INTERNATIONAL EDITION
March 2013

Tunnels AND TUNNELLING

PIPE DREAMS

Direct Pipe case studies show the technology in action

North America • Precast Segments • Tunnel Environment

A COST OF PRICE

THE UK has been hit by a supply chain scandal in the past month that seems unrivalled in recent years. One of the most regulated industries has spectacularly failed. British and European consumers have been eating horsemeat disguised as beef. This scandal offers a warning on price driven markets. The introduction of horsemeat into beef products has affected the lowest price readymade meals. Opportunists in the supply chain delivered cheap 'beef' to undercut competition.

The recession is driving price competition in all markets and it is vital we are aware of the risks.

John Lynch, assistant director of engineering and architectural services with the department of general administration for the state of Washington warned in the early days of the recession of how the bidding process can change.

In a paper for the National Association of State Facilities Administrators and the Associated General Contractors of America Lynch explains that during a recession, the quantity of construction activity decreases, especially in the private sector, and the competition for the remaining work increases. Public works projects become sort after. "In past downturns," says Lynch, "owners learned that the hyper-competition for public projects has a number of negative consequences:

- An increase in the likelihood that the low bidder has a bid price that is insufficient to complete the work. This could be due to an error in the takeoff, leaving something out by error, or intentionally under bidding to 'buy the job' with the hope of making up the difference in change orders
- The subcontractor's bid to the general contractor may also be insufficient
- Some of the contractors and subcontractors in this market are likely to be stressed and on the verge of bankruptcy

If a contractor defaults on a contract it will usually impact cost and schedule on the project. Lynch explains that, "for the subcontractor, taking work for under value may be a way of maintaining cash flow, but can lead to poor credit or possible bankruptcy. A subcontractor [going bust] is a serious problem for the project."

When projects are more scarce bidders that do not normal bid on the works might try their hand. This could well be true of the horsemeat scandal where some of the abattoirs being investigated were new to butchering horses and perhaps less familiar with the severity of the restrictions or more willing to take chances in a tough climate.

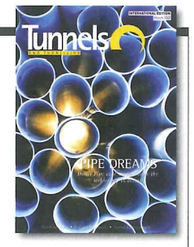
"As a public owner," says Lynch, "this presents several concerns. Do bidders understand the unique requirements in the project? Are bidders familiar with contract conditions? Are bidders prepared for the billing procedures and possible impacts to cash flow?"

Lynch warns against price driven contracts but the future of a project and getting the right price is inseparable. The focus is on understanding and trusting your supply chain and your contractors.

Those who have recently eaten a Findus 'beef' lasagna will appreciate what astronaut John Glenn meant when he said: "As I hurtled through space, one thought kept crossing my mind: every part of this capsule was supplied by the lowest bidder"

Jon Young
Editor

Cover
The Direct Pipe technology is given a run out as Diana Pfeff of Herrenknecht details several cases of its use



Next issue
The April issue of Tunnels will be distributed at this year's Bauma. The regional focus will be on central and eastern Europe, while technical articles will cover waterproofing, TBM procurement, double-deck blasting, mine vehicles and the URUP method

In this month...

10 YEARS AGO

A 10m wide, 5m deep hole has swallowed two gardens situated above a tunnel for contract 240 on the Channel Tunnel Rail Link (CTRL) in east London, UK. Thirty five residents were evacuated and the contractor, a Costain/Skanska UK/Bachy Soletanche JV, filled the hole with concrete. The tunnel may have intersected a disused well.

