which were mostly located within a depth of eight meters," said Zheng Yulin, director of the city's cultural relic bureau. Tunnelling also avoided the ancient city walls.

Xinhua added, "Altogether six subway lines with a length of 251km are scheduled to be built in Xi'an by 2020, which is part of the city's ambitious plan to become one of China's biggest cities." See *T&TI* next month for a report on the Xi'an Metro.

OSAKA, JAPAN

Hitachi Zosen conducted a factory reception test towards the end of last month for a TBM ordered by contractor Shanghai Tunnel Engineering Company (STEC). The TBM tested is the final machine destined to work on contract C920 of the Singapore LTA's Downtown Line Two (DTL2).

"The machines for contract C920 were each manufactured in EPB configuration," a Hitachi Zosen spokesman told *T&TI*. "Four machines were commissioned in total, each of 6.63m in diameter."

The USD 275M C920 works cover Newton Station and associated tunnels. It was originally scheduled for completion in 2015 by LTA.

DUBAI

Dubai's Metro Green Line opened on schedule on 9 September and logged 106,000 passengers on its first two days of operation. This includes journeys in integration with the current Red Line with which it connects.

Adnan Al Hamadi, CEO of Dubai's Road Transport Authority (RTA), said that the number of passengers recorded was a clear testament to the growing culture of public transport.

The underground line is to have a further surface extension pending opening of more property developments. Dubai Metro is operated by Serco Middle East.

AUCKLAND, NEW ZEALAND

Draft versions of four major economic and infrastructure plans for Auckland, New Zealand have been released for public consultation. Stephen Selwood, chief executive of the New Zealand Council for Infrastructure Development (NZCID), simultaneously published concerns over funding.

Selwood last month said, "The plans are highly ambitious in nature and set out a bold vision for the future development of the city […] While there will be almost universal endorsement of the vision […] There is still considerable work to be done on integrating each of the plans into a fully cohesive, coherent and compelling development strategy for Auckland."

The four plans: the Auckland Plan, the Economic Development Strategy, the City Centre Masterplan and the Waterfront Plan were released on 20 September for the submission period, which will end on 25 October.

Selwood added, "Each plan has its signature infrastructure projects, such as light rail for the Waterfront Development Plan, heavy rail in the CBD Master Plan and combined western aligned road/rail tunnel in the Draft Auckland Plan, but it is not at all clear how these will work together or how they could possibly be funded given that there is already a NZD 10-15bn (USD 7.7-11.6bn) deficit facing the council to deliver on its current transport plans."

Delhi metro first railway paid to be green

INDIA

The Delhi Metro became the world's first railway awarded UN carbon credits last month. The credits worth INR 470M (USD 9.5M) annually for seven years were awarded to operating body Delhi Metro Rail Corporation (DMRC). The average 1.8M daily journeys recorded reduce pollution in New Delhi by 630,000 tonnes a year.

A UN scheme called the Clean Development Mechanism (CDM) was set up to award credits as a financial incentive to cut greenhouse gas emissions. A DMRC spokesman added, "This is the second CDM project from DMRC to be registered with the UN body in the last three years. DMRC's first CDM project on regenerative braking had also achieved many international firsts.

The Delhi Metro passed strict UN requirements to scoop the credits

"Every passenger who chooses to use the metro instead of car/bus contributes in reduction in emissions to the extent of approximately 100g of carbon dioxide for every 10km."

The spokesman added, "No other metro in the world [qualified for] carbon credits because of the very stringent requirements."

Skanska-Traylor wins 86th Street station

USA

The MTA last month awarded a contract to excavate the 86th Street Station cavern of the Second Avenue Subway project in New York to a joint venture of Skanska USA and Traylor Bros.

Valued at USD 301M, the contract included excavation, installation of the structural lining and construction of the station's basic structure. The joint venture will also perform utility work and underpin existing buildings adjacent to the work site.

"With this award we move one step closer to making the Second Avenue Subway a reality for our customers," said Michael Horodniceanu, president of MTA Capital Construction.

Construction at the 86th Street Station cavern was set to begin late last month as *T&TI* went to press. Work should be completed by autumn 2014.

The USD 4.45bn project to build Phase One of the Second Avenue Subway is the largest expansion of the subway system in generations.

Almost half report negative health impact of underground work

***T&TI* online poll: Do you suffer from any medical conditions as a result of working underground?**

Yes	46.7%
No	53.3%

Report says graduate engineers wasted

GREAT BRITAIN

Some 24 per cent of UK engineering graduates have taken unskilled positions said a report from Birmingham University. 'Is there a shortage of scientists?' was presented to the British Educational Research Association (Bera) annual conference in London, UK last month. The report added that some 46 per cent of 2009 engineering graduates entered fields related to their subject.

Confederation of British Industries director for education and skills policy Susan Anderson said, "The shortage of science, technology, engineering and maths graduates is an issue for businesses."

However, report author Emma Smith said, "It is astonishing, in the light of claims of science graduate shortages, that so few new graduates enter related jobs."

News in brief

Mumbai Metro's first line to be ready by late 2012
Project executor Mumbai Metro One Private Limited (MMOPL) last month announced that Mumbai's first metro corridor from Versova to Ghatkopar via Andheri will be ready by the end of 2012. MMOPL said that several stations including Jagruti Nagar and Airport Road are almost 95 per cent complete, others are at 70-75 per cent.

New Jersey and DOT settle ARC tunnel debt
US transportation secretary Ray LaHood announced an agreement with New Jersey governor Chris Christie for the state to reimburse the federal government USD 95M for money that was supposed to be spent building the ARC Tunnel between New Jersey and New York. Christie cancelled the tunnel a year ago and the department has since sought repayment of USD 271M of federal money.

Feasibility study for 20km Netherlands rail connection
The M55 consortium led by Mott MacDonald and Baca Architects submitted a feasibility study with its proposals for a new 20km railway connection in the Netherlands on behalf of the operating company Werkmaatschappij Almere-Amsterdam (WAA). It included a 9km tunnel. Under Ijburg and Ijmeer, with two underground stations.

Seattle U-Link progress
The two TBMs mining the University Link light rail extension project in Seattle have advanced approximately 945m southbound, and 488m north towards Capitol Hill.

QRail invites interest in 'urgent' Doha Metro

QATAR

Qatar Railway Corp (QRail) last month invited expressions of interest from local, regional and international companies for the design and construction of the Qatar Integrated Railways Project (QIRP) – Doha Metro.

"The invitation is a major opportunity for local contracting companies to join in consortia with large international contractors to design and build six urgent construction packages," said Eng Saad Ahmed Al Muhannadi, CEO of QRail. "These include 22km of underground tunnels as well as 15 underground stations in the first stage."

The statements were made at a set of industry awareness events in May and July this year. More than 700 representatives visited from around the world. In addition to the underground work, required elevated works, roads and utilities diversions were described as critically important. QRail was set up to support and co-ordinate the growth of Qatar's rail industry and will develop the appropriate legal and legislative frameworks to ensure that all local and international regulations are met.

In April QRail signed a five-year contract with Parsons International and Aecom to construct the Lusail Light Rail Transit system. Some 7km of underground route and seven underground stations from a total of 30km and 24 stations will be built to serve the new Lusail City development.

Crossrail Royal Oak portal early completion

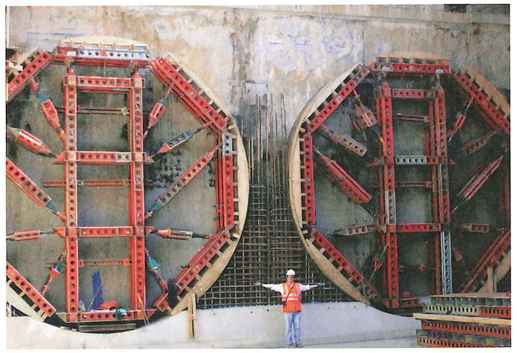
GREAT BRITAIN

Crossrail's Royal Oak portal was completed a month ahead of schedule. Works included a massive ramp structure to take the Crossrail tracks from surface to the tunnels. Construction began in January 2010 by a Costain and Skanska JV. Capita Symonds designed the portal.

At the end of the ramp, a concrete headwall was constructed with a pair of 7.24m-diameter tunnel eyes created for the installation of steel rings. The eyes mark the exact spot where the TBMs will kick off excavation for the Crossrail tunnels.

A Crossrail spokesman said that prehistoric animal bones were unearthed during excavation. These will be transferred to the Natural History Museum.

The Crossrail project requires five tunnel portals, to be constructed at Pudding Mill Lane, Victoria Dock, North Woolwich and Plumstead, as well as Royal Oak.



Above: Tunnel eyes installed at Royal Oak portal, the first of five required (photo © Crossrail)

Tennessee seeks funds

USA

The City of Chattanooga, Tennessee, US is planning an upgrade to the Wilcox Tunnel.

The City Council approved a resolution last month to authorise the mayor's application for a USD 25M federal Transportation Investment Generating Economic Recovery (TIGER) III grant. It also agreed to provide another USD 17M in funds. The USD 42M project relies upon the grant to proceed. Proposed works would include a new, two-lane eastbound tunnel and retrofit to the existing one-lane westbound tunnel.

News in brief

Federal funding for Southeast high-speed rail
The US Department of Transportation last month awarded USD 48.3M to North Carolina and Virginia to advance the development of the Southeast High-Speed Rail Corridor. The state of Virginia will receive USD 44.3M for environmental analysis and preliminary engineering. Virginia's Department of Rail and Public Transportation will contribute USD 11.1M to the project.

Strabag scoops Toronto wastewater tunnel
The Regional Municipality of York has awarded a CAD 290M (USD 296M) contract to Strabag to build a 15km wastewater tunnel in the Greater Toronto Area, Canada. Tunnelling will be performed using four TBMs made by Caterpillar Tunnelling Canada with a diameter of 3.6m, provided by the client.

FCC opens two sections of Despenaperros pass in Spain
Spanish contractor FCC announced it had opened two sections of the mountain highway from Madrid to Andalusia. Tunnels involved were the 420m Corzo tunnel, the 240m Cantera and the 1,925m Despenaperros.

Industry split on local tender bias

T&TI online poll: Should the tender process be weighted in favour of local companies?

Yes	50.0%
No	50.0%

CH2M Hill announces buy out of Halcrow

USA

Us consultant CH2M Hill will take over Halcrow for GBP 124M (USD 192.8M) it was announced last month.

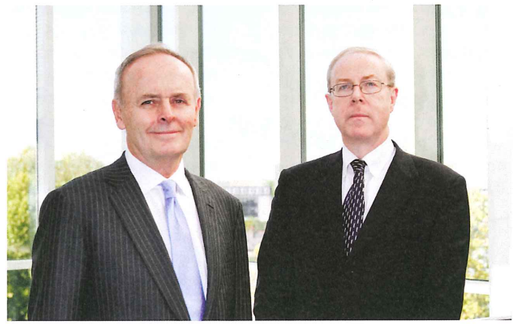
The agreement was expected to close in November as *T&TI* went to press, subject to the approval of Halcrow shareholders and the UK High Court.

Halcrow CEO Peter Gammie said, "The board's decision to approach CH2M Hill to discuss the sale of Halcrow is the culmination of a business relationship going back many years. We have worked together on many occasions and have become very much aware of each other's strengths and working practices."

CH2M Hill chairman and CEO said, "This acquisition is a game changer for our clients. Our global footprint will be deeper and our bench strength will be even more robust. By combining our resources and leveraging our collective technical know-how, we will set a new standard for the marketplace.

Best of all, our two firms are ideally suited in terms of cultures, markets, geographies, and we have a shared long-term vision for the future."

UK-based Halcrow was founded in 1868 and has specialised is engineering as well as planning, design and also in management services, mainly for infrastructure projects.



Above: McIntire (left) and Gammie at Elms House, Halcrow's London HQ

Bekaert acquires Qingdao Hansun

CHINA

Bekaert successfully closed the transaction to acquire the Qingdao steel wire plant of the Hankuk Steel Wire of Korea. The shares of Qingdao Hansun Steel were purchased in July through Bekaert's company in Hong Kong. The purchased company was renamed Bekaert (Qingdao) Wire Products.

Macdow annual review

AUSTRALIA

With its 2010/11 annual review published last month, McConnell Dowell announced AUD 2.85bn (USD 2.78bn) in secured new works. Despite what it referred to as a 'challenging trading environment'. The company's work in hand was valued at AUD 3bn (USD 2.93bn).

Revenue declined by four per cent to AUD 1.94bn (USD 1.89bn) despite the record level of work in hand. Profit after tax decreased by 57 per cent to AUD 35.3M (USD 34.42M). The balance sheet showed AUD 326M (USD 317.9M) cash in hand.

The report focused first on the firm's safety record. It featured even above the financial review in the CEO's report. Recordable injury frequency rate dropped 25 per cent from 8.33 to 6.14 with lost time injury frequency rate at a 15 per cent reduction from 0.8 to 0.68 out of a total 38.1 million man hours. To view the McConnell Dowell annual review e-book, visit: www.macdow.com.au

News in brief

Sao Paulo ring road prequalifications
Prequalification has begun for construction of the north stretch of the Rodoanel Mario Covas beltway. The 44km of road will include seven tunnels. Five of the six tender lots include tunnel work. Lot one has a 1.2km tunnel, lot two a 350 and 850m tunnel, lot three with a 1.65 and and 1.07km tunnel, lot four with a 290m tunnel and lot five with a 1,087m tunnel. Construction will begin in March for completion in late 2014. Visit the Sao Paulo highway department's website for more: www.dersa.sp.gov.br

Asia equipment tender
Invitation to tender for equipment in Neuhof tunnel on A66 motorway at Fulda, Germany. Contract value EUR 9.6M (USD 12.8M). Deadline for accessing documents is 1 November. Contact tel: +49 661 6005-0, or email: post.asv-fulda@hsvv.hessen.de

Norwegian tender for electrotechnical followup
Deadline 7 November for five control engineers for followup of electrotechnical systems and ventilation during engineering and construction in five eastern counties in Norway. Contract will last from January 2012 to December 2014. Further information available from Ole Gripstad of Statens Vegvesen. Tel: +47 815 22 000

Swiss highway safety equipment tender
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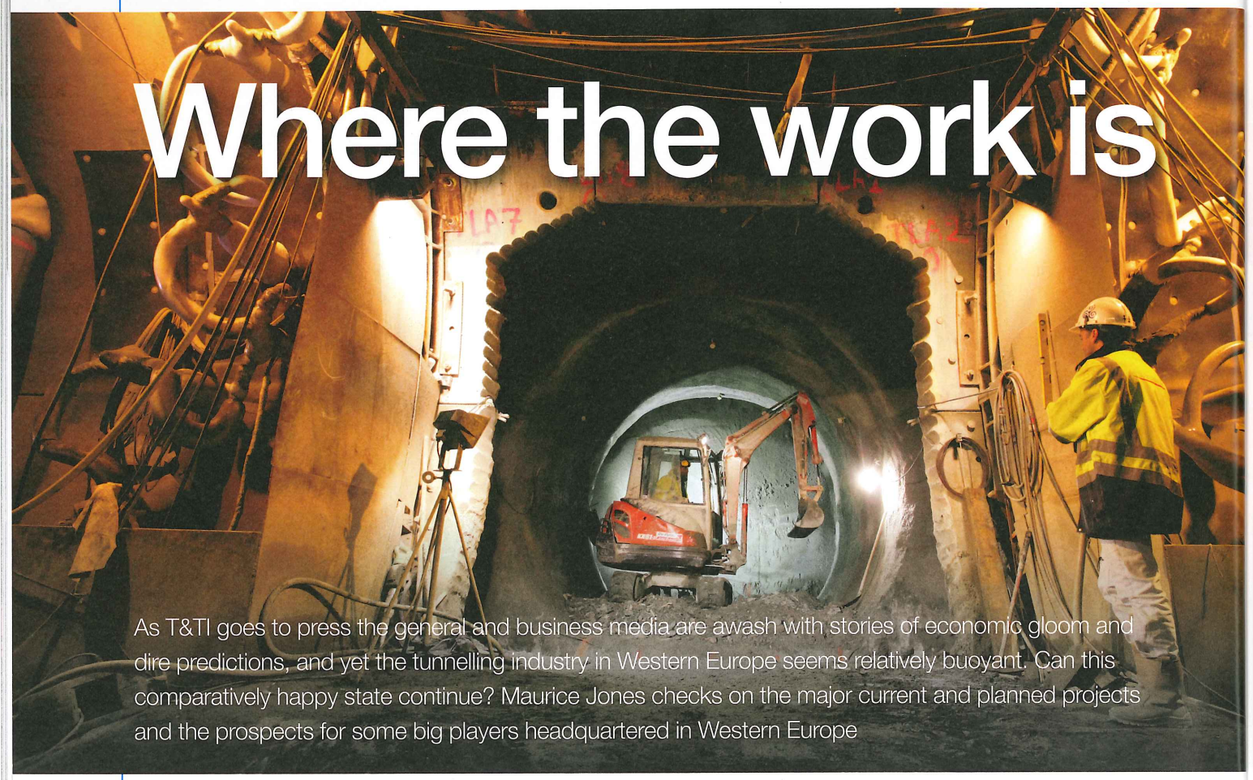

As T&TI goes to press the general and business media are awash with stories of economic gloom and dire predictions, and yet the tunnelling industry in Western Europe seems relatively buoyant. Can this comparatively happy state continue? Maurice Jones checks on the major current and planned projects and the prospects for some big players headquartered in Western Europe

Although not in boom conditions, the tunnelling industry in Western Europe still appears to be in a relatively healthy state with major projects under way in most countries. And yet companies are naturally nervous about the future.

London's Crossrail recently announced, in conjunction with contract awards, that the project was now 'unstoppable', apparently with some considerable relief, even though the Government's capital spending review had cleared the core of the project. It should be remembered that Crossrail was originally intended for completion for the London 2012 Olympics but, like many other major projects, had been delayed by early planning and financial concerns.

Throughout Europe it is natural to ask, "What happens when the current work has all been completed?"

Demands

The most common demands that should create tunnelling work are urban growth and congestion, aided by rapidly increasing fuel costs. Urban rail projects are a substantial activity, although not so much as in the rest of the world. These can place great demands on the tunnelling contractors and project managers, mainly to ensure that there are no settlement incidents and that logistics do not unduly affect normal city life.

Although cross-country high-speed rail projects with tunnels are still in action, such as in Germany, Spain and planned for France, the originally designated Trans European Network projects are nearing completion, with the exception of the new Lyon-Turin rail link. The emphasis has somewhat transferred to the infrastructure requirements of the new members of the EU in the East, and their neighbours, with major contractors following this work.

As for utilities, the major tunnelling market of sewerage is now reduced due partially to successful compliance with EU anti-pollution directives due to earlier projects, and better industrial practices including the 'polluter pays' principle. Exceptions in the UK include Southern Water's Brighton scheme, which ironically had been delayed by environmental objections, and Thames Water's Tideway main sewer project (including the Lee Tunnel).

Other utilities requirements include power cable tunnels (such as National Grid's London project), whether to meet increased power demand, avoid storm damage or perhaps to link in with new sources such as wind farms), plus telecommunications.

Tunnelling is only a small part of the activities of some of the biggest names in Western Europe's tunnelling industry, and much of that is off home soil. For example, Swedisg Skanska is active in general construction throughout Europe, but much of its large tunnelling work is now in the United States and Eastern Europe. An exception is shaft and headworks for a National Grid project in London.

Spain

Many other contractors are also looking further afield, perhaps for the first time. This is no truer than in the case of Spanish contractors and consultants that have seen the domestic tunnelling market, largely EU-funded, reduce rapidly. Thus these contractors have successfully bid for contracts in the UK, the US and other countries. It has been pointed out that this has a lot to do with good relationships with their bankers (see *T&TI* Comment, Feb 2011, page 3). The same will apply to other large and diversified contractors.