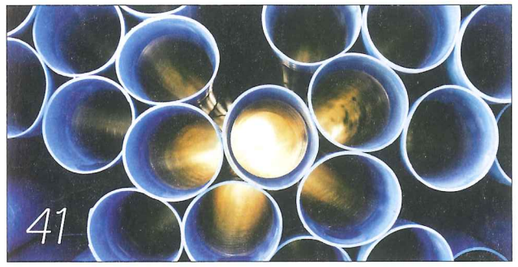
20 YEARS AGO

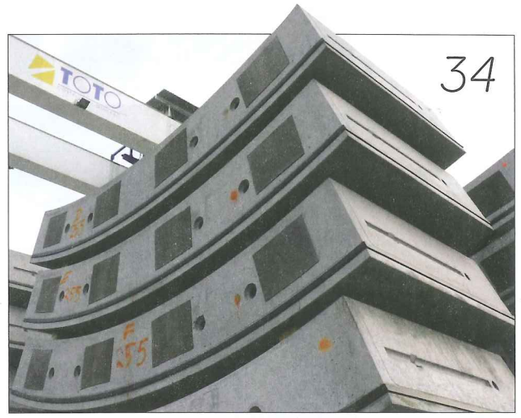
The "biggest single tunnelling project in the entire world", the Superconducting Super Collider (SSC) began two months ago. The Obayashi-Dillingham JV started drilling with its huge, 14ft (4.3m) Inchworm Robbins TBM through Eagle Ford shale and chalk.

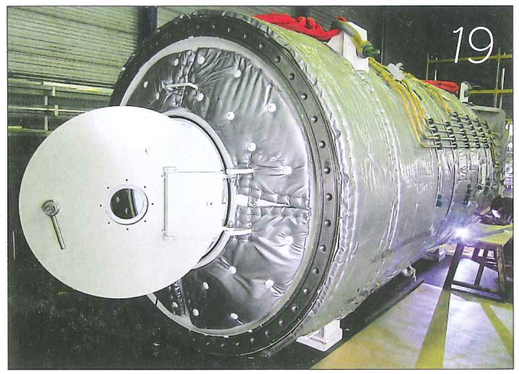
40 YEARS AGO

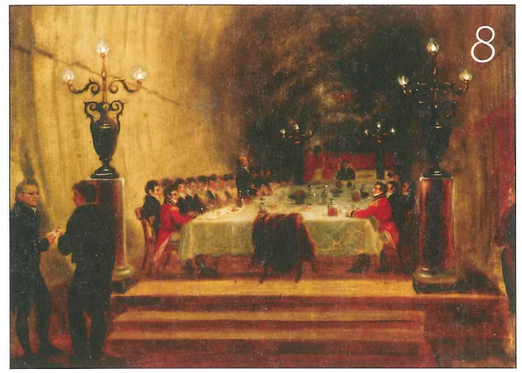
The Tunnels editorial team writes that it is disappointing to read in current national papers that there unresolved problems relating to the financial control of the Channel Tunnel project in the UK. By now, it is "fairly well assumed" that the RTZ report to be presented to the government in the next few months will recommend that Chunnel construction should go ahead without delay. Another report is claiming a carve up of the profits will delay the project. This is unbelievable after a year of intense activity that has boosted confidence in the client. Much benefit will be lost if construction is delayed past the 1970s.

In this issue









Contributors

Allen Mitchell
Allen is a senior project engineer for Metro Vancouver and is the project manager for Metro Vancouver's Port Mann Main Water Supply Tunnel project.

Donald Lamont
Donald was HM Inspector of Health and Safety and Head of Tunnel and Ground Engineering at the UK's HSE before becoming principal at Hyperbaric & Tunnel Safety he has extensive experience in high pressure compressed air.

Alain Preaut
Alain is sales director for CBE and is based in Saint Avertin, France. His experience has given him expertise in the demands of projects worldwide for segmental lining solutions.

News briefs

GREAT BRITAIN

The Road Tunnel Operator Association (RTOA) told Tunnels its Level Three Diploma in Road Tunnel Operations was approved by Ofqual and has been in use since 1 February. The qualification includes an optional module on the operation of active fire suppression systems.