France

The biggest current tunnelling project in France, the Toulon highway tunnel to speed traffic around the city is approaching completion. Other major projects include the Lyon Metro (where the French tunnelling association and several other West European tunnelling associations are meeting this month) and the long-awaited Lyon-Turin rail link.

There are also plans still on the books for high-speed (TGV) rail to unserved regions of France, around and even through Paris, plus metro (RATP and RER) extensions in greater Paris. Underwriting by the government is by no means certain however. Through mergers and acquisitions, France also boasts some of the largest tunnelling contractors in the world, with a wide international base such as Vinci, Bouygues and Dragages.

Italy

The Italian government has been annoyed by its recent credit-rating reduction, claiming that it earns enough to service its debt. Whatever the truth of this, the nation stills has substantial transport tunnelling underway including use of the world's largest diameter TBM built to date (by Herrenknecht) for the Sparvo Tunnel for a highway in central Italy. Italy also exports its skills to a great extent, notably by Impregilo, Seli and Rocksoil.

Germany

As the leading economy in Western Europe, the tunnelling market in Germany should give a good indication of typical activity. However, its make-up has substantial differences from other countries mainly because long-distance travel by high-speed rail and road is still the dominant driver for demand.

The German tunnelling association and research organisation Stuva publishes detailed annual statistics of current and planned tunnel construction. The latest report by Alfred Haack and Martin Schaefer of Stuva shows a buoyant market. Transport tunnel construction increased from approximately 138km in 2008-09 to 159km in 2009-10 with a forecast of planned tunnelling for 2010-11 of 381km. Most of this is for Deutsche Bahn's (DB's) long-distance railways, creating faster routes through ranges of mountains and hills, totalling 91km in 2009-10.

DB finances are backed up by a vibrant multi-national transport business and not just national requirements.

Above: **Artist's impression of the new Stuttgart main rail station, a key part of Germany's high-speed rail network**
Opposite: **Excavating cross-passages in frozen ground for Antwerp's Liefkenshoek rail link tunnel to serve the port [Photo: CFE]**

Eire

Famously affected by the current European economic situation and a collapse in the property market, Ireland has little tunnelling left as the Dublin Metro North and DART Underground projects have been cancelled and the Metro West postponed following planning delays and a financial review.

The Limerick Tunnel also demonstrates the dangers of private finance initiative projects when things don't go right. The tunnel, as a business, has had its credit-rating downgraded since revenues are not as high as expected. This demonstrates the delicate balance that has to be struck between toll charges and the increasing cost of vehicle fuel.

Belgium

The Liefkenshoek rail tunnel (see *T&TI* July 2011 page 33), recently broken through, is an example of how innovative financing is producing a badly needed asset that will result in wider economic benefits.

This is perhaps a principle that could be followed by all projects facing difficult conditions. In this case the new rail link will allow faster transfer of goods to and from the Port of Antwerp, increasing both activity and revenues.

Netherlands

The Nord-Zuid rail route in Amsterdam, now under construction, (see feature, page 30) demonstrates the technical challenges that tunnelling engineers still have to meet and overcome, both in old urban situations and newer techniques in the innovative use of immersed tube tunnels.

Self help

Tunnel promoters in western Europe have to think with innovation, in business terms as well as technically. Perhaps one major way forward to future work is self-help, albeit in co-operation with other specialists such as planners and even bankers. It is rather too easy to say 'go where the work is', which is Asia, but this has drawbacks.

So when governments have no money for capital investment or bailouts, and with credit being squeezed, one answer is for tunnellers to 'consort' with others to promote a particular project, which has to benefit society (so politicians can claim credit) and make money (as financiers will want a 'dead cert'). These days project financial control has to be strict as there is little chance of governments providing safety nets, and the public is getting increasingly annoyed at being an easy touch with increased charges and taxes.

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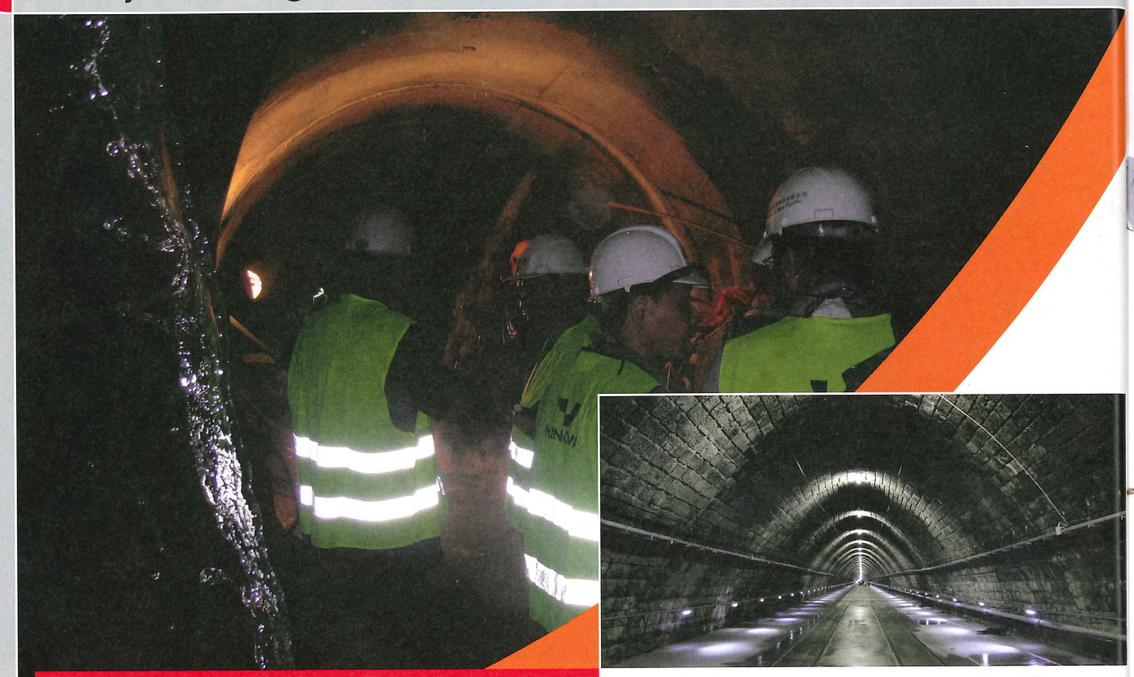

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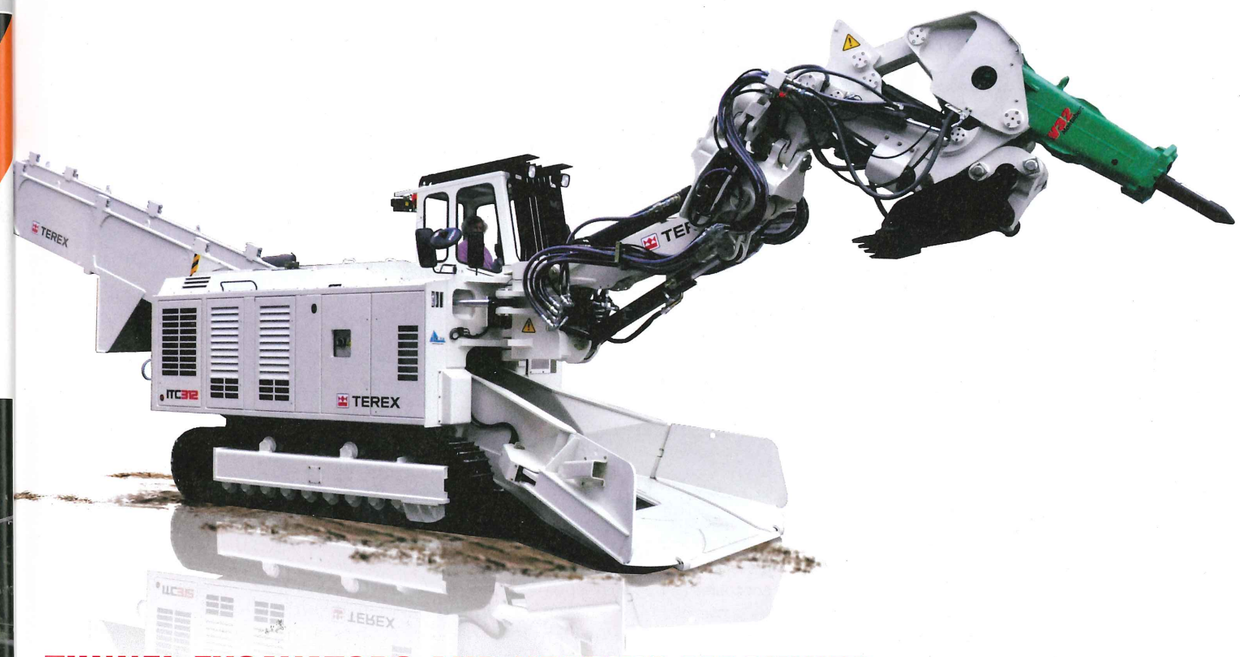

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TCR a century on: five worksites in one

Tottenham Court Road is undergoing two major development projects, for Crossrail and London Underground. The ageing station's concrete structure has had over 100 years to set and with few records to warn of what lies beyond it, tunnellers have to be ready for anything - there are even rumours of a discarded TBM. Alex Conacher visits the site and meets with resident tunnelling bigwigs

The London Underground office towers over the Tottenham Court Road Station upgrade worksite. Cramped, spiralling staircases take *T&TI* past floor after floor packed with workstations; computers surrounded by PPE are the first indication of a high tech project combined with the physical demands of interfacing with century-old existing tunnel works.

Reaching the top, though still not as high as the viewing gallery, it is possibly the highest vantage *T&TI* has seen a tunnel site from. The windows give a dizzying view down on the sprawl of carefully coordinated men and machines below as they swarm around what is a very compact site for the work required.

Turning back to the room, Ben Coultate, Tottenham Court Road stakeholder manager is joined by Les Hamilton, London Underground programme manager for Tottenham Court Road; Rob Gordon, JV section manager for Northern Line platform works; David Harper, JV section manager, tunnels and Steve Lousley, JV senior section manager, tunnels.

Coultate launches into describing the need for upgrade works at the Tottenham Court Road. "It was originally two stations," he says. "One for the Northern Line and one for the Central Line. They were joined together – not in a great way – in the 1930s. There are a lot of operational problems left over from then."

London commuters feel the pains of a metro system that, at its oldest points, was under construction around the time of the Crimean War. Engineering marvel that it is, present rush hour demands leave it as a sad mockery of the original vision.

A passenger arriving at Tottenham Court Road, on either line and after squeezing out of the carriage, is thrown immediately into a tide of commuters rolling towards the single exit on either platform. There are a lot of cross flows of people in the lower concourse area as passengers head to the escalators, then it's up to a small ticket hall. At this point the crowd runs headlong into columns blocking off ticketing gates and then jams itself into little staircases up to the street.

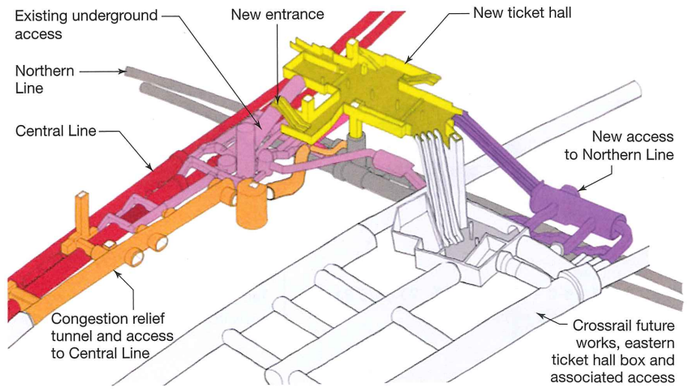
Coultate adds, "The station is under the main junction between Oxford Street, Tottenham Court Road and Charing Cross Road, you couldn't pick a busier part of London to give our contractors a healthy logistics challenge. For the last 20-plus years London Underground has been trying to upgrade the station, but it has taken such a long time to get through planning processes. And now we are through, this is what we are doing."

New underground space to fight congestion

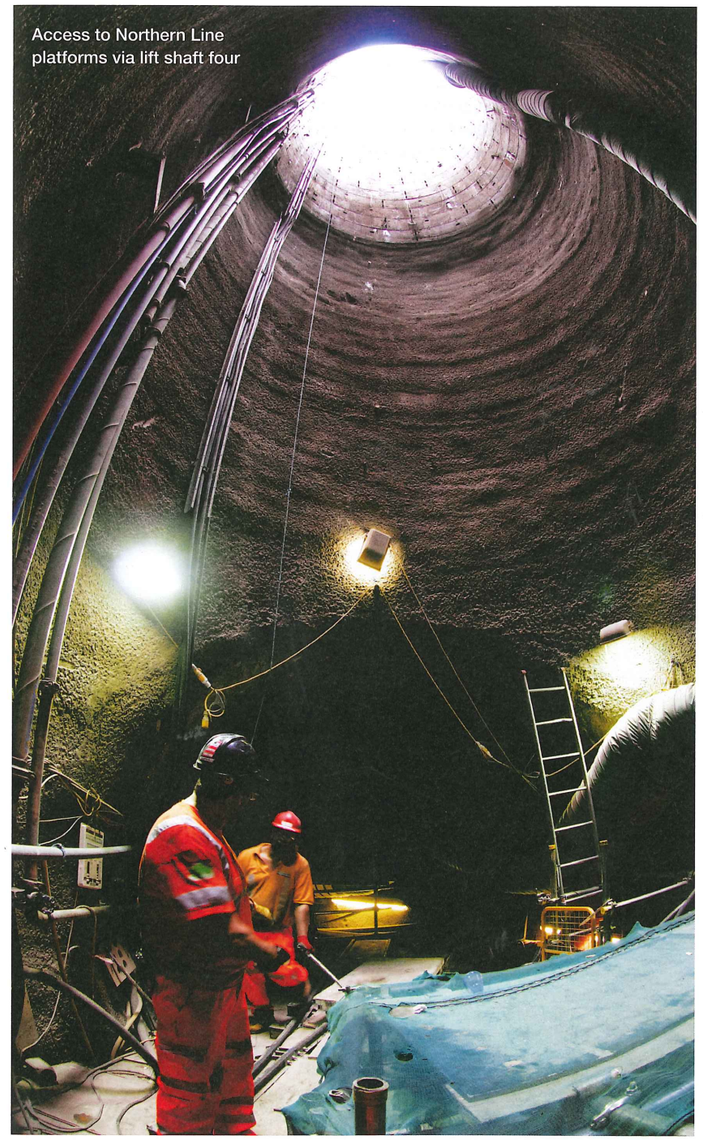
Tottenham Court Road Station's upgrade is part of a massive investment in the London Underground network. The aim at Tottenham Court Road is to increase capacity, reduce journey times and improve reliability. Step-free access is also a goal of the upgrades. The Tottenham Court Road works will total GBP 1bn (USD 1.55bn), GBP 500M (USD 772M) for both the Crossrail and London Underground portions of the works.

Tottenham Court Road currently handles 147,000 people every day, far more than planned for. When upgrade works are complete, the station will be able to handle 200,000 journeys per day. The ticket hall will be nearly six times the current size.

Coultate adds, "This is a projection to the middle of this century, so the capacity demands are as far away as we can reasonably predict. There are other capacity enhancements that may come forward in time, one of those is Crossrail Line Two which will be another new railway connecting through Central London between Victoria and Euston.



Right: **Figure 1, Tottenham Court Road station and upgrade works**



Access to Northern Line platforms via lift shaft four

"So there are other things in the long term planning, but particularly here the key stations we need to work on for London Underground are obviously Tottenham Court Road, Victoria where Taylor Woodrow and Bam Nuttal are also working as main contractor excavating tunnels and Bond Street where we have a major tunnelling project there worth around GBP 300M (USD 463M).

"We are also developing ideas for works on the Bank Station upgrade. So a programme of major station projects is in place funded by the Department for Transport as part of the comprehensive spending review. Those are all part of the tube upgrade."

The Tottenham Court Road London Underground upgrade itself involves an eastern ticket hall for access to the new Crossrail station, an extension to the existing basement level ticket hall beneath the plaza in front of the Centre Point building and beneath Charing Cross Road. New entrances will be built at the corner of Oxford Street and Charing Cross Road, at the front of Centre Point facing north and another facing south. Some 320m of sprayed concrete lined tunnel will also be constructed. The primary lining for these tunnels has been designed as a steel fibre reinforced structure, whilst the secondary lining has been designed as conventional reinforced concrete. As *T&TI* visits, shaft four has been mined to a depth of 30m and a 23m-long stub tunnel has been excavated, which will connect to tunnel works later on in the project to provide congestion relief for the Central Line section.

The main works ongoing as *T&TI* goes to print are major structural alterations to the Northern Line platform tunnels to allow new routes to and from the ticket hall; again this will relieve congestion on the hundred-year-old platforms. Three shafts have been completed on site so far and work has begun on the fourth. There will be six lift shafts in total following the upgrade, with one as a fire lift.

Rob Gordon explains the platform works. "We needed to replace the side wall sections of platform tunnel segments currently built as hoops with new vertical side wall props wherever we intended to build these new staircases and lift shafts. This is to provide space and the correct level of structural support to excavate between the two platforms. In total this requires the replacement of around 195 side wall sections of the tunnel rings across both the north and southbound platforms.

"During the closure we are constructing seven new opening sets for new staircases and lift shafts, requiring the replacement of approximately 130 sidewall props. One of biggest challenges with any works in the old Victorian tunnels with the cast iron linings is to actually get them out. If you excavate out to the back of it then you've got a free face and they come out relatively easily with a bit of 'miner's persuasion', but if they are solid behind then traditionally you burn them, try to burn the plate out then smash a bit, get a jack in and then jack it out. It would usually take the better part of three to four shifts to do that, and the process is not conducive to a section 12 environment."

Gordon continues, "Another tried and

tested method is to use angle grinders, but this can cause fractures. We used a standard milling machine. You set it up on a little angled frame between each of the segments and what the machine does is very accurately machine away and cut a slot out of the plate. Grinders actually cut the next ring as well, compromising three rings rather than the one. This has probably been the biggest factor in cycle time improvement, taking the process down from three to four shifts to less than one. With 195 rings, that is a lot of time saved. From a cost point of view, as well as reducing workforce risk, it is much better."

Donal Coughlan of designer Halcrow adds, "Due to the limited space between the platform tunnels, sections of the existing cast iron lining have been removed to allow the steelwork framing to be installed. The design of these elements needed to take account of the construction hazards associated with lifting and positioning heavy steelwork in areas of limited headroom. In addition, constraints needed to be placed on the number of rings that could be broken out to ensure the adjacent cast iron tunnel linings were not overloaded."

Below: View of site from Centre Point in April showing compact site conditions

Enabling works

Four years of enabling works are before the main engineering gets underway. Work started on the project in 2007. Lousley points out; much of the enabling work is heavy engineering in its own right. During a 10-month programme, some 1.4km of trunk utilities were replaced or strengthened in the area. This included an 18in gas main, a 21in water main, a 24in water main and two 9in water mains, all of which were believed to be made of cast iron, and due to settlement from tunnelling works would need to be strengthened. One of the largest obstacles dealt with is Joseph Bazalgette's Mid Level Sewer, 15m below Oxford Street. The sewer runs very close to the Central Line tunnels and also has to be strengthened.

Donal Coughlan tells *T&TI*, "One of the critical features of the works on the project is the presence of the Mid-Level Sewer, which is a Victorian brick-lined sewer which runs along Oxford Street and is located directly above the Central Line. As part of the modification works two new overbridges are required to connect the new Interchange tunnel with the Central Line platforms.