SAUDI ARABIA

The Ministry of Municipal and Rural Affairs and the Commission for the Development of Mekka is studying a 4km tunnel for pedestrians, stretching from the northern part of Jamarat Bridge in Mina to the northern courtyards of the Grand Mosque in Mekka. The study that is being finalised showed the project would cost SAR 800M (USD 213M). If launched, it will take about 24 months to complete.

GREAT BRITAIN

The Prince of Wales and The Duchess of Cornwall recently joined passengers to travel by Tube as part of a visit to mark the 150th anniversary of London Underground and celebrate the important role that engineering and infrastructure plays in the UK. This was Prince Charles' first trip on the Tube in 33 years.

GERMANY

Bank robbers dug a 30m tunnel into the safe deposit room of a Berlin bank and escaped, setting a fire as they left to cover their tracks, news reports revealed last month. The tunnel led from an underground garage into the bank's safe deposit room. Police besieged and eventually stormed the safe room where the thieves had holed up only to find out they had escaped through a tunnel dug by accomplices.

TRUCKLOAD OF BURNING CHEESE CLOSES NORWAY TUNNEL

Norway Some 27t of brown cheese caught fire in January while being transported by truck. The fire raged for five days, causing traffic blockages and closing the Brattli Tunnel in Tysfjord, Norway.

The cheese, 'Brunost', which is a caramelised brown goat cheese, blocked off the 3km tunnel when it caught fire. Brown cheese is made from whey and contains up to 30 per cent fat. Officials told local news reporters that the cheese proved extremely difficult to put out; the fire filled the tunnel with toxic gases that hampered recovery operations.

Andy Evans, chairman of the UK's Road Tunnel Operator Association, told *Tunnels*: "Fatty foodstuffs have a tremendous energy content and can fuel a very high powered fire in a tunnel. Since such foodstuffs are not 'dangerous goods' they don't fall within the sixth issue of the ADR Directive Road Tunnel controls. In reality they can present a far more likely tunnel fire hazard than do petrochemical fuels.

"I don't think the tunnel operations industry has a united view on whether any further regulations should be introduced – tunnel operators are aware of the danger that such foodstuffs represent and understand the implications implied by further regulation. Of more importance to tunnel operators is that the dangers presented by seemingly innocuous vehicle loads are fully understood and that their tunnels (and the extensive expensive equipment and systems within the tunnel – the Life Safety Engineering Systems or "LSES") are appropriately protected to withstand such incidents.

"The installation of active fire suppression systems (very high capacity 'sprinkler' systems) in road tunnels is a very active area of research and debate within the industry. The use of such systems has been shown to be potentially very effective in controlling tunnel fires."

The driver transporting the cheese noticed fire in his truck trailer and abandoned the truck. No one was injured in the fire and only one other vehicle was in the area at the time. The accident happened close to one of the tunnel's exits.

Upgrades needed to prevent Australian tunnel deaths

Australia A coroner has called for safety upgrades to new road tunnels across Australia to prevent fatal crashes such as the March 2007 Burnley Tunnel crash that killed three people, local news reported last month.

Victoria state judge Jennifer Coate recommended a number of safety initiatives to be used in the country's road tunnels, including the installation of emergency lanes or bays, and a ban on changing lanes. State transport minister Terry Mulder stated that some of the changes could be implemented in future tunnels across the state.

However, Western Australia is about to remove emergency lanes to make room for more drivers, while in NSW emergency stopping bays are already in use in major tunnels.

Chilean mining company awards MTM contact

Chile A contract for the delivery and testing of a Mobile Tunnel Miner (MTM) has been confirmed between Aker Wirth and Codelco, the world's largest producer of copper. The contract, which was signed at the end of 2012, will see the machine tested from mid-2014 in the Chuquicamata mine in Chile where the underground mining of copper is planned for the future.

Aker Wirth's MTM will bore a network of tunnels in the Chuquicamata mine in preparation for later mining of rock containing copper.

"Previously, tunnels of this type were blasted out of the rock in copper mines," said Ulrich Frenzle, VP Mining & Construction at Aker Wirth. "These will be created mechanically for the first time with the MTM, thus improving tunnelling efficiency and safety in the mine significantly."