"These overbridges, which pass under the Mid-Level Sewer, will cause ground movements resulting in additional strains in the sewer brickwork. This movement will be mitigated by installing horizontal concrete-filled steel tubes from the nearby disused Post Office tunnel. These pipes provide support to the ground and thus mitigate ground movements. These pipes have a design external diameter of 340mm and are spaced at 508mm centres based on the width of the Post Office tunnel cast iron segment pan widths."

Lousley adds, "London Underground has constraints on what it is allowed to go close to. A two diameter buffer is usual but settlement gets assessed and reviewed subject to finite element modelling. Thus the extent of the work that has to be carried out is found, varying the requirements [with the situation], for example what is beneath the ground and its strength. Effectively LU operates by set rules which it adapts.

"Massive amounts of infrastructure [surround the works], not an ideal but the fact of the matter is we are in central London, an immensely busy place for people and pipes and this needs to be dealt with. We will construct around 100 spiles out from the Post Office tunnel, almost providing a bed underneath the sewer."

Ben Coultate says, "It would be fair to say we've had [to manage the project around] a lot of existing utilities. We've had four years of diversions, so imagine that every section of highway with platform underneath has a full set of utilities jammed underneath it. There is a lot that's had to be moved, sewers, gas mains, water mains, telecoms, power.

"It's a big challenge but not an insurmountable one. It shapes how you tackle these projects to deliver on time; a key risk to address as soon as you can in the project. We designed the scheme to best deal with them. We had a massive amount of street works preceding the main contract and that's now behind us honestly. We've got some more street works at the end of the programme when we come to build the final scheme. What you see outside doesn't look like [the drawings] yet; we will put the highway back after we are done!"

Another concern according to Gordon was making sure that the site was fully assured, ready and compliant prior to construction. Full height fire-compliance hoardings across both lengths of the full platform to facilitate various hot works and security, separating hot works from normal, ongoing train operations was a vital consideration for London Underground. Gordon adds, "Behind the hoarding you have a 600mm gap in the nosing stone and then you have the trains. The physical bringing in of materials 24/7 has not been easy. We had to bring stuff we couldn't drop down the shaft in by train."

Right: Figure 2, located in one of the busiest areas of Central London, the Tottenham Court Station upgrade project must weave through complex and ageing existing infrastructure as well as minimising surface disruption for locals, tourists and business

Interested parties

A contracting JV of Taylor Woodrow and BAM Nuttal working in a 50:50 partnership is undertaking work on the Tottenham Court Road station upgrade. Rob Gordon, JV section manager for the Northern Line platform works tells *T&TI* that the Vinci-owned Woodrow decided to get out of competitive tendering 12 years ago during the housing market boom, but is now back and tendered for the project with BAM Nuttal under the Taylor Woodrow name rather than Vinci. He adds that there is a good recognition of the Taylor Woodrow name in the UK tunnelling community.

Halcrow is the designer for the project with sprayed concrete lining design by Dr. Sauer. The client London Underground was appointed as the nominated undertaker by the Crossrail Act 2008. As works on the project began in 2007, London Underground performed enabling works under the remit provided by a planning application to commence street works. Coultate tells *T&TI* that one of the key risks for the project was the enabling work and there was a need to get it out of the way as soon as possible to allow work to begin on the new station on time.

Conclusion

"We have fortnightly engineering workshops where we meet with representatives from the other projects," says Coultate. "We discuss developments and share experience. One of the main items of discussion has been our Northern Line works at Tottenham Court Road. It lets us cooperate between projects."

The Terex Schaeff ITC120 excavators in use at Tottenham Court Road are an example of this inter-project cooperation. After completion at Tottenham, they will be transferred to Victoria. The nature of the works at each site has caused a natural staggering of the projects enabling this efficiency.

"This has been several different projects rolled into one. Street works, traditional tunnelling, state of the art technology – a real mix. No part of the project is altogether more demanding or expensive than the others, it is an enormously complex civil project. Although in Central London, the site is very large, you can tell walking around that there are four or five sites worth of work going on; it is compact and so complex that we have a full time logistics manager just to get deliveries in.

Coughlan adds, "The project has produced a number of interesting challenges including integrating the design of the new station with the existing station, assessing the impact of the works on adjacent buildings, some of which are listed, as well as existing utilities such as sewers, gas mains, etc, and accommodating the requirements of the new Crossrail station. The assessment of these items has required the use of empirical methods as well as more complex two-dimensional and three-dimensional numerical modelling taking account of the ground conditions which comprise Made Ground overlying Terrace Gravel which in turn overlies London Clay."

As *T&TI* goes to press shotcreting works are beginning on the Northern Line platform walls to fill in the sidewall sections.

The project monitors around 1,000 targets round the clock, which include over 300 third party assets. Daily trend movement monitoring is important considering the value of the buildings in the area. Monitoring inside the tunnel, profile techniques by an Amberg survey system are used to download the shape of the excavation into an EDM. An engineer can check the profile from this. With SCL strength is achieved quickly, but still takes time and during this the ground load is coming on and starting to constrict, so the team needs to be careful.

Coultate and Gordon finish, "Some of the things we have done, we were told were impossible with our timescale, which just goes to show the innovation that has gone into this job."

Brenner push

Excavation and procurement are advancing at the Brenner Base Tunnel with the third exploratory tube contract due to be awarded shortly and planning continuing for the main bores in the Alps. Report by Patrick Reynolds

While drill and blast excavation makes steady progress from the north end of the exploratory tube for the 55km long Brenner Base Tunnel to narrow the gap with the TBM-bored southern end, bids are currently being assessed for a central section that will pass through a major fault zone with high overburden. To add to the scope of work on the Periadriatic Line package, the contract will also include some minor preparatory underground works for the main rail tunnels construction on the Austrian-Italian rail link.

The greenlight for main construction on the trans-Alpine rail project was given earlier this year to the developer and owner Brenner Base Tunnel (BBT), following the formal funding commitment of the Austrian Government which came a few months after those from Italy and the EU. Austria and Italy are each covering just over a third of the cost of slightly more than EUR 8bn (USD 10.8bn), while the EU has committed to meet 30 per cent.

Left: The Brenner Base Tunnel runs north-south from Innsbruck to Fortezza

However, it will not be until about 2015 that tender calls are issued for the main tunnel works, which will be the biggest contracts on the scheme. Three contract packages are anticipated at this stage, and construction work is programmed to start in 2016 to enable the scheme to be finished by 2025-26.

Until the procurement of the main works are underway a series of further tunnelling contracts will be let for the various access adits along the alignment, such as the Wolf-Two package, the Ampass adit, the Mauls (Mules) branch adit, and the works to take the exploratory tunnel through the tectonic zone. There are also, potentially, two lots at either end of the twin-bore running tunnels to establish the portals and excavate 1km along each 8.1m i.d. tube. In parallel, if not before, there are also the current works to complete – the Innsbruck-Ahrental works and the Wolf-One package.

Route and geology

The route of the Brenner Base Tunnel will be generally straight, almost north-south, below the rugged Alps to link the Innsbruck bypass in Austria with Franzensfeste (Fortezza) station in northern Italy. The link will be 64km long, including the existing bypass which will join the under construction Lower Inn Valley rail project.

To run as single-track tubes about 70m apart, and with a service tunnel positioned between and below them, the main rail bores will be linked by three cross passages per kilometre. Near the ends of the main tubes there will also be evacuation tunnels. The scheme also includes three multi-function underground stations, one at Innsbruck bypass, as mentioned, and two others to the south, at about 20km intervals – St. Jodok (near Steinach in the middle of Brenner Base Tunnel) and Trens (close to the Mauls [Mules]).

Constructing this triple tunnel layout, stations and access adits calls for difficult Alpine geology to be negotiated, not least the Periadratic Line which is a complex fault zone where the European and Adriatic (African) tectonic plates crush together.

Besides hydrogeological challenges in the zone and elsewhere along the alignment, the route also presents large variations in strata – Quartz phyllite, Bunder slates (containing dolomites, quartzites, anhydrites, greywacke sandstone and other slates), gneiss and Brixner granites. With such geology and overburden extending up to approximately 1,600m, there is also potential for squeezing conditions.

Presently, BBT expects almost three-quarters of excavation for the main tunnels to be performed by TBM, the balance by drill and blast – which will also be used for the stations and adits.

Excavation progress

The Brenner Base Tunnel is a project of many phases, and parts, one of which has already been completed – excavation of the southern end of the exploratory tunnel, in the Aicha-Mauls (Aica-Mules) package.

As an extension of the earlier site investigation phase, the exploratory tube will provide key data and experience for design of the main tunnels. BBT is also in discussions to learn lessons from tunnelling experience on the 57km long Gotthard Base Tunnel, in Switzerland.

Once completed, the Brenner rail link will use the exploratory tunnel as a service tube, also helping with drainage as possibly carrying power and data cables.

Aicha-Mauls

The 10.4km long, southernmost section of the 5.6m i.d. exploratory tunnel is the Aicha-Mauls (Aica-Mules) package, which was bored by TBM.

The 1.8km long Mauls lateral access adit helped to retrieve the TBM but is also needed for further exploratory, and later main, tunnel work as well as allowing a branch to be excavated to support future construction of Trens station.

Launched in early 2008, the 6.3m diameter double shield machine completed the almost 32m² cross-section tunnel by November 2010. The excavation was performed by Seli as part of a JV with Pizzarotti, Bilfinger Berger, Alpine, Beton –und Monierbau, Jaeger, Collini Impresa Costruzioni, and Societa Italiana per Condotte d'Acqua.

The advance of the northward bore was successful but it did experience some higher rock strengths (up to UCS 220MPa) and resulting cutter wear, which drastically slowed progress. Then the TBM encountered high pressure groundwater up to 27 bar in a fault zone, which damaged a stretch of already built concrete segmental lining. Recovery works included ground stabilisation and replacement steel rings along the section affected by the unanticipated anisotropic stresses.

The contract package also included a 400m long spoil transport tunnel.

Innsbruck-Ahrental

While the TBM drive was coming to a finish in the south, at the opposite end of the exploratory tunnel – in the Innsbruck-Ahrental package – the initial excavation work on the 26m² excavated tube was getting underway. The Ahrental adit will provide access for construction of the Innsbruck station and main tunnels.

Finding a large, obstructive boulder at the portal was not the best beginning but progress using drill and blast along the 5.6km long section has been steady for the JV of Strabag and Porr Tunnelbau. The minimum finished width of the exploratory tunnel is 5m.

Blasting got underway in earnest by February 2010, and in the first year approximately 2.2km was excavated. By the beginning of September 2011, a further seven months on, another 1.1km has been blasted, completing almost 60 per cent of the length under the contract. BBT says the daily advance is 8m-10m with up to five blasts.

BBT adds that, based on surface geology, it is predicted that several fault zones will be met but none have been encountered so far though there have been thin shear bands, along which quartz phyllite has been 'crushed to a clay-like state'. Groundwater conditions have been much less of a problem than anticipated, with flows of less than 0.1l/s.

The package also includes the 2.4km long Ahrental adit with a 10 per cent slope and 90m² cross-section. Located close to Wipp valley fault, the rock mass is 'remarkably fractured' and further complications in the geology came from gravel layers and loose rock in the upper part of the profile. Proceeding in relatively short, 1.3m advances, the face is being opened in crown-bench-slab stages, and in just over a year, half of the adit has been built.

The design and planning consultant is ILF, and construction supervision is by a JV of Bernard Ingenieure, Bernd Gebaur and Intergeo Basustellenkoordinator.

Wolf-One

The Wolf system of lateral access adits is in the middle of the project, and will create access for construction of St. Jodok station and future main tunnel works. The scale of the access works has led to them being split into two packages – Wolf-One and Wolf-Two. Planning and design of the Wolf sections has been handled by IC Consulenten, and construction supervision is provided by a JV of HBPM Ingenieure and BWB.

Initial tunnelling work on the Wolf-One package began in April and has involved multiple parallel excavations totalling approximately 1.9km by drill and blast. The package involves three different tunnels – the 200m long Wolf adit, the 702m long Padaster tunnel and the 1,000m long Saxener tunnel.

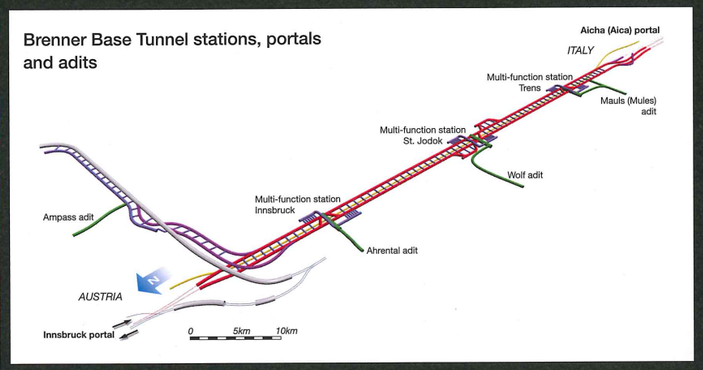
Wolf adit has a gradient of 10 per cent and cross-section of 104m². Padaster is a spoil conveyor tunnel with eight per cent slope and cross-section of 84m², and leads from the Wolf adit to the deposit site. The Saxener tunnel, which has a gradient of 10 per cent and cross-section of 65m², will take traffic onto the construction site.

Construction of the Wolf adit and Padaster tunnel is complete, and by early September more than a third of the Saxener tube had been blasted. The contractor is a JV of Swietelsky Tunnelbau and Swietelsky Baugesellschaft.

Excavation Plans

Of the packages coming up, that of the Periadriatic Line on the exploratory tunnel is the shortest, at a mere 1,350m long, but the geological conditions will be the most

Excavating Brenner's exploratory tube



challenging. The tunnel is long enough to bridge the tectonic fault zone. While the package also includes some main tunnel work it is only preparatory, and will not involve construction of parallel short stretches of main tunnel through the weak, high stress zone.

Tunnelling will be done by drill and blast as well as mechanical excavation, and the section will link to that built by the TBM which stopped, as planned, short of the fault zone to be dismantled in a cavern carved at the end of the Mauls (Mules) adit.

There will be further packages for works on the exploratory tunnel, but BBT says the tube will not be fully built before excavation starts on the main tunnel contracts in 2016.

Development of the main tunnels is to commence with packages at each end to create the portals and about 1km of each tube. Tenders for the packages are to be issued around 2012.

No plan has been given for how the stations are to be built – if part of main tunnel packages or separate contracts.

In the meantime, the most immediate other tunnelling works coming up are the excavations just starting at the Ampass section, and those to come at the Wolf-Two and Mauls branch tunnel.

For the Ampass section, at the north end of the Brenner scheme and off the main north-south axis, a JV of Strabag and Porr Tunnelbau began work last month to build the 1.4km long adit.

The tunnel is an access tube with a cross section of 35m², and is needed for excavation of the rescue tunnel to parallel to the Innsbruck bypass.

The Wolf-Two package will create a 3.5km tunnel by drill and blast to complete the local adit system started by Wolf-One. Planning and design is being performed by a group of consultants – IC Consulenten Ziviltechniker, GWU Geologie – Wasser Umwelt, BWB Ingenieurburo, Lombardi-Reico Srl, and Hbpm Ingenieure.

Sinking a station

An extraordinary variation on the immersed tube method, combined with innovative foundation works, has been used to take the Amsterdam north-south metro line underneath the 19th century Centraal Station, reports Adrian Greeman

Completion will take place late this month of a long running project to tunnel underneath the 19th century central station in the Netherlands capital Amsterdam. The successful outcome will help vindicate the work of civil engineers and tunnellers on the difficult and sometimes fraught north-south line project.

The scheme has taken nearly a decade of planning, design and foundation development and an extension of immersed tube methodology, with major works underway from 2004, in different phases, for this section alone.

But despite the age of the historically protected late 19th-century building, the sensitivity of its old timber pile foundations, and challenging soft ground conditions, a new metro line tunnel space now exists underneath it. There has seemingly been no change to the structure above, which has been kept open and fully operational throughout the project.

As other works are completed the new box section tunnel underneath will be connected to the TBM driven tunnels still being bored to the south, and to a still-to-be-built immersed tube crossing of the Ij river on the north side of the station, which connects the new 9km long metro line to the isolated north Amsterdam districts.

The City client and the contractors on the project are all keen to show off their success here because the north-south line has been a contentious and fraught project from the start of planning in the 1990s, with some public opposition. It follows an even more contentious scheme in the 1970s for the city's first line, east-west, which caused demonstrations by environmentalists.

Times are not the same as the politically heated 1960s and early 70s but there have still been significant concerns about the line's route through the historic canal-side city centre, which apart from its cultural significance is also a major world tourist attraction. Virtually all of the buildings here are significant.

Not only that, they are highly sensitive, since the city is built on mostly soft sand and silt of marine and fluvial deposits with tens of thousands of centuries-old timber piles supporting most of it. An accident with a badly placed slurry wall some years ago, which undermined a critical building close to one of the station pits on the southern part of the route, did not help the public image of the scheme.

World economic banking failures in 2008 did not salve the public mood as delays and costs also rose on the project; the scheme is thought now to be costing near to EUR 4bn (USD 5.4bn) compared to an initial EUR 1.5bn (USD 2bn). It will not finish until 2017 instead of an original 2011.

However, the new line of some 9.8km long is an important link to connect northern Amsterdam across the river IJ, through the centre and to the south of the city where there is a new World Trade Centre complex. But to pass the congested and famous old city, it must go underground in a 3.12km long bored tunnel, and making this caused significant fears. It is also below ground in the immersed tube and station area.

In fact, despite two incidents – another smaller failure of sheet piling – tunnelling so far has gone well. An early project on the line was to set up a huge automated total station monitoring system for the buildings

Left: Figure 1, Amsterdam's north-south line alignment showing Centraal Station on the south bank of the river Ij

along the route, with vast amounts of data being collected hourly. It indicates that settlements for the twin bores have so far been within the very tightly set limits.

Centraal Station

The station project was one of the most sensitive sections of all. It is the central hub of the city at the centre of its concentric rings of canals, and the point of entry for many visitors. But for this reason it was important not just for the line to pass under the station but also for there to be a stop there. It has to connect to the main line and also the east-west which crosses here too.

But how to do it was a major issue. Not only is the main building 'untouchable' to quote Bas Obladen, a specialist foundation and jet grouting consultant who worked for contractor Strukton on the scheme, but there were significant problems for the glass and steel arched roof enclosure which covers the tracks and 13 platforms just alongside it. Settlement could unacceptably alter torque forces in the frame shattering glass panels.

On top there was no question of closing the station, which is a key part of the busy Netherlands rail system and now its high speed line to Brussels and Paris. Some 300,000 commuters use it daily.

Ground conditions and the foundations meant conventional methods would prove difficult. The original brickwork station building is founded on a reclaimed sandy island formed on the river Ij shoreline in the 1880s, with wooden piles. There are more than 8,000 in total, ending in stiff clay just before the well-known Amsterdam 'second sand layer' about 18m down in the mixed alluvial, clay and silty ground.

"When God created the world he forgot to put any ground here the old story goes," says Obladen. "So he used the bits and scraps left in his box. It is very mixed and difficult, the layers changing constantly metre by metre, some vanishing, others appearing as you move along." Usually there are three sand layers, where most piling ends, the deepest at around 60m where bigger modern foundations reach to.

The so called 'first sand layer' about 12m down, which is where the old houses are piled to, peters out under the station towards the river, adds Mark Vlaanderen, Strukton's engineering manager for the immersed tube float in this summer.

Above: Settlement under Centraal Station could cause damage to the station's glass roof

All the old piles would have to be removed to tunnel under the station. So engineers were faced with the problem of how to support it.

Station support

The answer was to use a table construction, says Obladen, a giant slab supported on piles at the side to which the building loads could be transferred. Once in, the timber piles could be removed along with much of the ground to make a space underneath.

But even then a giant cavity around 20m for cut and cover construction would probably be too risky, with some movement possible even with struts or top-down methods. It would require very strong and rigid side walls to resist lateral forces.

Space for work on piles or other structures was also limited with headroom restrictions in the main station hall of around 8m height and less under the roofed

platforms. The intention here was to use the existing underpass concourse which gives access to the platforms.

The 30m wide passage from the station itself runs towards the river and could be widened and refitted with a very thick floor slab, which would then act as the top slab for excavations underneath. Together with the station itself this would create a space just under 140m long.

But the under-platform concourse is only 3m high under the concrete troughs running above, which hold the tracks for the trains, and little more under the platforms, creating severe headroom problems for many works.

To cut the risk a solution was devised to create the giant cavity without dewatering. Instead the groundwater, which is high everywhere in the Netherlands, would continue to fill the excavated space balancing the pressures from the ground either side, says Vlaanderen.

To install the necessary tunnel box, including enough space for platforms, in this space an immersed tube method could be used, floating the box underneath the building. It was a method that could take advantage of the river running behind the station, and would be an extension of an immersed tube that was being built for the Ij anyway.

That had its complications since this box is a station section and therefore wider, and it does not connect directly to the Ij crossing; there is an intermediate area of concourses and access stairs and escalators, being built conventionally just behind the main station.

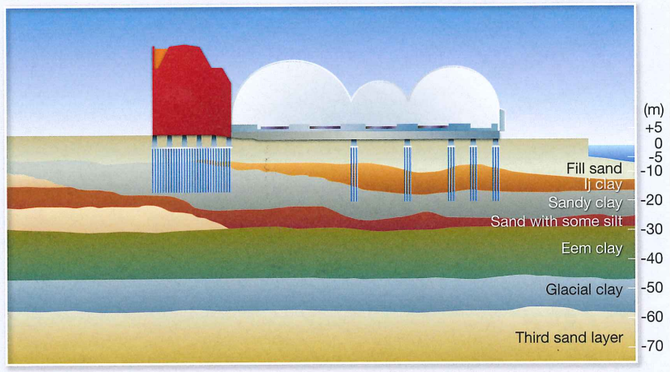
But those issues came later. The first challenge for the main contractor Strukton, and joint venture partner Van Oord, was how to form the side walls to support the top slab of the chamber beneath.

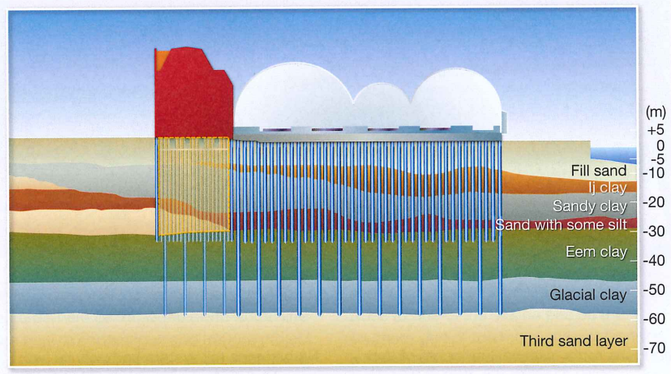
The easy part came first. A diaphragm wall could be made for the end of the box, working on the station forecourt. This would seal the end of the excavation underneath the station and separate it from other construction work outside and the TBM work further south.

Inside the station building and underneath the tracks, however, a diaphragm wall was not possible to create the sides of the box. The rigs are just too big and cause too much vibration.

"Pile driving with vibration machines was also ruled out because we could not cause vibration," says Obladen, "nor very much noise."

For the station itself "the only kind of process that would fit all the many constraints was jet grouting," he says. Rigs could be used inside the entry hall area from which the work was done.





Above: Figures 2 and 3, showing the geology and location of the existing and new piles

For the track concourse another method was devised, using vertical microtunnelling.

But jet grouting is notoriously fraught with the dangers, both of ground heave and of inadequate column formation from shadowing, ground effects and air effects.

A new form of structure was devised using jet grouting combined with piles in a 'sandwich wall' some 2.5m thick. This would be formed with two outer rows of Strukton's Tubex piles, which could be made with a low headroom machine. Two of these were done 30m apart, each 40m long.

For each, two lines of 457mm diameter piles were drilled at 1m centres. In between, 800mm jet grout columns sealed the spaces. A monojet system was used as the least likely to be problematic in the ground.

"By making two pile and jet column walls with the south end closed by the diaphragm wall and piles along the far end, you could make an enclosure," says Obladen. Dropping 30m, this ended in a clay layer whose impermeability meant "you had a closed box just under 3m wide to make the sandwich."

It was safe then to jet grout the interior, he says, because any heave pressure would not escape to the outside ground. Interior columns were of varying sizes overlapping to make a stiff impermeable block.

Obladen, an expert on jet grouting, was closely involved over a long period developing and testing the precise grout mixes and parameters for this work, and various control systems from video monitoring to audio detection of the circular sweep of the grout path. He wrote software to build a three-dimensional representation of the jet grout columns using pressure and volume readings from the grout rigs.

Other developments were needed too including new types of low headroom rigs for the Tubex piles which had enough power to go to 65m depth. Existing machines can manage 30m.

"Most of the wall simply seals the 'sandwich' but some of the piles extend further into the third sand layer to carry load," says Obladen.

In construction, part of the station concourse was sealed off and temporary works used to support the station walls in the sandwich area. Another newly created machine called the Brutus then removed the timber piles without vibration, using powerful jacks to pull them like teeth, sometimes taking three days.

"The timber was in astonishingly good condition," says Obladen. "Not rotting even two years later in the air."

Extensive ground monitoring and measurement of the building itself was carried out. "We used all the data to constantly adjust the grouting," says Obladen. "So you can say it was a true observational method."

Once made, a concrete framework connected the two walls to take the loads from the main building to the sides, leaving the centre free for excavation of the chamber beneath.

The continuation of the chamber for another 90m under the very low headroom track area was done using another innovation, adapting microtunnel machines to work vertically, to bore very large diameter piles.

Machines were adapted by Strukton's own design team. The manufacturer IHC made the four machines used.

Piled walls

"There are various issues such as spoil transport which are different. Also as you drill down the pressure increases in a way that is not true horizontally. Bearings need to be different too," says Obladen.

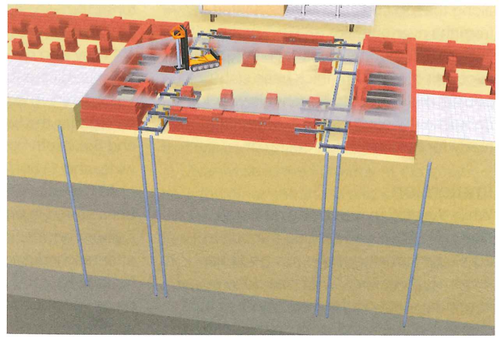
To avoid blowouts the drill head worked inside a slightly over-diameter cone piece 1.94m in diameter, 20mm more than the cutter. Behind came a 1.82m diameter casing surrounded by an annulus filled with bentonite. "The cone seals the drill hole and is sacrificed at the end," says Obladen.

A retractable outer ring of teeth was used on the drill head so that when it finished it could be brought back through the casing.

At the top meanwhile was a mobile drilling frame running on rails, with a jacking mechanism to push the 1.8m sections of tubular casing down behind the machine in three passes. A rail mounted crane unit tailored to fit over the jacking frame was used to bring in casings or other equipment. The casing sections were complex needing the various spoil

Above: The grand welcome of Amsterdam's Centraal station

Below: Figure 4, a visualisation of piles being bored within Centraal Station



transport tubes, measuring instruments, access ladders and other items according to their position. They were made up in a yard outside Amsterdam and delivered just in time.

"For the pile walls the lifting crane ran on the same rails as the frame and was carefully designed to just fit over the frame within the very tight headroom," says Obladen. To allow it past, the jacking frame had retractable wheels; the frame itself was locked down during each pile operation with four screw-in Leeuw anchors.

"Anchors were needed to prevent rotation too," says Obladen. The tubular casings had a clutch piece either side which connected to the next pile in the same way as a sheet pile, and therefore no twisting was allowable. Hydraulic clamps could adjust the position.

"We made every third pile first," he says. "Because these were 65m deep and would be foundation load carrying. Then the other two were only 30m deep to the impermeable clay as they simply hold back the ground."

Between the two rows of 2m diameter piles, the original concourse floor has now been replaced with a heftier post-tensioned slab to act as the chamber roof.

It was done in two halves later tensioned together, because the concourse had to be kept in use for passenger access and so could only be done in two halves, with a 15m wide section available. The outer row of microtunnel piles and the half-width of slab were done on one side and then the other with false work columns were created in the centre line, using Leeuw screw piles. That allowed the existing slab to be demolished and the new one be built.

When the station and concourse slabs were ready, excavation could begin. The first 6m depth was done using excavators in the dry in 2009 with walings along the pile walls and struts across for support.

After that, the cavity was flooded and the work continued using portal cranes running along the top and spoil barges floated in from the river outside.

Some 18 months of work completed the excavation with a 1m thick base slab poured underwater in March this year to complete the cavity, leaving everything ready for the immersion operation.

Immersion

While the station was being prepared, starting in 2005 and running through to 2008, the immersed tube has also been under construction. "That was done as part of another contract for the immersed tube crossing of the Ij and work on the northern section," explains Mark Vlaanderen.

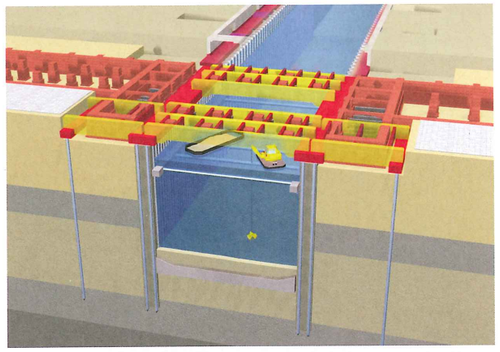
The station work is divided into three sections; the forecourt of the station; the under station work; and the riverside quay area just outside De Ruyterkade station. As it happens the JV between Strukton and Van Oord has all of these contracts, but they remain separate. It is known as Combinatie Strukton van Oord, or CSO.

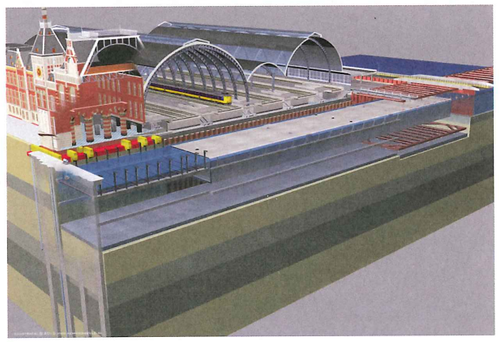
"There is another contract for the immersed tube crossing of the river Ij as well" says Vlaanderen. Strukton happens to be in this grouping too, which is a JV with Heijmans called Zink; Strukton's operational arm Strukton Afzinktechnieken Mergor, is doing the actual immersion work.

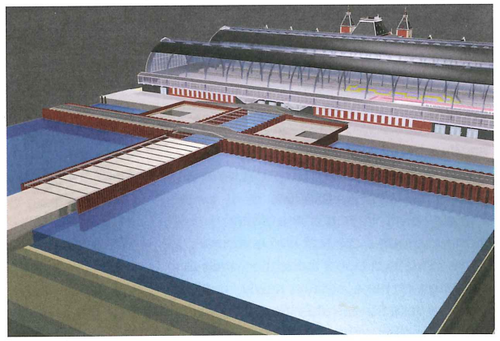
Even without the overlaps the building of the station segment, along with the four units needed to cross the Ij, made good sense. The crossing JV had a space on the north bank, a coffer-dammed drydock perpendicular to the river. The space will eventually become the approach ramp and cutting for the north-south line into the river tunnel but was first used to build the segments one by one.

"They also did the station segment, which is different to the others," says Vlaanderen. The river units are just big enough for the twin tracks with a 12m width and 8m depth but the station piece is 21m wide, and 136m long.

All the units were floated out and have been stored in one of Amsterdam's nearby harbour basins, initially for two years but after rescheduling changes on the project, for four. First to come out was the station piece which was floated into position this summer in an unusually complex operation.







Top: Figure 5, excavation of the chamber beneath the concourse; Middle and above: Figures, 6 and 7, visualisations of the front and rear of Centraal Station as the immersed tube segment is floated in

"The problem is to get the unit into the station and underneath a number of struts at the end," says Vlaanderen. The chamber has remained strutted across underneath the station building end, not because the sandwich walls are not strong enough, but to add an extra layer of risk protection he says, "Just in case."

To bring in the section a three-stage operation was required with the water level needing to be dropped 1.5m and then 3m inside in order to have room for flotation tanks and other equipment on the top of the segment and to manoeuvre the unit in stages. The first drop in water level is needed to get under the station at all, the second to fit the equipment. The final part underneath the struts and the far end is then done by fully submerging the element enough to pass through.

For the first phase a sheet pile coffer-dam was piled 80m out into the river in May. This, together with the 60m length of the quay works excavation would provide the space for initial reception of the unit. The sheetpiles were installed from barges using vibrators, pushing the piles down 32m, the last two metres keying into an impermeable clay. "There is no sand to get through here in the river," says Vlaanderen.

At the end of May the big unit was floated from its storage point in a carefully planned operation using four tugs pulling and one pushing. Though a straightforward operation, care had to be taken not to hit the quays for the famous free pedestrian ferries which link the north of the city to the south by the station.

Once in the prepared box the end could be sealed with sheet piles and the water pumped down 1.5m to allow the next stage. "It was not possible to do the whole 3m drop in one go because the cofferdam would have needed to be hugely strong and therefore expensive," he explains.

But the 1.5m drop was sufficient for the levels to match those under the station. A temporary works wall sealing off the station was removed therefore and the unit gingerly pulled forwards.

"We have a winch wire running over a pulley fixed on the diaphragm wall which separates the chamber from the forecourt area," says Vlaanderen. The pulley cable used only 2t of force on the 20,000t unit to give it a gentle motion in the water.

The unit was halted 40m from the end wall because of the struts above. But that was enough to bring the far end within the quayside works space which could then be sealed with a cofferdam gate on the riverside which was much heftier than the first. "It is part of temporary works for later when the quayside works are dewatered to 18m depth," says Vlaanderen. "But it is much shorter than the extension into the river and therefore less cost".

Now the water level could be further dropped by an additional 1.5m creating the space to fit out the unit with immersion pontoons filled with suspension winches, piping for later sand backfill operations, a primary tower for survey purposes, which is folded down and erected later.

All this was for the immersion operation itself, which would guide the unit underneath the far struts and into its final position. Water-filled tanks were used inside for ballast and the units were winched from the flotation units above, along with a pull force from the end pulley.

"It is essentially a standard immersion with which we are very familiar," he says. He adds that the Busan-Geoje crossing in Korea with summer typhoons, deep water and open seas was much more difficult. The company was a specialist subcontractor there.

But there were unusual risks of collision with the walls and with the new foundation of the station.

Positioning of the unit was slightly unusual. Taking advantage of the internal walls four wood-faced columns were used as guides at the side. Each was fitted with flat pneumatic jacks, flat air bags used in the oil industry to lift heavy objects. By pumping in air they could adjust the plan position of the unit and even rotate its longitudinal alignment slightly. It had to fit with a plus or minus 20mm tolerance.

The end position was adjusted too using steel shim plates inserted from a gantry on the front of the unit. Until the float-in and lifting of the primary survey tower on the unit the exact position of the 1m thick diaphragm wall could only be measured from the far side on the forecourt works.

A more unusual feature of the immersion involved the unit being hung from the ceiling slab, rather than being positioned onto prepared foundation pads as it would be in a normal open trench. But the underwater concrete slab was already serving a structural function and it was better not to do anything to it.

To hang it, special steel brackets had been anchored into the ceiling at four points. On the floating segment were four substantial steel beams, which were on hinges and lying flat. Once in place they were raised up and attached to the ceiling brackets, an operation requiring some delicacy in the positioning.

That done the ballast could be increased to load each of these hangers to 150t rather than the 25t or so during immersion. That made the whole structure much heavier, in preparation for sandflow underneath and for backfilling, due in October.

That awaits completion of a new bulkhead to seal the under station area and simultaneously create a complete cofferdam around the cut and cover works on the Ruyterkade Quay area.

Inside a sand mixer unit on the deck delivers the backfill through 20 pipes to the underside arranged alternately inside and outside. Under each outlet 'pancakes' of sand build up.

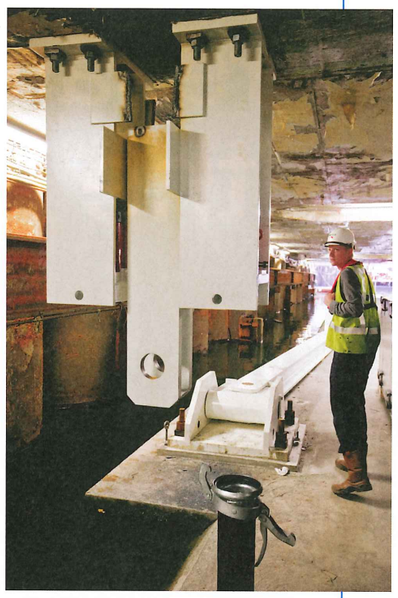
As they do so the back-pressure on the concrete unit begins to increase, says Vlaanderen, and this is measured by the reduction in load on the four hanging beams, each of which is fitted with hydraulic jacks for fine adjustments. The reduction in load allows the measurement.

With final position adjustment done the backfilling will be done to about one metre, to fix the box position. Then the hangers can be removed and the load taken by the sand ready for a final backfilling in October.

The finished box will still be isolated and must be connected through from the contract in the station forecourt where the main ticket hall and entrances are being built. "We shall use, or rather the contractor for the forecourt, will use ground freezing for that operation," says Vlaanderen. After that will come track and signal works.

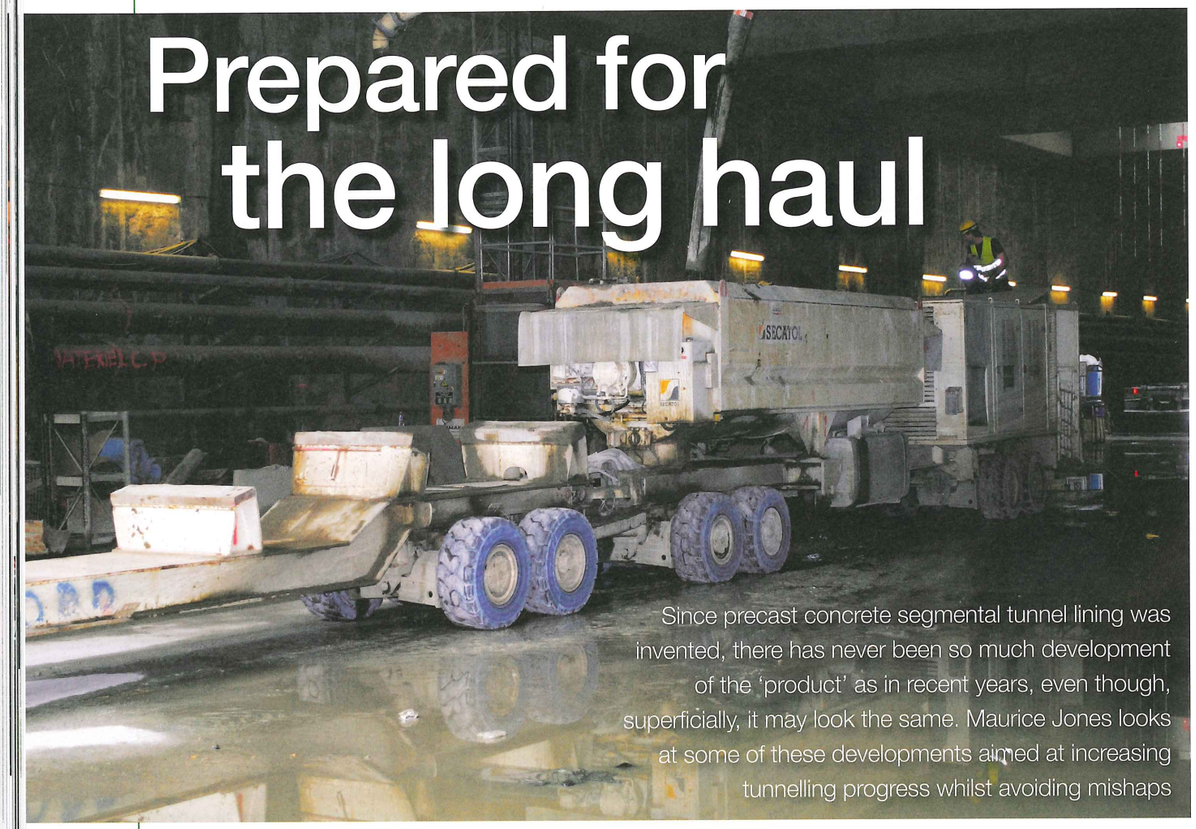
Meanwhile in the 60m box at the quay end, the other entrances and access points will be created in a dry dewatered space inside the now complete sheet pile area. This will also be connected to the under station box eventually by ground freezing.