The self-propelled machine excavates rock with four powerful hydraulically actuated arms fitted with disc cutters. The muck is conveyed to the rear of the machine by a loading apron with loading disks and via a chain conveyor where it is loaded. In addition to circular cross sections like those achieved with a TBM, the MTM can also cut rectangular and horseshoe-shaped or semi-rectangular tunnels with a bore diameter of up to 6m. The turning radius of the 40m long MTM is only 12m.

"We expect to set new standards in mine development with the MTM," said Frenzle. "Its development fully reflected quantifiable customer benefits and also safety issues."

THAMES TUNNEL MARKS 170 YEARS WITH APPEAL

Great Britain The original Thames Tunnel, famous for its use of the first ever tunnelling shield, opened 170 years ago this month. Opened on 25 March 1843, the tunnel is now the oldest part of the London Underground (LU) system, which celebrated its 150th anniversary in January.

Robert Hulse, director of the Brunel Museum, which sits above the tunnel entrance, said, "In this our anniversary year, we launch an appeal to fit out the Grand Entrance Hall as underground museum gallery and performance space. We are seeking sponsors for each step down into the chamber. We are also announcing a number of celebratory events, including public walks through the Thames Tunnel, by kind permission of the Commissioner of Transport. Coinciding with planned engineering works, these dates will be announced shortly.

"We are looking to arrange special events, dinners or receptions or private walks for *Tunnels* readers and for the BTS."

See the insert in this issue of *Tunnels* for more information on the appeal.

Brunel Museum trustee and chief civil construction engineer for Hong Kong's MTR, Alan Myers, said of the importance of the tunnel and museum, "I am touched by a sense of history associated with the Brunel name. The vision and ambition of the men, and also their sense of responsibility to society that the challenge of getting across the river needed to be tackled. For many years they went down this shaft and made important decisions on how best to proceed. Modern tunnelling owes so much to their inventive methods of rising to the challenges and their endeavour to succeed: the brick caisson shafts, and the tunnel shield to protect the workers. I suppose a modern equivalent can only be wondering whether the Channel Tunnel was possible."

Above: A banquet held by Brunel in the Thames Tunnel to prove its safety. The event was the world's first underwater dinner

promoters of the company and other investors. "The modality of sharing benefits between promoters and public investors is yet to be decided," Joshi said.

The road project, estimated to cost INR 20bn (USD 371M), will connect Kathmandu with Hetauda.

Government officials said the estimated cost is too low and funding sources are not clearly demonstrated in the detailed project report the NPBCL submitted in November 2012.

However, NPBCL officials claimed cost estimation was well calculated and funding source is clear as many institutions and people have already expressed commitments to invest.

"The success of the project depends on people's participation and collective work of local people, domestic contractors, professional institutions and banking sector of the country," Joshi said.

The project, which is targeted to be completed within four years, will help the country save INR 22bn (USD 408.5M) a year by reducing fuel imports, argue officials of the company. "Our target is to make people able to travel from Kathmandu to Hetauda and vice versa in 45 minutes," Lal Krishna KC, vice president of NPBCL, said.

FDOT reaches deal on Port Miami tunnel payment dispute

USA The Florida Department of Transportation (FDOT) and the company building the USD 1bn tunnel have reached a deal over a payment dispute, local news reports stated last month.

Under the settlement, FDOT will pay Miami Access Tunnel (MAT) USD 58.5M for reinforcing the limestone subsoil so boring would be more stable.

MAT had originally sought USD 67.5M, however the companies negotiated the settlement down to USD 58.5M. The settlement closes an issue that marred the early stages of the project in 2011.

As workers prepared to start boring the tunnel from the MacArthur Causeway to the port, MAT asked FDOT and its partners -- Miami-Dade County and the City of Miami -- to provide additional money from a contingency fund to cover the expenses linked to the extra grouting.