And next year comes the immersed tube operation across the Ij river.



Above: Brackets were installed in the concrete floor slab to hang the immersed station box

Prepared for the long haul



Since precast concrete segmental tunnel lining was invented, there has never been so much development of the 'product' as in recent years, even though, superficially, it may look the same. Maurice Jones looks at some of these developments aimed at increasing tunnelling progress whilst avoiding mishaps

The manufacture, storage, transport and installation of precast concrete lining has not always received the care and attention that is required for efficient tunnelling. The consequences are usually damage to segments, necessitating their replacement, or mix-ups in delivery causing tunnelling delays. Added to these are client and engineer demands for detailed reporting and records so that any mishaps or faults in installation can be traced back to their cause, as far as is possible.

Such manufacture and supply cannot just be regarded as filling a mould with concrete and waiting for it to cure, so recent developments have been aimed at improving on any such tendency.

Materials

Fibre manufacturers of all types have had a long campaign to replace or add to traditional steel reinforcement in precast lining, and with increasing success. 'Synthetic' polymer fibres also have a role, now well understood, in preventing damage in the case of fires in tunnel use by melting and providing passages for pressure relief and so detering spalling damage.

A drawback of traditional reinforcement, apart from the price of steel, is the depth of unreinforced concrete needed to cover a rebar cage. This is susceptible to spalling damage during handling. Fibre manufacturers have shown that inclusion of their product in the mix toughens the outer layers of a segment, greatly reducing significant damage during handling, as has been shown by records of a few segment replacements necessary on the Channel Tunnel Rail Link tunnels (now HS1). Both steel and synthetic fibres have now been used for complete replacement of the rebar cage as structural reinforcement. In the case of 'synthetic' fibres this is not the same as the microfibers normally used for fire protection.

The precast market now provides another battleground, in addition to sprayed concrete lining, for fibre suppliers such as Bekaert, Maccaferri, Propex and EPC that serve the tunnelling market.

Moulding and curing

Where the size of the project or continuous orders justifies it, casting plants are organised using a carousel arrangement to pass moulds under the concrete mix feed and then, if ambient temperature variations justify it, through a curing oven.

The low dimensional tolerances often specified these days have been criticised, especially as actual measurements can be affected by conditions like temperature variations, concrete shrinkage and even damage in transit. However, it follows that the use of high accuracy moulds will give the project a head-start in quality control.

Herrenknecht Formwork is delivering static moulds to Roger Bullivant's Buchan precast plant in the English Midlands for Costain's eight-year National Grid contract for cable tunnels to improve power supplies to London. The order comprises two sets of 30 moulds for 4,000mm and 3,170mm i.d. tunnels. The moulds are fitted with vibration systems for concrete mix consolidation and air-bubble removal.

'Combisegments' were first designed by

Left: **Segment trailers without load and a grout tanker form a Metalliance train for transportation to the face**

Herrenknecht Formwork for a sewer in Tsaritsyno to the south of Moscow, Russia. They have an integrated glass-fibre-reinforced plastic (GRP) liner to protect against sewage corrosion with a single construction process, with the liner inserted at the moulding stage.

Plastic dowels are used to connect the segments. The thinner lining made possible by this construction makes a construction cost-saving contribution to the higher costs of the lining.

The Tsaritsyno project also used, for the first time, seal profiles anchored into the concrete on moulding. A grove in the mould houses the EPDM structured seal from PDT-Profiles (Phoemix Dichtungstechnik) that is then cast into the segment as the concrete is poured. In this case the GRP line is also laid into the mould for holding on the concrete segment. Seal casting (anchored gaskets) is also used by Morgan-Sindall at Ridham Dock for Lee Tunnel segments (see page 52) where CBE has supplied eight sets of moulds for an 8.5m-diameter ring. Other advantages of this procedure include the elimination of the possible environmental hazard of gasket glue solvent, greater production precision and fewer chances for seal assembly error.

Mould construction, together with the associated equipment, has become a very competitive business with specialist concrete equipment manufacturers such as CBE, Ceresola and CIFA all taking part in addition to Herrenknecht.

Handling

One means of gentler but secure handling is by the use of vacuum pads on whatever handling and manipulation device is being used. This eliminates the point-loading of hoist connections and clamps, thus reducing local stresses in the concrete, with the potential for reducing damage.

Vacuum pads were reportedly first developed by Kawasaki at the suggestion of TML contractors for the Channel Tunnel for more efficient segment placement through a rotary erector, although a successful prototype was produced by the contractor Thyssen in the mid-'80s for the Three Valleys Water tunnel near London. There followed the award of a patent to the Thyssen developers and manufacture by Markham of Chesterfield. Since then the principle has been adopted by many manufacturers for all situations of segment handling including casting works manipulators and hoist attachments as well as erectors in TBMs. The concept has become so advanced that segment loads of up to at least 16t can now be handled.

Transport

The use of traditional flat-bed rail trucks or other vehicles for precast segment transport places a considerable onus on the local operative to ensure that the segment load is placed in the right position with the required packing to prevent undue stresses. Thus there is considerable potential for human error.

More dedicated vehicles have been introduced recently that generally comprise trackless tractors linked to trailers designed for various materials carrying duties, and even manriders. Two companies making such vehicles are Metalliance and TechniMetal Systemes.

Metalliance's TSP multi-function vehicles on rubber-tyred chassis the powerful TSP 90 for hauling a train of segment trailers and the smaller TSP28M.

TechniMetal multi-purpose trackless or railbound vehicles come in three basic designs for TBM supply carrying segments and grout for annular gap filling. Vehicles with 12 wheels have a maximum payload of 18t, eight-wheel vehicles carry up to 50t and a double-structure 14-wheel chassis can have a maximum payload of 100t. The first is specially designed for metro tunnels while the second has a low lift distance for segment loading. In addition, as an option, the front cabin can be collapsed for easier loading and unloading. TechniMetal also makes special hoist clamps for segment handling.

Control and reporting

Most clients and supervising engineers are now demanding rigorous quality control procedures with full reporting. It follows that the procedures themselves should be as automatic and foolproof as possible to save time and maximise reliability.

Consequently precast segmental lining production and installation should be integrated into the computerised tunnel construction management systems now becoming widely available. Although some operations are still identifying segment rings with marker pens, the increased reliability of industrial barcode (or similar) identification tags makes such procedures a virtual necessity. The importance of correct segment delivery has already been mentioned. VMT's Ring Management Program (RMP) carries out optimal planning of a ring sequence calculation faster and arguably more reliably than the most experienced TBM operator. The system can be set to calculate for only a few rings ahead or the complete tunnel. The system considers all parameters of influence for the best choice of ring including thrust jack pressure, tailskin clearance, any specific ring design criteria, cruciform joints incidence and the position of the TBM on the design axis. The procedure includes the calculation of any correction curve required through using the optimum ring sequence.

A recent addition from VMT is the Gaptrix instrument assembly to remove human error from checking the tailskin clearance. The semi-automatic system uses a Leica Disto instrument with Bluetooth data transmission technology to link with the TBM guidance system, eliminating tape measures and manual recording for later system input.

Bolting and fixing

Important considerations include the safe attachment of service lines and other items to the tunnel lining, without uncontrolled drilling through the concrete. Various fixture aids, such as metal channels, have been developed that are attached to the bolts used for segment ring assembly thus preventing hazardous point loading on the segments themselves.

Segment bolts and bolthole locators have been designed with the aim of easier segment ring assembly and, in the case of bolts, preventing corrosion for the design life of the tunnel.

Takenaka of Japan has developed a fluorocarbon polymer coating process that creates a thin, hard film on bolts etc that has been tested successfully in extremes of temperature and corrosive media. Applications have included transport and drainage tunnels for the Japan Ministry of Land, Infrastructure, Transport & Tourism, the Japan Railways Construction Public Corp, the former Metropolitan Expressway Public Corp, the Osaka Municipal Transportation Bureau, the Osaka Prefectural Government, the transportation bureaux of Nagoya, Kyoto, Kobe, etc, and other tunnel clients such as the Trans-Tokyo Bay Highway, Tokyo Gas, Kansai Electric Power, Hanshin Electric Railway and Kansai Rapid Railway.

If a high-temperature environment is anticipated, such as for fire resistance, Takecoat Ceramic is available.

As pre-cast segmental lining production emerges from a construction process to a manufacturing operation, so does the 'tunnel factory' approach reality through adopting industrial procedures for 'best practice' and quality control.

t in practice

quarries and supply constraints are tackled at the Peenya precast plant in India. speaks with Yogini Vimalanathan of Mott MacDonald and Russell Brown of CEC

The Bangalore metro project boasts the first TBM to be used in a southern Indian state and the first slurry TBM to be used anywhere in the country. As with many Indian cities, crowded, narrow streets define an outsider's view of Bangalore. But being around 1,000m above sea level and armed with a booming IT trade, the city is more affluent and also cooler than many of the other cities clamouring for metro access.

The project comprises a north-south and an east-west line, the latter being constructed by a JV of Taiwanese contractor Continental Engineering Corporation (CEC) and India-based Soma. CEC's Indian arm CICI is carrying out the tunnelling works and Soma is excavating the stations (see *T&TI* July 2011, page 22).

Lay of the land

The Peenya precast yard supplies the metro project with tunnel lining segments. The plant is 20km from the site. "We estimate that it would be economical up to a maximum distance of 35km if we are only supplying segments and not our ready mix," says CEC project manager Russell Brown. After that the land prices do not change by much, and the increasing transport costs would be the only factor.

"We are also central to the delivery of raw materials, so there is no benefit in moving closer to one of them at the expense of the others."

Brown adds that the two batching plants – Plant One supplying segment concrete and Plant Two acting as a backup as well as supplying concrete for civils work, including ramps, track bed concrete and cut and cover tunnels – take deliveries only during the night shift to avoid traffic congestion, so moving further away would be undesirable for this reason too.

India-based batching plant manufacturer Polytech Automation supplies the plants that were purchased new by CEC some three years ago. The plants were installed in November 2010 and operated in house by CEC personnel. In addition to Brown, Albert Chiang is CEC/CICI deputy project manager, Kasem Reinpracha is CEC/CICI factory manager and William Chan is factory manager for YaLi.

Plant setup

Segment production is subcontracted to Taiwanese segment manufacturer YaLi, the same company used by CEC for segment production for the Delhi metro project. It is one of the largest such contractors in Taiwan and China.

"The moulds we use were manufactured by CBE in China and are steel," says Brown. "They are built to French standards and are checked by Mott MacDonald." Static moulds are used, six for the 5.6m internal diameter rings for the Hitachi Zosen TBMs on the project and two for the 5.8m internal diameter rings for the Robbins machine.

Static moulds are in use because of the low capital expenditure compared to a carousel system (see feature, page 52). It is beneficial to lower investments when continuity of projects is unknown. Brown adds that CEC is not currently considering supplying concrete or segments to other contractors. Indeed, due to the rate of progress, Peenya would currently be unable to supply other contracts.

The production rate is two segments per day per mould segments as *T&TI* goes to press. Brown says that they have only just started to cast the Robbins.

Below: A resin based curing compound is applied upon stripping

Mix design detail for M-50 grade concrete:

• Cement:	350kg
• Fly Ash:	70kg
• Water:	133kg
• 20mm aggregate:	656kg
• 12.5mm aggregate:	537kg
• River sand:	727kg
• Admixture (PC based):	2.45kg

Due to commodity price fluctuations, Peenya alters suppliers on a monthly basis. Fixed rates are not given due to rising prices caused by government closures of illegal quarrying sites, resulting in a decreasing supply. Demand is rising due to the impressive number of large infrastructure projects in the Bangalore area of Karnataka.

Peenya precast factory makes use of CBE moulds. Segment production is subcontracted to YaLi

The site is ahead of schedule with its segment manufacturing.

The factory process works six days per week on a 24-hour cycle. This equates to 72 rings per week, with a daily production rate of 12.

Steam curing is used to accelerate the process and, upon stripping, the segments are sprayed with a resin-based curing compound. Rate of heat loss is closely monitored to ensure it remains in the 22°C heat loss curve. Actual heat loss is approximately 7°C per hour, says Brown.

Segments are handled by scissor clamps and suction pads. The suction pads are more ideal as the stripping strength is 12N/mm² as opposed to the 15N/mm² offered by scissor clamps. The suction pad, supplied by CBE, allows the segments to be stripped earlier. *T&TI* was onsite in June when the vacuum lifter was delivered.

Converted tipper lorries transport the segments from the yard to the tunnel site. Three segments are carried per lorry and are stacked with the concave facing up.

Segment design

The mould conceptual design came from Chris Smith of CRS consultants and Mott MacDonald's UK office. Yogini Vimalanathan of Mott designed the segments, which were checked and approved via Bangalore Metro Rail Corporation's chief engineer for design and underground stations N.P. Sharma.

Vimalanathan details the general design criteria of the segmental lining for the Bangalore metro. "On the dimensions, the 5.6m internal diameter is dictated by the train structure gauge, provision of a third rail, services and fittings of a raised walkway. A surcharge load of 50kN/m² is stipulated in the client's requirements and ground water leakage must not exceed 0.1l/m² per day for the segmental lining with no more ingress than 0.2l/m² per day for any 10m length of tunnel.

She adds that casting tolerances are very tight, with a tolerance on radial joint surface of +0.5mm/-0mm and a tolerance on segment width and circle joint surfaces of +1mm/-0mm. Tolerances on the trial ring were +8mm/-0mm for both the outer and inner diameter and +/-20mm for the outer circumference, which is measured on three levels.

"The precast concrete segments are subject to short term and long term loads," explains Vimalanathan. "Short term includes handling, stacking, erection, TBM shove forces and annular grout pressure. To resist these loads, two layers of reinforcement are provided along the intrados and the extrados of the tunnel lining.

"There are also load conditions when the segments would not have reached the 28 day cure strength of 50N/mm²." Vimalanathan continues, "De-moulding of segments takes place within 24 hours of casting. At this stage the concrete strength has to be a minimum of 15 N/mm² and stacking segments can only take place when the cure strength has reached 25N/mm². Timber battens are used to separate the segments when they are stacked with a tolerance on the batten position of +/-100mm.

"When the segments are in the ground the ring is in compression and the segments are designed as short columns subjected to axial forces and small bending moments. The most highly stressed zones in a segmental concrete lining are the circumferential joints, through which the TBM shove forces are transferred and the radial joints, through which large compressive hoop forces due to ground loading are transferred."

Brown adds that only steel reinforcement is used, and no fibres are added.

The full circle

"The ring consists of a 72° trapezoidal

Precast in practice

Water shortages, rogue quarries and supply constraints are tackled at the Peenya precast plant in India. Alex Conacher speaks with Yogini Vimalanathan of Mott MacDonald and Russell Brown of CEC

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The full circle

"The ring consists of a 72° trapezoidal

Above: The steel CBE moulds were built to French standards

segment, four 67.5° rhomboidal segments and an 18° wedge shaped key," explains Vimalanathan. "The angled radial joint across the ring is sloped at 1:7. This arrangement ensures that cruciform joints never occur. The tight interlocking configuration of the segments forces the tunnel ring to be built circular and prevents ring ovalisation due to bad build.

"The 1.5m-long ring minimises manufacturing cost and maximises the rate of construction. To negotiate the alignment curvature a suitable ring is needed to correct for line and level during construction. The tightest curve on the bored tunnel alignment is 270m. The tunnel ring has a 55mm taper to accommodate a 170m minimum curve, which allows for error corrections if the TBM goes off line.

"The radial and circumferential joints have flat surfaces with chamfers and rebates along the edges and corners of the segments."

"The chamfer and the rebate prevent edge contact, which could result in spalling during ring erection, TBM shoving and subsequent loading of the lining. A 3mm plywood packer is glued to the trailing edge of the ring to assist in smoothing out any irregular surfaces caused by lack of fit of segments and to spread and assist in absorbing TBM thrust ram loads.

"The circumferential joint contains dowels at 22.5°. The dowels are anchored using embedded sleeves in the pre-cast concrete segments. The dowels act as locating devices speeding up the ring erection and enable the ring to be built circular.

"The universal rings are rolled to achieve the required alignment with the key taking up any of the 16 positions around the circle.

"The radial joints have two spear bolts [by Cooper & Turner] per segment."

Vimalanathan adds, "It is normal practice to reduce the moment of inertia of a segmental lined tunnel ring depending on the number of joints and treat it as a flexible ring. This is advantageous as it attracts less bending moment under non-uniform ground loading.

"However, on the Bangalore Metro, due to the trapezoidal and rhomboidal segments, which nearly locks all the joints preventing articulation about the radial joints, the ring was considered to be rigid."

Co-extruded Datwyler composite gaskets are used, consisting of an elastomeric carrier (EPDM) and hydrophilic facing material. The gaskets resist a working pressure of 2.5 bar and a test pressure of six bar at a 10mm offset and 8mm gap.

Properties of the lining	
Description	Bolted concrete lining properties
Concrete grade	fcu = 50 N/mm²
Steel bar reinforcement	fy = 500 N/mm²
Segment type	Five segments and a wedged key
Ring width	1,500mm
Excavated tunnel diameter	6,160mm
Internal diameter	5,600mm
Thickness	280mm
Gaskets	Datwyler extruded gasket
Circle joints	Dowels
Radial joints	Spear bolts

Quality control

Brown tells *T&TI* that quality control is handled by having a close working relationship with their client Bangalore Metro Rail Corporation and the client's agent general consultants Rites-OC-PBI-Systra, who compliment the CEC quality control and assurance team. He reports 0.5 per cent rejected segments so far, saying that every raw material wagon is tested for conformity of cement, sand and gravel. Initially the site had a high failure rate of raw aggregates, but with the suppliers now aware of the standards demanded, Brown says that the failure rate has become insignificant. He credits this to the onsite CEC quality control department, which includes client engineers, general consultants and is managed by general consultant project manager Nigel Butterfield for underground works.

Challenges

One complication that has to be worked around on a daily basis is that of water supply. "With water shortage and mains supply issues, we have to provide water from our own bore wells," says Brown, "These draw water from 200m below and we constantly test for compliance. It actually needs to be chilled during the summer months to avoid overheating during the initial setting of concrete."

Vimalanathan concludes, "With tapered rings and trapezoidal and rhomboidal segments, calculating the segment dimensions proved extremely arduous on the Bangalore Metro. It is important to note that when calculating segment dimensions the segment width should always be calculated using the projected length of the segment on the plane containing the minimum and maximum ring widths and not the arc length."

Segment handling and installation

While the long-term function of segmental tunnel linings is to withstand the loads imposed when in the ground, the designs have to encompass not only the ground loads but also the loads during manufacture, transport and erection of the lining. Yogini Vimalanathan of Mott MacDonald and Lesley Parker of FP McCann Precast describe some of the issues that need to be taken into account when designing segmental tunnel linings

There are a number of stages in segment handling. With a segmental lining arrangement finalised and the moulds supplied, the first stage would be de-moulding when the concrete strength is low. To free up the mould for casting of the next segment, the precast segment is taken out of the mould at the earliest possible time.

Trials are carried out using the moulds proposed for segment production to establish the minimum stripping time, such that removal of the mould will not damage the surface of the concrete.

The de-moulding strength is often not just dependent on the concrete segment handling but on a number of other factors:

- Can the pins be removed from fittings and holes?
- Holes in the segment may slump and cause problems when bolts are inserted at a later date.
- Cast in plastic sockets may turn if the threaded mould pins are taken out too early at a low concrete strength.

A minimum strength is required around the circle and radial joints; so when the side panels of the mould are released they do not cause the gasket groove and the fitting recesses to spall.

The designer will specify the minimum strength at which the segment can be taken out of the mould based on the length and thickness of the segments and the quantity of reinforcement in it. The minimum de-moulding strength is usually around 15Mpa. There are no codes or standards which give appropriate bending and shear capacity of concrete for strengths less than 15Mpa.

Vacuum pad lifting is the gentlest form of lifting where the stresses induced in the segment are more uniformly spread. If vacuum pads or scissor lifts with side grabs are not used, lifting anchors may be located in the circle joints. In this instance when the segments are lifted by their thinnest side there will be a reduction in the lifting capacity, especially if they are only reinforced with fibres, and the concrete would need to reach a higher strength at lift.

It is assumed that the edges projecting beyond the vacuum lifter act as a cantilever. The segments are checked for shear and bending capacity.

The segments are at their most vulnerable stage during de-moulding and need handling with care to prevent hairline cracks which can open up under loading.

The grabs extend along the circumferential edge of the segment. Bearing stress and shear stresses induced around the perimeter of the grabs have to be checked assuming no reinforcement acts to enhance the shear strength of the segment due to the proximity of the free edge of the segment.

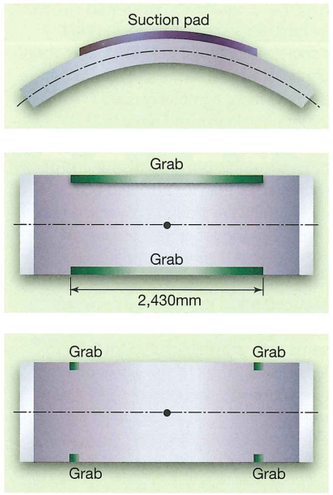
Segments stored in a different orientation to that cast will require a turning frame.

Temporary storage for curing or for installation of gasket

During storage, segments are checked for sagging moment at the centre, hogging moment at the support and also for shear at the supports.

It is common practice to specify that a load factor of five be applied to segments during handling. This is based on a dead load factor of 1.4 and a dynamic amplification factor of three, which gives a combined effect of 4.2 which is then rounded up to five. This factor of safety

Below: **It is assumed that the edges projecting beyond the vacuum lifter act as a cantilever. The segments are checked for shear and bending capacity**



ensures that the segments do not crack under sudden jerky movements.

Lifting a single segment off frame using grabs

The grabs used to lift the segment off the frame are smaller and support the self-weight of a single segment during the lifting operation. Bending moments for this case are the same as those for the temporary frame above. However, there is the additional bending moment induced across the width of the segment owing to the nature of the grab.

Segment stacking

When segments are stored in the yard prior to transportation to the launch shaft site it is common practice to stack each ring on its own which simplifies the transportation stage (see figure 2, above).

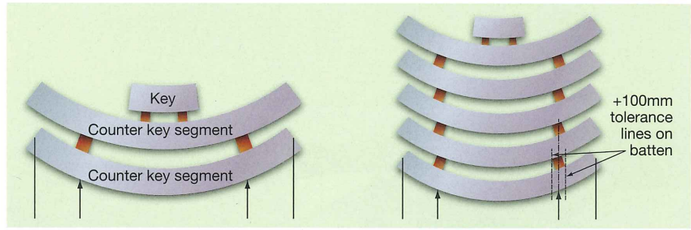
Segments can be stacked supported either on their back, front or side.

With a full stack of six segments forming a ring, it is appropriate to assume that the load factor of five is not applied to all six segments. We would assume that the top three segments are stacked onto the bottom three, and therefore a load factor of five is only applied to the self weight of the top three segments whilst 1.4 is applied to the lower three segments which would already have been placed in position.

The timber batten positions are determined such that the hogging moments induced at the supports are equal to the sagging moment in the middle of the segment. This makes the most economic use of the hoop reinforcement provided equally along the intrados and extrados of the segment. This is often approximated by contractors to ¼ points.

The battens should always be in line. However this could be difficult on site and therefore usually a positioning tolerance of +/-100mm is allowed for in design.

The height of the segment stacks has to be limited to prevent instability caused by mis-aligned battens. With vertical stacks, the number of segments in a stack is limited to two or three as the gaskets may be crushed under the timber battens.



Left: **Figure 1, options of lifting by grabs and vacuum pads. Vacuum lifting is the most gentle, as with grab lifting loads are less uniformly spread;** Above: **Figure 2, battens in line for segment stacking**

Segment erection

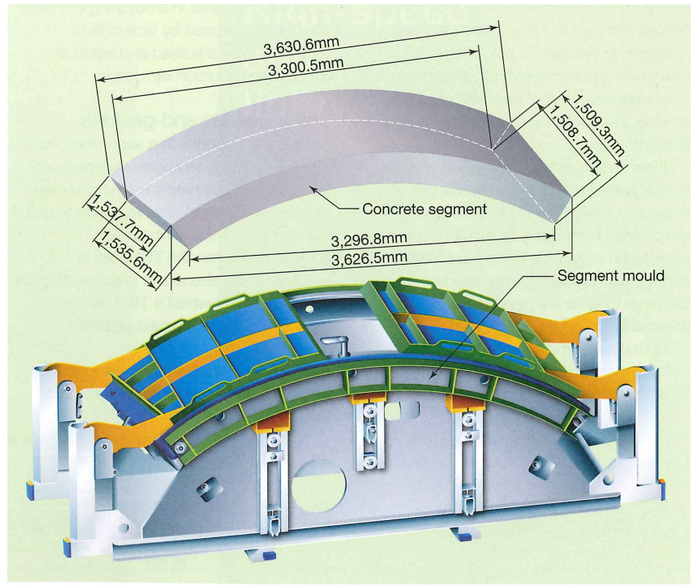
Before installation the segments will have reached the 28 day strength. They will therefore have the strength to be lifted by a central lifting point if the segments are reinforced with steel bars. But if the segments are reinforced with steel fibres, the stresses have to be more uniformly distributed and will therefore be lifted using vacuum pads.

By doing so the risk of fibre reinforced segments cracking in the tunnel and causing injury to the miners can also be eliminated. Once underground, the segments will be lifted off the segment transporter in the backup, transported to the ring build area by a carousel, and positioned by the TBM erector which will either use a mechanically fixed lifting point which is screwed onto the segment cast-in lifting socket located on the centre of gravity point of the segment or lifted using vacuum pads with safety shear pins.

Ring geometry

Ring geometry greatly influences the segment installation process. Tapered rings allow for changes in the alignment from a

Below: **Figure 3, segment dimensions and mould**



Above: **Segments supported on frames while curing to full strength**

straight to a curve and a clothoid without any packers. Rolling the ring, the varying segment positions provide the directional corrections required to achieve the desired alignment.

A balance has to be struck between speed of erection and an economic design. For many projects one of the key costs is the overall duration of tunnelling. The larger the segment size, the fewer the segments and number of joints which need to be bolted together and made watertight. The minimum number of segments that can be accommodated in a ring is five plus key. However, to reduce the risk of flexural failure with steel fibre reinforced segments, a minimum number of segments in a 6m internal diameter tunnel would be seven plus key.

In the past most tunnel linings have been rectangular in plan with the top and key segments having radial joints which are inclined to the long axis. But now trapezoidal segments for smaller tunnels and rhomboidal/trapezoidal segments for larger tunnels are being more commonly used.

As the name implies, trapezoidal tunnel linings have trapezoidal shaped segments. There is some evidence that trapezoidal segments are easier to erect and assist in ensuring that the ring is built circular prior to grouting and prevent cruciform joints even without ring roll. However, the geometry of the segments requires greater space for erection and longer jacks.

Both radial and circumferential joints have a chamfer/rebate along the edges and corners of the segments. The chamfer and the rebate prevent edge contact due to manufacturing and build tolerances, which could result in spalling during shoving, ring erection and subsequent loading of the lining. A thin self-adhesive packing is used between segments on the circumferential joints which assists in smoothing out any irregularities caused by lack of fit of segments and to spread and assist in absorbing propulsion ram loads.

Bolts, dowels and gaskets

The purpose of bolts in a segmental lining is only to provide temporary support until the grout annulus hardens. The bolts are required in the short term to keep the radial and circumferential joint gasket compressed when the TBM ram is released. They also assist in supporting the segment weight whilst a TBM ram is removed to install the next segment.

In the 1980s curved bolts were favoured as they required smaller pockets in the concrete segments. But with the reliability of plastic cast in sockets spear bolts have become more commonly used in linings of 200mm thickness and greater. The advantage of spear bolts is that they only require a single pocket although the pocket size is larger than for a curved bolt.

The bolts are placed in oversized bolt holes allowing for certain amount of construction tolerance and movement at the joints. The design of bolt fittings in enlarged holes is a balance between allowing enough movement and at the same time providing sufficient fixity to achieve a circular tunnel within given tolerances with the help of TBM thrust rams and the surrounding grout annulus.

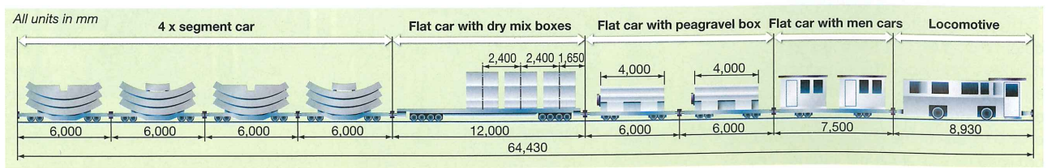
Dowels are very often proposed for circumferential joint connections. Unlike bolts, dowels require no pockets. Dowels act as locating points when segments are brought together and they also prevent lipping between circumferential joints. However, the dowels require the thrust force from the TBM to push the segment into position as they snugly fit within the segment to provide shear and tensile resistance to keep the gaskets compressed when the TBM rams are retracted to install the next segment. However, dowels cannot be re-used like bolts.

To keep the tunnel watertight in tunnels constructed below the water table and in permeable ground, gaskets are provided in grooves close to the extrados of the tunnel lining. Gaskets girdle the segments and are installed in the segment manufacturing facility before the segments are taken underground. One of the most recent developments in segment manufacture is to include the installation of the gasket by incorporating it in the segment moulds.

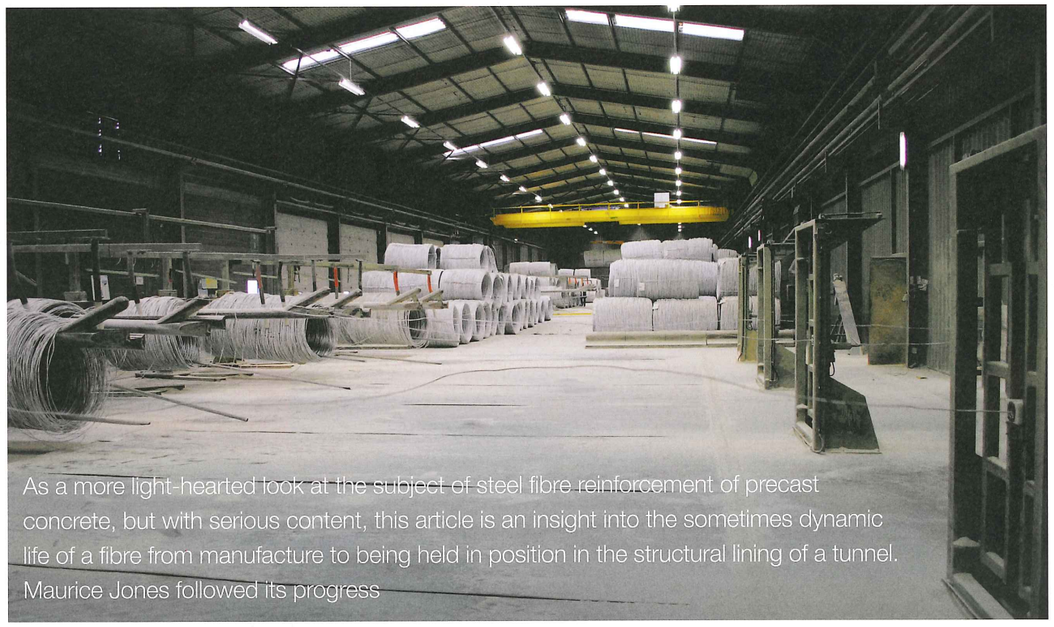
Conclusion

These requirements will also have to be weighed against other factors such as local skills and materials and the possible re-use of equipment and plant which may limit options for the segment design. In future, the use of fibre reinforcement for tunnel lining manufacture is likely to become more widespread as is the use of multiple lifting points to support larger segments.

Below: **Segment transportation in the tunnel showing cars and locomotive**



Holding it together: the birth and life of a fibre



As a more light-hearted look at the subject of steel fibre reinforcement of precast concrete, but with serious content, this article is an insight into the sometimes dynamic life of a fibre from manufacture to being held in position in the structural lining of a tunnel. Maurice Jones followed its progress

The idea of using fibres for construction materials reinforcement is hardly new since the Romans were using horsehair in mortar around 200 BC. But in 1960, Batelle in the US patented the production of straight fibre from wire for concrete reinforcement; and in 1970 Bekaert added hooked ends to improve anchorage, followed five years later by the idea of gluing fibres together to improve handling and mixing.

Bekaert has been working with (mainly steel) wire since its founding in 1880 and is now the world's largest producer of drawn steel wire products. At Bekaert's plant, established in 1990 in Moen, Belgium, life can be quite lonely for operatives as the total workforce is only 75 in this highly automated and efficient production facility, producing millions of Dramix steel fibres every day. Is this article we follow the path of just one of them from rod to casting.

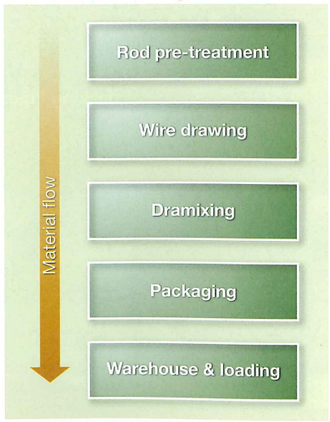
Various types of mild (bright) steel fibres, 30-60mm long and 0.55-1.05mm in diameter, are produced here for both pre-cast and sprayed concrete tunnel lining, with another major application being large concrete floors without joints.

Bekaert first started producing steel fibres next to the current headquarters in Kortrijk, Belgium. Now there are nine Bekaert plants around the world producing wire construction products and related products such as brick ties. These include the recently acquired Korean plant with 3,000 employees, another in China with 7,000, and a probable new one in Colombia under discussion.

Moen is Bekaert's highest producing plant in the world at 55,000t per year, but appears very unassuming from the outside. Inside, production equipment is laid out to promote efficient materials flow on parallel production lines through the works (see figure 1, right).

The operatives are organised into teams of eight plus one technician, and each has personal responsibility for a whole production line. Work periods are seven days on, seven days off. There are seven Dramix production lines with 35 dry-process wire drawing machines using lubricated dies of steadily decreasing internal diameter. Each line runs 36 wires.

All machinery, except for standard packaging machinery, has been designed and manufactured by Bekaert itself.



Right: **Figure 1, production flow for the Moen plant from delivery and pre-treatment to warehousing and dispatch**

The start

Material for fibres at Moen comes from several suppliers, such as Tata Steel (formerly Corus) in Germany, as coiled rod of 5.5 or 6.5mm diameter. The first job is to prepare the thick wire for the production lines by first taking scale off the rod.

Chemical descaling for 80 per cent of the supply is carried out at nearby Zwevegem by pickling in an acid bath, and lime applied to neutralise the acid, provide temporary rust protection, and act as a carrier for lubricant. The coils are then quickly delivered to Moen. Mechanical scaling at Moen is used for larger diameters and consists of rolling the rod to bend it in two directions, thus cracking the scale, and passing it through rotary wire brushes, leaving minimal contaminant to be washed off.

Drawing

The next preparation stage is to ensure sufficient lubrication to pass through the drawing dies. Dry soap of a particular type is used for lubrication but this has to be held onto the relatively smooth wire throughout the process. The rod is therefore passed through a warm bath that applies a crystalline lubricant carrier to the metal for a rough surface.

Rotating conical dies, with inserts made of Widia tungsten carbide or diamond, are used to reduce the diameter of the continuous wire by about 25 per cent each time. These inserts are changed once a week to maintain the correct diameter, but are also valuable and so are recycled at the Zwevegem plant for use in larger dies.

First three machines, designated CAZ, reduce the 6.60mm rod to 1.05 or 0.90mm diameter. The drawing process naturally elongates the rod, into wire by then, and also heats up the steel. The lubricant, forced into the wire by the die, must therefore be resistant to both pressure and heat. Next there are four 'BAZ' machines for further reduction from 5.50mm to 2.30mm diameter or 6.50mm down to 3.35mm.

The main and final reductions are achieved through 12 DAZ machines and 16 'CDZ' machines to reduce 2.30mm-diameter wire to 0.62 or 0.55mm and 3.25mm wire to 1.05, 0.9, or 0.75mm-diameter fibre wire.

Typical elongation might be one metre of 5.5mm-diameter rod producing 30m of 1mm-diameter wire and eventually 100m of 0.55mm diameter fibre material. Lubricant soap is removed at the last die.

Opposite: **Line feed of chemically treated wire rod - the dust is lime;** Right: **Head of the main wire drawing lines at Moen;** Below right: **Set up for testing the bending performance of a standard Dramix-reinforced concrete beam in the lab at Moen**

The drawing process not only reduces the wire diameter to fibre size but also increases the tensile strength of the steel. This must be greater or equal to 1200MPa.

The drawing line speeds can be up to 2,000m/min on eight lines, practically invisible to the naked eye and noted only by specialist instrumentation. This is a great increase on the 30m/min of the initial rod feed. The forces used in the drawing line have to be carefully controlled by a series of capstan and 'dancer' pulleys as well as the instrumentation. The fastest (CDZ) line is controlled electronically and has hydraulic brakes for safety. Excessive force could cause a line break and serious production problems. Continuous operation is essential to achieve high production rates, with even the coils of rod being welded together before entering the line to maximise continuity.

This reliably controlled high line speed is necessary to ensure maximum economical production. A typical line speed of 1,500m/min from a 1,500kg feed drum will produce 42,857 fibre lengths per minute. The only way production can be further increased at Moen is by more upgrades to line production since there is no room for more expansion of the facilities.