NPBCL lacks tangible plan to repay tunnel highway investors

Nepal Nepal Purwadhar Bikas Company Limited (NPBCL), which is planning to develop the Kathmandu-Hetauda Tunnel Highway through public funding and institutional investments, does not have convincing plans to repay the investors, government officials in Kathmandu said on 23 January.

Kush Kumar Joshi, president of the NPBCL, at an interaction program, couldn't elaborate on how the company intends to repay investers in the project.

Officials of Ministry of Physical Planning and Transport Management said the company, which aims to generate investment from public, should have a clear plan on how it intends to repay them.

The company, which aims to collect investment from around 264,000 people, has not developed any framework on how the benefits will be shared among

The sixth and seventh machines for London's rail-based transport network have completed their factory testing at the Herrenknecht factory in Germany and are now in the process of being dismantled, boxed up and transported to Rotterdam, where they will be put on a ferry to Tilbury in Essex, Crossrail announced recently. All the machines' components are expected to arrive at Crossrail's sites within the next month where they will be reassembled.

Environmentalists term Penang's undersea tunnel project needless

Malaysia An environmental group said the proposed undersea tunnel linking the island to the mainland, which is part of a MYR 8bn (USD 2.6bn) infrastructure package unveiled by the Penang Government, is redundant.

"The Penang Bridge is not that congested. The second Penang Bridge will also be completed soon. So, a third link between the island and the mainland is not necessary," said Malaysian Nature Society Penang branch adviser D. Kanda Kumar, who was commenting on a package that includes the 6.5km Gurney Drive-Bagan Ajam undersea tunnel. Chief Minister Lim Guan Eng had been quoted in online news portals as saying that the state executive council had decided to award a company the tender to construct the four roads.

Although Lim did not name the company, it is known that the package of projects will begin in 2015.

The group, said Kanda Kumar, was also concerned that the tunnel would lead into a mangrove area in Seberang Prai, which was visited by thousands of migratory birds, including endangered species from Siberia, Japan and China.

A public transport system, he added, should first be put into place before such mega projects were implemented.

However, Penang Consumer Protection Association president K. Koris Atan said he was in full support of the projects.

Meanwhile, at another press conference, Lim said the state government was prepared to face objections over the projects.

"We will bite the bullet and let the people decide whether they want these roads or not. Our proposed roads will cut through reserve land and uninhabited areas so there is no question of relocating residents," he said.

HIGH SPEED TWO REVEALS PHASE TWO ROUTE

Great Britain The government-owned client for the UK's proposed north-south high-speed rail megaproject has unveiled its preferred route for the project's second phase. Opponents to the scheme still object to the proposed alignment, and also the GBP 32bn (USD 50.4bn) indicated cost of the overall rail link.

High Speed Two (HS2) will link London to Birmingham, with a second phase of the project extending this link to both Manchester and Leeds.

Speaking last week, UK transport minister Patrick McLoughlin said, "I'm afraid we will upset some people, but I appreciate that and we've got to try and do as much as we can to alleviate the damage wherever we can. You can't build a brand new line and not have problems. There will be some areas where you are going to have to negotiate.

"But we will be announcing several new stations which I think will be great engines for regeneration, and I think by us announcing it now, the local authorities on the route can plan and get the best advantage out of HS2."

Campaign manager for the Stop HS2 movement, Joe Rukin said, "HS2 is the wrong investment at the wrong time. The country is supposedly bust, we are seeing cuts in services all over the place, but the Government wants to spend money on a train line which will only benefit the richest in society and line the pockets of construction lobbyists with vested interests.

"There are more holes in HS2 than a Swiss cheese, which is why the government [has] faced five legal challenges. To announce the route for stage two before the rulings on those judicial reviews is simply irresponsible."

Work in full swing on Abu Dhabi green sewerage tunnel

UAE A 41km 'green' tunnel, one of the largest and longest gravity-driven sewerage networks in the world, will ensure that odour emanating from sewers will be a thing of the past.