Once the wire has been drawn down through the series of dies to the required diameter of the fibre product, spools of the wire are transferred to the final production line for cutting, bending the ends and, if necessary, gluing together. A double pay-off system at Moen operates two 36 spools, although this is not the biggest as two other Bekaert plants in Asia and Europe run with 48 wire lines.

Sticking together

First the wire is straightened in parallel runs as this makes it easier to glue the final fibre products together, using less material. The gluing process and nature of the adhesive is a closely guarded secret. The glue has to be water soluble after about one minute for quick and thorough dispersal of the fibres in the concrete mix, preventing fibre 'balling'. The constituents of the glue must not affect the chemistry of the concrete. The glue used includes 50 per cent water when it is applied but, once on the continuous fibre wires, the water is evaporated in an induction-heating oven and then cooled.

At the end of the line, immediately after the cooling process, the wire is cut and shaped in one operation (also secret) to form the familiar glued comb bundles of fibre, ready for packing and dispatch.

Packaging and dispatch

Bekaert fibres are designated by material, length and aspect ratio. In tunnelling the product designations commonly used are 65/35 and, for precast segments, 65/60 as with our 'hero' subject.

During packaging synthetic fibres can be added for Duomix mixed products for concrete protection in fires.

All packaging, into bags of various sizes, is carried out automatically, with final palletising and shrink-wrapping of 1,200kg for 20-kg bags, and 800- and 1,100-kg 'big bags' for bulk handling, and is all accomplished by robots.

Above: **Dramix fibres on their way to the mixer at the Costa Rica segment casting plant for Seli's hydropower tunnel contracts in Panama**

Quality control

Bekaert rightly thinks of its fibres as structural elements produced to a clear engineering specification, rather than as a commodity. An equally clear, independent or independently audited testing and quality control procedure back up this claim.

Each consignment carries ink-jet coding for traceability according to Bekaert's ISO 9001 (v2008) procedures, so that, in the unlikely event of a product fault, it can be checked back to the source of the problem. Bags carry the ink-jet print of date, time and line of manufacture, whereas pallets and one or half-tonne 'big bags' carry a forwarding label with the same information. 'Big bags' are used to charge dosing units at high capacity customer installations, mainly batching plants.

In addition to ISO 9001 compliance, the Moen plant has also achieved ISO 14001 registration (environmental standards) through Bureau Veritas; the first plant in Europe to do so.

Bekaert operates a standard documentation system covering product specifications, the work process and instructions to customers and users, amongst other things. The company's quality control systems are integrated with this and cover all European operations. It operates at two levels, the first being at the (Moen) production plant and the second through separate testing at the concrete lab housed at Zwevegem, which also serves the rest of the world.

At the plant, quality control starts with checks on input supplies. The Bekaert purchasing department is mainly responsible for checking the incoming coiled rod, and there are similar checks on lubricant soap, glue, etc with a test report completed for each delivery. New suppliers have to go through a rigorous testing programme before approved.

On the production line operatives have whole-line responsibility and this includes quality checks such as possible wire ovality using a micrometer and length of cut fibres. Other production checks include fibre geometry using a magnifying profile projector, testing for tensile strength, and ductility during bending. More detailed testing is carried out in the concrete lab. Bekaert says that its quality control standards are higher than those required by the relevant EN European Standards.

CE product marking was achieved in 2008; the first manufacturer to do so. Under the CE certification all structural products, such as the steel fibres for precast concrete segments and sprayed concrete, are subject to Class One independent inspection. Non-structural products can be certified through in-house testing.

Quality control includes integration with customer claim handling so that any faults can be traced back.

Modern applications

Looking ahead, one of Bekaert's emphases is continuous product development, even in 'mature' markets for wire. To carry out this aim there is a EUR 60M research and development budget employing 400 people worldwide.

In addition to the successful product development mentioned earlier there are Dramix Green, a galvanised fibre to eliminate corrosion, and stainless steel version for extreme demands. The latest innovation has been head of building products R&D Ann Lambrechts' idea to flatten the ends of the fibres for better anchoring in the concrete. This increases the bending tensile strength of concrete by 32 per cent, with the better anchorage improving crack control and enhancing durability. The work won Lambrechts the European Inventor Award this year.

Recently there has been a priority to package products for easier handling and mixing, often demanded by government health and safety legislation. In addition to the glued fibres, various forms of dispenser or dosing systems are available including the latest Dramix RB belt conveyor dispenser for dosing smaller quantities (250g bags). Most Moen fibres go out in either 'bulk bags' for mechanical handling or palletted paper sacks.

Work continues in co-operation with leading concrete ready-mix producers such as Lafarge. The use of short, high-carbon steel fibres has resulted in their production of a 'ductile concrete' with strength in excess of 200MPa.

'Sustainability' is a common buzzword in discussions about modern construction practices, and tunnelling should be no exception. One aspect, as ever, is how structures can me made cheaper whilst maintaining or improving on the specified structural performance. Bekaert Dramix plays its part here too. Steel fibre reinforcement is claimed to be environmentally friendly ('green') as a basic concept, as it can be used to replace some or all of the thick rebar cages otherwise used in design to improve the tensile strength and toughness of concrete elements. This obviously saves on steel, mineral resources and the energy for manufacture. In addition, Bekaert is now using at least 20 per cent recycled steel in its production.

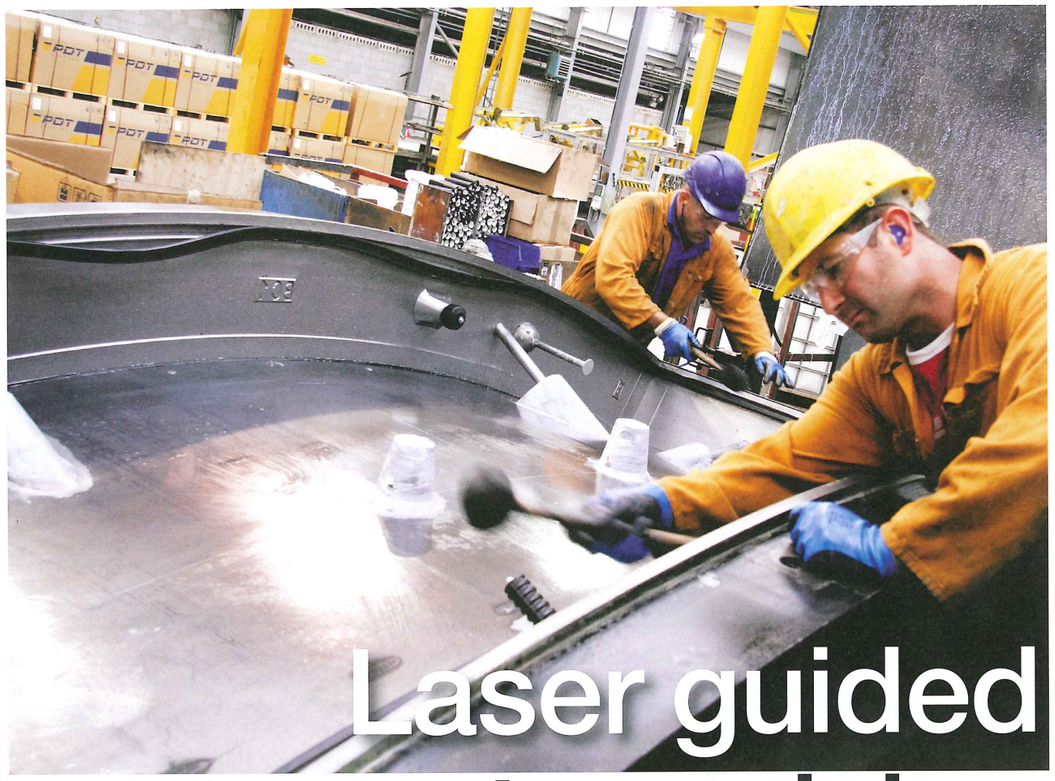
Leading tunnelling contractors and designers, notably Colin Eddie at Morgan Sindall, have been examining how concrete linings can be made thinner for the same performance such as at the London Heathrow Airport Baggage Tunnel - with sprayed concrete. It follows that concrete usage would then be lower; a major factor in reducing a project's carbon footprint. Thinner linings using steel fibre reinforcement can require high-carbon steel material however, rather than mild steel, and this costs around twice as much, so the whole exercise is a matter of balance in financial as well as performance terms.

In the mix

Bekaert consults on fibre dosing procedures, including fibre distribution, for all sizes of concrete mixing, and supplies dosing equipment for many applications to ensure a steady feed according to the concrete specifications. The latest developments include the Dramix Booster automatic bulk dosing system and the RB belt dispenses that carries soluble paper bags of fibres, each weighing 250kg.

So, our 'hero' is one of many thousands of fibres in the hundreds of tonnes being delivered around the world, in this case to Costa Rica where segments are being produced for contractor Seli to line the Monte Lorio hydroelectric power project headrace tunnels just across the border in Panama. The segments are being made with only steel fibre reinforcement - no rebar cage - using Dramix 80/60 fibres (60mm long and 0.75mm in diameter).

Sample segments, 250mm thick, were independently tested to destruction for Seli by the Laboratorio di Strutture e Prove Materiali at the University of Rome ('Tor Vergata') to confirm maximum loading performance.



Laser guided segment precision

T&TI visits the Morgan Sindall precast facility at Ridham Dock in Kent, UK. The plant is currently supplying segments for Thames Water's Lee Tunnel. Alex Conacher takes the grand tour

Morgan Sindall's precast factory at Ridham Dock near Sittingborne in Kent, UK, was set up 10 years ago to support Morgan Sindall's tunnelling business unit and supply segments to the Heathrow Terminal Five project. It was sited at Ridham, not only to be close to the tunnelling work on that project, but also due to its proximity to London for future work.

As well as Heathrow, the plant has since supplied a variety of Morgan Sindall's other projects including Croydon Cable Tunnel, Belfast Sewers Project, Hendon to Colindale Cable Tunnel and the Brixton to Honor Oak water tunnel (part of Thames Water's London Ring Main extension). Ridham Precast has also supplied the Brighton and Hove 'Cleaner Seas for Sussex' sewer project (see *T&TI* September 2010).

Lee Tunnel

Ridham Precast is currently supplying the segments for the Lee Tunnel, part of Thames Water's London Tideway Improvements programme. Awarded to MVB, a joint venture consisting of Morgan Sindall, Vinci Construction Grands Projets and Bachy Soletanche, the 7.8m internal diameter, four mile (6.4km) long tunnel utilises a tapered universal ring design comprising seven segments plus a key.

Production fired up in March 2011 after trials in February. One of the two carousels at Ridham is dedicated to manufacturing segments for Lee Tunnel, and will take 2.5 years to fabricate the segments required. The other carousel is currently idle, ready to supply other projects.

Factory operation

Dave Hicks, engineering manager at Ridham Precast, says that the high turnover speed achieved with a carousel system makes it a far superior method to static moulds. Though this is with a higher start-up investment. Martin Hill, production and works manager, adds: "This translates into a more efficient means of manufacture, with more production per mould. With static casting, when concrete is moved over greater distances, quality can suffer. With our process it is typically less than five minutes between concrete production and placement."

"This development is so much more advanced, yet many of our competitors have stuck with static moulds."

The plant uses an onsite batching plant. "You will never get sufficient quality with a batch ready mix," says Hill, "you need to batch on site." Ridham Precast uses a Skako Denmark supplied batching plant which has been designed for steel fibre reinforced concrete production. "Overwhelmingly we produce steel fibre reinforced concrete often with the addition of polypropylene fibres. The steel fibres come collated as glued strips from Bekaert. This is key to good fibre distribution in the concrete as loose fibres tend to ball."

Hicks continues, "How the steel is put into the mix is key. We have worked with Skako to absolutely eliminate balling. It's all about a combination of the timing of conveyor belts, premixing and how the belts move. If you get everything right, you get a very good distribution of fibres.

Mick Town, Ridham's precast manager, points out that "this is a highly modern plant. In older ones the fibres were introduced later in the process, resulting in an inferior distribution through the mix. When a Lee Tunnel inspector examined a segment we cracked open, he reported a 'better than expected' fibre distribution."

The fibre hopper feeds 30kg per m^3 of Bekaert Dramix steel fibres into the process via a combination of vibrating feeders, weigh hoppers and conveyors. The steel fibres are added to the aggregate weigh belt after the aggregate has proportioned. The timing and action of the discharge of the aggregate belt premixes the steel fibres with the aggregate. This helps good fibre distribution and prevents bridging as the fibres are fed into the mixer. The capacity of the plant is tactically reduced from $2m^3$ to $1.5m^3$ with the steel fibres as one of the measures to prevent balling. Polypropylene fibres of 32 micron thickness are added to prevent spalling of the concrete in a fire. These are cut on demand from a fibre tow and fed directly into the mixer. Mix time is four minutes with about 30 seconds for weighing up. The batching process works in parallel so while one batch is mixing, the next is being weighed. A bucket conveyor delivers the mix to a waiting casting hopper at the production line. The whole process is fully automated.

The moulds use electric vibrators to compact the concrete and research has been undertaken to find the optimum vibration. Hicks recalls a problem five years previously with stiff moulds: "CBE, who manufacture our moulds, now employ a vibration analysis specialist to ratify all their mould designs."

There are nine production stations on the production line, with the 40 moulds moving between them on the carousel. Each has approximately 10 minutes to complete its tasks before the carousel moves on, but only once each station has signalled its readiness to continue. The control system is interlocked until all consents have been obtained. A lamp is illuminated for each station on a display board as they declare themselves ready so that the line charge hand can see the location of any delays.

One concern with the carousel system is that the movement of the pallet is enough to refluidise the concrete, so a lid is closed tightly on top of the poured concrete to ensure the correct form is maintained.

Although he describes it as a highly automated factory, Hicks tells *T&TI* that, while it might be new to segment manufacture, the technology in use at the plant was already established in other industries when he brought it in 10 years previously. "In many cases, fresh blood can invigorate an industry, new ideas can be brought in that are obvious to an outsider but revolutionary to the established way of doing things."

Glueless gaskets and steel moulds

The gaskets are provided by PDT Profiles (formerly Phoenix Dichtungstechnik) and are physically cast into the concrete, which is a recent development. "Conventionally," says Town, "you would cast grooves into the concrete and apply the gasket with an adhesive. This process is dirty, smells and is generally unpleasant for the workers. Now that we no longer use glues and chemicals, that is not a problem. The quality is also second to none, the segments are visibly much better than glued gasket ones, and it means that you can store them outside without the environment affecting the adhesive. We had a backup system in case there were unforeseen problems – we could still glue gaskets on, but it has not been needed."

Before concrete is poured into the moulds, gaskets are fitted by hand to a rebate around the sides of the mould. They are then hammered in firmly by a rubber mallet, concrete is poured, and the gasket is firmly embedded in the segment as it cures. *T&TI* is told that it is possible and simple to remove the gaskets if necessary, but they are secure enough that they will not come loose by accident.

Town adds, "We are the first to use this system in the UK. It was used on a very small scale in Moscow on a sewer tunnel. Our use here is a major step up for the system. All it took was someone to shake things up by actually having the courage to do this."

Town says that their preferred mould supplier, the French company CBE, already had a relationship with PDT so it was just a question of asking them to come up with a scheme for casting gaskets into the segments. Town says, "We've had zero problems. It ticks all the boxes. The gaskets

Opposite: Fitting cast in gasket to segment mould eliminates the need for unpleasant adhesives; Below: The finished product is a neatly fitted gasket with no staining. It is fitted tightly enough that it will not fall out but can be removed at will. All photos © Morgan Sindall

Right: **Finishing the extrados face of a segment in the mould**

are a little bit more expensive but you don't need to buy the glues or invest in the cleaning materials.

"You do need decent moulds and other factories might struggle if they relied on concrete or poly moulds. Steel moulds are necessary to meet the kind of tolerances specified for the Lee Tunnel project. We are down to parts of a millimetre accuracy."

Heat

The JV requires the plant to prove the de-mould strength of segments, says Town. "To do this we embed thermocouples and looked at the temperature over time of the curing process. Using software supplied by OTB Concrete, this gives us the concrete strengths so that we know when we can lift and when we can't."

"We've never had any thermal cracking, but we need to be able to prove that we will not. It also enables us to optimise curing, reducing the energy use but maintaining the strength." Segments spend five and a half to six hours in the moulds.

De-moulding and storage

Vacuum lifters strip the segment from the mould where it is inspected. It is then turned vertically and picked up with lifting anchors. The segment is stored on its edge to save space and to protect it from damage. Close to zero damage has been seen at the site so far but if a segment is rejected, it will be crushed and recycled. A local recycling company would sell the material as sub base.

Only 39 segments had been rejected when *T&TI* visited the site out of 3,600 total, including deliberate segment breaks for testing and trial segments used for ring builds.

Below: **Batching plant material loading belt carrying aggregate and fibres**

The Ridham site can store around half of the segments required for the Lee Tunnel project, which is approximately 2,000 rings. A supply buffer of three months' worth of rings ahead of advance rate expectations is usually required.

Getting the picture

Nod Clarke-Hackston, VMT sales manager tells *T&TI*, "The use of a 3D laser checking apparatus was included in the tender documents for the Lee tunnel project. The Ridham plant had been successfully producing high quality segments for the past 10 years without such a system, but as it was required in the specification it was purchased and is now being used every day to check the dimensional accuracy of the one in 50 segments that the contract calls for.

"Although the dimensional tolerances required for the project are specified in the tender it only gives the dimensions and not the conditions under which these should be achieved. No temperature is specified or a time in the aging of the concrete. All the measurements taken are temperature corrected as is necessary in any precision metrology. But the reference temperature against which the comparison is made is not. Similarly it would be better to do the dimensional checks when the segments have reached optimum maturity at 28 days.

This however would lead to a potentially large amount of incorrect segments being produced prior to checking so a compromise of checking the dimensions after de-moulding is taken.

"During the initial training of the Ridham team by the VMT engineer a check on the moulds was carried out and it was here where they discovered there was some torsion in a few of the moulds. This would not have been possible with the traditional way of checking, but once identified it was a straightforward task to rectify.

A unique identity is given to concrete in each mould and segments have a barcode sticker applied to them when de-moulded. Segments histories are stored in the factory database in case information is required in the future. *T&TI* is told that this is not an industry norm, and segment identities scratched on in crayon are not unheard of.

For the Ridham plant the system includes a Faro lasertracker although similar instruments from Leica and API have been supplied in VMT's systems. The lasertracker follows the movement of a precision retro reflective prism encased in a hardened stainless steel housing that the operator moves across the faces of the mould or segment. The instrument records the coordinates of the measured points (typically several thousand per face) across the segment.

From this a 3D image is built up of the structure with a software package called Spatial Analyzer, produced by US-based New River Kinematics and distributed by VMT in Europe.

A VMT software package called TubGeo gives a comparison between the measured object and the original CAD drawing of the segment. If a problem is seen to develop, you can then check the mould. The kit cost Ridham Precast approximately EUR 220,000 (USD 300,000).

Soil conditioning for clays in EPBMs

In this, the first of a two-part paper, the authors review previous work on the properties of soils including clay and the problems it can cause in its excavation with particular reference to slurry shield and EPB machines. The second part will be published in the November issue of *T&TI*

Where tunnel excavation is carried out in soils with high clay content, a loss in stability of the tunnel face is often prevented by creating a support pressure. One of the problems that can occur while boring through fine-grained soil is the adherence of clay to the TBM cutting wheel, inside the excavation chamber or in the transportation line, which might lead to long delays in progress. Since the economic success of a tunnelling project can depend very much on the clogging potential of the encountered clay formations, it is of vital importance to understand this phenomenon and find possible solutions. Currently there is no effective soil conditioning technique based on scientific data. This article shows the clay mineralogy for tunnel projects with clogging problems and new handling methods based on the 'diffuse double layer' (DDL) theory. The decision on which tunnelling method to use is prioritised based on the lithological characteristics of the soil to be bored. A slurry shield machine is used in incoherent and highly permeable soils with no fine grain content (figure 1, below). This method, however, requires a complex preparation plant for slurry, the recycling of material and disposal of large amounts of sludge (Greatti, 2004). EPBMs are now the most widely used technology because they can operate in a much broader spectrum of lithological conditions and do not require expensive additional equipment. The soil permeability for EPB drives can reach values of up to k=10-3m/s for the most porous soils (e.g. BPNL Lyon-Turin) and comes down to practically impermeable clay (Heathrow T5) (Langmaac, K 2006).

The face support pressure in an EPB shield is maintained using the soil either as it is excavated or conditioned (Kupferroth et al, 2001). With a slurry machine it is not always possible to stabilise a tunnel face in cohesionless soil below the water table. In contrast with EPBs, (provided that water inflows are controlled) major collapses are not possible as there is no space for the soil to flow into (Milligan, 2000).

However, EPB shields can only be used in soils that have specific characteristics. In fact, soft clays can cause instabilities at the tunnel face when the following equation is not verified (Peck, 1969):

$$c_u > \frac{(\gamma \cdot H - p_a)}{4 \div 6}$$

where:
c_u = undrained cohesion;
$\gamma \cdot H$ = total stress due to the coverage.
p_a = earth pressure for support.

If the undrained cohesion is less than the calculated value, an extrusion of clay into the hollow space can occur. Thus, the soil where the EPB technology is suitable must have the characteristic that its plasticity can be increased and that it can be remoulded, while maintaining a sufficient strength in the screw conveyor that supports the pressure. This can be achieved by adjusting the consistency of the material in the excavation chamber by means of water or a conditioning agent, which in the case of the EPB technology could be foams and polymers. The choice of a specific product depends on the geomechanical characteristics of the excavated ground (Greatti, 2004). Since this technique is used in homogeneous as well as in heterogeneous ground conditions, the TBM cannot be designed for the optimum of a specific geology, but for the overall optimum (Langmaack and Feng, 2005).

Below: **Figure 1, the application ranges of pressurised slurry and EPB shield machines according to particle diameter (d mm) and distribution in various loose ground types [After Herrenknecht AG]**

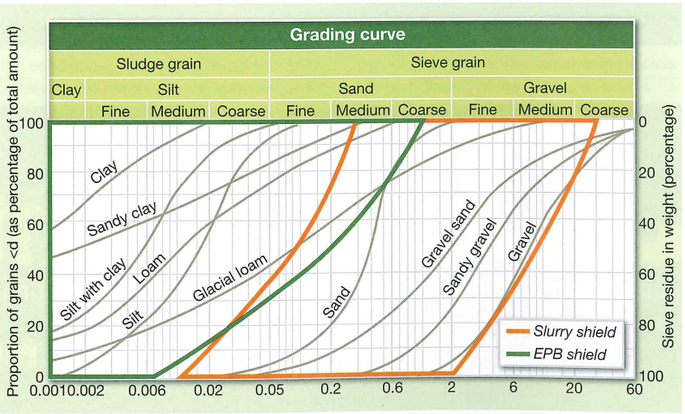


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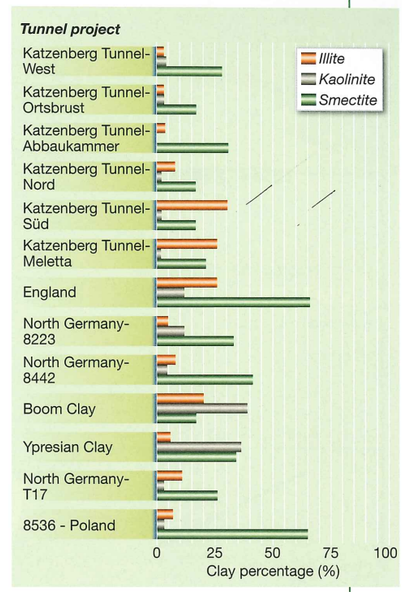
Figure 2: Case studies of tunnels with clogging problems

Project	Ground conditions	Problems encountered	Reference
WMATA Washington, US	Clay, clayey sand, gravelly sand	Highly plastic clay sticking in head chamber	Clugh & Leca (1993)
Abbey Sewer, England	Mercia Mudstone	Discs of clay stuck to TBM	Smith (1997)
Lille Metro, France	Ypresian Clay	Clay caused clogging	Mauroy (1998)
Tunnel, Antwerp, Belgium	Boom Clay	Clay caused clogging	Kooistra (1998)
Izmir Rail Transit Systems, Turkey	Silty sand, clayey sand, clay	Clogging of foam and injection pipes	Jancsecz et al (1999)
Metrosur, Madrid, Spain	Clays and silts	Clogging at the cutterhead	Feng (2004)
Roma 4 Venti, Italy	Vatican clays	Clogging at the cutterhead	Langmaack & Feng (2005)
Antwerp railway, Belgium	Find sands with clay inclusions	Clogging during excavation	Christiaens et al (2005)
Pantai Trunk Sewer, Malysia	Mudstone, shale, phyllite	Adhesion of excavated soil	Tsujigami et al (2006)
Toulouse Metro, France	Most clays with sand lenses	Clogging at the cutterhead	Martinotto & Langmaack (2007)
Bologna Metro, Italy	Clayey soil	Sticking clay	Egli & Langmaack (2008)
Katzenbergtunnel, Germany	Meletta Clay	Clay caused clogging	Weh et al (2009)



Above: **Figure 3, clay mineralogical analysis on samples with known clogging problems**

Clogging

When excavating with a TBM, adhesion of clay to parts of the machine or the transportation equipment can occur in different steps of the construction processes: cutting, conveying, deposition, etc. However, such clogging problems arise not only in tunnel construction, but also in other industrial areas such as the processing of clays in the mineralogical industry, dredging operations in earthworks or vertical and horizontal boring as well as in other fields of geotechnical engineering. In each of these areas, clogging may cause a severe reduction in performance.

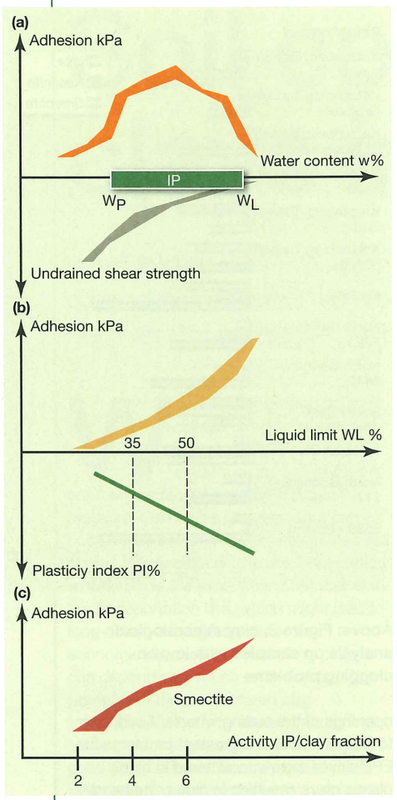
Unfortunately, there have not been many case studies on clogging so far, especially not when compared with the large number of tunnelling projects worldwide where EPB machines are employed. According to Thewes (1999), in earthwork operations clogging can occur even when the clay content is low. However, no information is given on the minimum clay amount. Kuhn (1989), Schlick (1989) and Beretitsch (1992) investigated the influence of adhesion on the planning and costs of earthwork projects. Other research has been done on the 'bit balling' phenomenon, which can occur during deep boring work (Garnier and van Lingen, 1959; Darley and Gray, 1988). Bit balling is a mass of sticky consolidated material, usually drill cuttings, that have collected on drill pipe, drill collars, bits and so forth. Navin et al, (1995), Beyer (1995), and Smith (1997) reported clogging problems during tunnel excavation due to plastic clays, leading to the blockage of the openings of the cutting wheels. According to Borghi (2006), the greatest problems for EPB drives were encountered in highly plastic clays, resulting in high cutterhead torque and difficulties in controlling the face pressure. Milligan (2000) summarised some of the reported case studies.

In figure 2 (above) some information from published case studies about problems encountered during EPB drives in soils with high clay content is listed. However, it is almost impossible to obtain information on the mineralogy of the respective clays.

In the course of a joint research project (Feinendegen et al., 2010) the clay mineralogy of clays from several tunnelling projects with known clogging problems was taken into account and XRD (X-ray diffraction) mineralogical analyses were performed on several clays. Unfortunately, due to the small number of projects, a general statistical analysis is not possible.

Modification of pore fluids chemistry

Jancsecz (1991) was the first who investigated clayey samples with regard to mechanical tunnel driving. He describes the dependence of the adhesion on simple soil mechanical parameters. The results from separation tests are compared to the undrained shear strength, the activity and



Above: Figure 4 correlation between adhesion and classical soil mechanics parameters: (a) water content v adhesion and undrained shear strength – IP = Plasticity Index; wP = Plastic Limit; wL = Liquid Limit, (b) liquid limit v adhesion and plasticity index, (c) activity v adhesion, (after Jancsecz, 1991)]

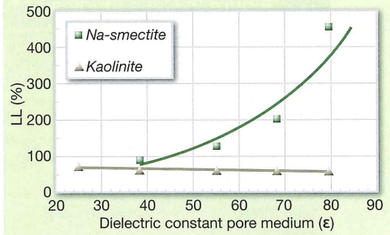
the plastic limits of the clays. A maximum of adhesion can be observed between the plastic limit (PL) and the liquid limit (LL) as well as an increase in adhesion with increasing plasticity (figure 4, above).

Very interesting is also his study of the activity (A), which is represented by the plasticity index (PI/IP) divided by the percentage of particles ≤ 0.002 mm. Different types of clays have different specific surface areas which control how much water is required to move a soil from one phase to another such as across the liquid limit or the plastic limit. From the activity one can predict the dominant clay type present in a soil sample. High activity shows large volume changes when wetted and large shrinkage when dried. Soils with a high activity are chemically very reactive (Skempton, 1953). The engineering properties of fine-grained soils are, besides many other conditions, strongly susceptible to changes in the stress state, the chemistry of the pore medium, wetting and drying cycles and temperature.

Most soil classification systems arbitrarily define clay particles as having an effective size of two microns or less and do not account for the clay mineral type and amount of exchangeable cation; probably the most important properties of the clay. Clay minerals are characterised by strong repulsive and attractive forces that vary significantly depending on their mineralogical composition and the net negative charge they carry on their surface, as well as the positive or negative charges on their edges. The electrical forces and the pore medium chemistry gain greater importance when the water content is high and the effective stress state is low. Since variations in mineralogy, cation exchange capacity and associated surface forces have a great influence on several physical and engineering properties (Sridharan, 2002) the clay mineralogy is an important factor in geotechnical engineering with respect to fine-grained soils.

Atterberg limits, which were originally developed for the purpose of soil classification, have been determined on pure clays with different pore fluids. In the recent past various attempts have been made also to correlate the Atterberg Limits with various soil properties like mineralogy, activity and swelling behaviour.

Hence, understanding the mechanism controlling the liquid limit behaviour assumes importance. Sridharan and Venkatappa Rao (1979) have discussed the possible mechanisms governing the liquid limit of kaolinite and smectite type of clays. Figure 5 (above, right) shows the liquid limit for these two clays with variation of the electrolyte concentration. From figure 5 it can be seen that the two clays behave in a strikingly opposite manner with respect to the change in pore fluids. Whereas a decrease in liquid limit is observed for Na-smectite with a decrease in dielectric constant of the pore medium, no change (or slight increase) of liquid limit has been recorded for kaolinite. For Na-smectite, the liquid limit decreases significantly from a value of 455 per cent for water (dielectric constant = 79.5) to 89 per cent for a 75:25 ethanol-water mix (dielectric constant 38.28). No liquid limit has been determined for pure ethanol with Na-smectite since the clay behaved more or less like sand showing no coherence anymore. From



Above: Figure 5, liquid limit for Na-smectite and kaolinite for pore media with different dielectric constants

figure 5 it is clear that kaolinite and Na-smectite, the two extreme types of clay minerals, behave quite differently under any given set of physicochemical conditions. Hence, the mechanism that controls the liquid limits of kaolinitic and smectitic soils cannot be the same (Sridharan 2002).

To explain the variation of liquid limit (i.e. of the mechanical properties) the colloidal characteristics of clays have to be taken into account. Extensive studies conducted at the Department of Engineering Geology and Hydrogeology of RWTH Aachen University revealed the existence of two different mechanisms governing the liquid limit of soils, taking into account the clay mineralogy and the pore medium chemistry. The results agree with those gathered by Sridharan and Venkatappa Rao (1979) and Sridharan et al. (1986, 1988). The properties of clays are determined and dominated by their large surface area per mass and hence, by their surface forces. To understand the behavior of clayey soil, it is necessary to consider the crystal structure of the clay minerals and the surface chemistry of the clay-water suspensions.

Since both attractive and repulsive forces of an electrical nature exist between clay particles (Rosenqvist, 1955; van Olphen, 1963), many factors are responsible for a net attractive or repulsive force. The primary parameters affecting the repulsive forces are the distance of the particles, the dielectric constant and the electrolyte concentration of the pore fluids (Lambe, 1958; van Olphen, 1963).

To be continued...

The final part of this paper will cover RWTH Aachen University's new tests for clay and handling methods.

References

To follow with part two in the November *T&TI*

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13th AFTES International Congress, Lyon, France
This three-day congress is organised by the French Underground Tunnelling and Underground Space Association (AFTES), with partner associations in Italy, Belgium, Spain, Portugal and Switzerland. Along with techincal sessions and an exhibition there are seven site visits planned for the congress, focused on underground space. Contact AFTES for more information: Tel: +33 (0) 1 44 58 27 43

26 - 27 OCTOBER 2011
Underground Infrastructure of Urban Areas, Wroclaw, Poland
Organised by the Wroclaw University of Technology's Institute of Civil Engineering, the Polish Society for Trenchless Technology and the ITA-AITES Polish group, this will be forum on the topics related to building tunnels and underground infrastructure in cities. Contact Andrzej Kolonko, Tel. +48 71 320 2914 or email andrzej.kolonko@pwr.wroc.pl

7-8 NOVEMBER 2011
Global Tunnelling Forum, Madrid, Spain
Annul tunnelling event focusing on international projects and will include representation from China and Thailand as well as presentations from leading tunnelling professionals across Europe. The forum will also provide the chance for individuals to engage in facilitated networking opportunities, including a sponsor speed networking session. More information at http://www.arena-international.com/gtf

6 - 8 DECEMBER 2011
STUVA Conference, Berlin
The 2011 biannual conference of non-profit research institute STUVA (the German Research Association for Underground Transportation Facilities) will focus on "Underground Construction for Sustainable Environmental and Climate Protection." New this year is a Youth Forum, an opportunity for young tunnel engineers to present. The winner of the STUVA young talent prize will be selected from the speakers, and awarded at the show. More information available from www.stuva.de Email: info@stuva.de

8 DECEMBER 2011
T&T International Awards 2011, Berlin, Germany
Launch of this event that promises to champion the industry's best efforts, greatest achievements and most impressive recoveries. There are categories on overcoming adversity, sustainability and innovation. For further information on entering and attendance e-mail: awards2011@tunnelsandtunnelling.com

12 - 13 JANUARY 2012
Shotecrete 2012, Tyrol, Austria
Prof. Wolfgang Kusterle and his team are hosting this conference and exhibition for shotcrete specialists. The conference will be in German with some presentation in English, and English summaries of all presentations will be available. The Final program will be available by October 17, 2011. For more information e-mail: spritzbeton@kusterle.net

21 - 22 FEBRUARY 2012
Fire Protection and Safety in Tunnels Asia, Singapore
With Asia having some of the longest tunnels in the world and some of the most rapid developments occurring globally this is the best platform to uncover current and future projects across the region and pinpoint the best strategies to ensure fire design is implemented accordingly. The conference will also include a site vist to a Singapore tunnel. More information is available at http://www.arena-international.com/fpstasia/

14-16 MARCH 2012
ISTSS 2012, New York, USA
Forum with the themes of risk and security, human behaviour, passive fire protecton and construction, active fire protection & fire fighting, ventilation and fire dynamics. The focus is shifting more and more towards security, with new the terrorist threats and the focus on how to solve these problems increasing. Organised by SP Fire Technology of Sweden. For more information see www.istss.se, email info@sp.se or tel.: +46 10-516 50 00

27 - 29 MARCH 2012
INTERtunnel 2012, Turin, Italy
Italy's only regular exhibition on tunnelling technology. For more information email: intertunnel@mackbrooks.com

24 - 26 APRIL 2012
3rd Int Conf on Shaft Design & Construction, London, UK
Organised by the Mining Technology Division of the IMMM and the BTS at 1 Carlton House Terrace. FULL PAPERS DEADLINE 31 OCTOBER. The scope includes all areas of design and construction of both civil engineering project and mine shafts. Contact Paul Harris at IOM Communications by email paul.harris@iom3.org, tel. +44 (0)20 7451 7302 or see www.iom3.org/events/sdc2012.

18 - 23 MAY 2012
World Tunnel Congress WTC 2012 & 38th General Assembly of the ITA, Bangkok, Thailand
Organised by the Thailand Underground & Tunnelling Group (TUTG) of the Engineering Institute of Thailand, the theme is 'Tunnelling & Underground Space for a Global Society.' For more information email: secretariat@wtc2012.com or visit www.wtc2012.com

24 - 27 JUNE 2012
North American Tunneling Conference (NAT), Indianapolis, Indiana, USA
UCA's biannual conference, which has continued to grow each year with more exhibits, techinical sessions & attendees. More information regarding housing and registrationwill be available at http://uca.smenet.org/ in spring 2012

18 - 21 SEPTEMBER 2012
Eastern European Tunnelling Congress, Budapest, Hungary
The Hungarian Tunnelling Association is organizing the 1st Eastern European Tunnelling Congress to share experiences and exchange knowledge of design, construction management, research results and technical developments of tunnels completed by the regional associations and experts. The planned regional sub European conference is open to all other co-organizers and participants as well as to those who having ongoing or completed projects, research works in this area. ABSTRACT SUBMISSION: 2 JANUARY 2012. More information at http://www.eetc2012budapest.com/

7 - 9 NOVEMBER 2012
13th World Conference of ACUUS, Singapore
The Associated research Centers for the Urban Underground Space (ACUUS) is presenting "Underground Space Development – Opportunities and Challenges." The intent is to focus on the new opportunities amid a re-focus on developing the urban underground space as part of sustainable development, and the many challenges and issues that planners, developers, and engineers face. More information at http://www.acuus2012.com/

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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. Details to follow. Speakers: Mike Black and Darren Page

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. Speakers: Dominic Cerulli and Frank Jenkins of (Bechtel) Dulles Transit Partners and Vojtech Gall of Gall Zeidler Consultants

15 DECEMBER 2011:
Cleaner Seas for Sussex
In order to treat the 95 million litres of wastewater generated each day by residents a new wastewater treatment works and 11km of new sewer were required. Now substantially complete find out how more than 11km of 1.8m and 2.4m diameter tunnels and associated shafts and pumping stations were completed. Speakers: Ben Green, Southern Water programme manager and Craig Reade, Costain project manager

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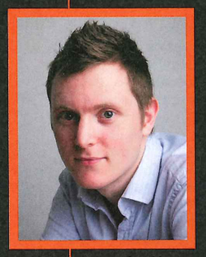

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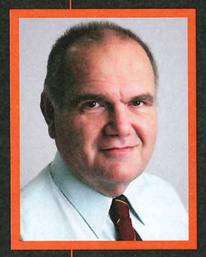

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