The eco-friendly tunnel will drastically reduce the carbon footprint of Abu Dhabi's sewerage system and save AED 4.2bn (USD 1.14bn) to be spent on energy and maintenance costs in the next 25 years.

About 33km that constitutes 80 per cent of the AED 5.7bn (USD 1.55bn) Strategic Tunnel Enhancement Programme (STEP), has been completed as of January and the rest will be completed by the end of 2015, Abdullah Ali Musleh Al Ahbabi, chairman of Abu Dhabi Sewerage Services Company (ADSSC), announced on 4 February.

The existing system deals with 400,000m3 of sewage a day, but the new tunnel can carry 1.7Mm3 sewage, which is the expected demand by 2030, said Nasser Khalfan Al Nuaimi, a department manager at ADSSC.

The new tunnel will do away with 34 pumping stations in the existing system that consume a huge amount of energy, said Alan Thomson, managing director of ADSSC. They will be replaced by one pumping station at Al Watbha treatment plant, he said.

The current system has the risks of emanating odour through the 34 existing pumping stations.

The new tunnel will end that problem, because the an inbuilt system in the tunnel will automatically extract odour from the sewage, which will be carried by gravity alone with pumping required only to take the waste water to the treatment plant at Al Watbha.

CROSSRAIL REJECTS UNITE'S CLAIMS OF BLACKLISTING

Great Britain Crossrail chief executive Andrew Wolstenholme has rejected claims of blacklisting from the largest union in the country, Unite. The company has asked for and received assurances from all its principal contractors providing confirmation that none have engaged in any blacklisting activity on the London project, Crossrail stated.

"Crossrail is not aware of, and has seen no evidence of, blacklisting of any kind in connection with the Crossrail project," Wolstenholme said. "If Unite has any evidence then we wish to see it; we have made this point a number of times and yet none has been forthcoming. Crossrail has written to the trades unions on several occasions setting out our commitment to taking firm, decisive and immediate action if any substantive evidence can be presented."

Wolstenholme added: "All contractors working on the Crossrail project must comply with the Employment Relations Act 1999 (Blacklists) Regulations 2010 which explicitly outlaws the blacklisting of construction workers. All our contractors are fully aware that blacklisting is unlawful as well as being a breach of contract which would result in immediate action by Crossrail."

Crossrail stated that the Consulting Association was closed down in 2009 following enforcement action by the Information Commissioner, well before the award of the first tunnelling and station construction contracts in December 2010.

In December 2012, Vince Passfield, Unite's deputy regional secretary for the London and eastern region, said: "Imagine Unite's horror in hearing that Crossrail contractors met with the Consulting Association, the organisation that compiled a blacklist of mainly construction operatives. The Consulting Association was raided in 2009 by the Information Commissioner's Office."

Unite stated that it is in the public interest that this matter is properly investigated by Transport for London and that the Crossrail board is held to account for the implementation of good workplace practices. Unite has campaigned strongly against what it considers to be the anti-union bias that exists across the whole project, which is expected to see the first trains running in 2018.

International interest in prequalifying for Fehmarnbelt project

Denmark A total of 24 different companies globally, forming nine different joint ventures, have applied for prequalification for the Fehmarnbelt Project, client Femern announced last month. The companies in the nine groups come from Denmark, Germany, Italy, Spain, the Netherlands, Belgium, France and South Korea, while companies from the UK and US are associated with some of the groups.

The interested companies had until 18 January to submit their application documents. Following the end of the prequalification application period, client Femern prepared an initial overview of the international construction industry's interest in the four main civil engineering contracts for the link project.

Each joint venture could apply for prequalification for more than one of the four main contracts.

"We're very satisfied with the response," says Steen Lykke, technical director, Femern. "As this project represents one of civil engineering's largest tunnel structures, we need the world's best construction companies. Having received a sufficient number of applications, and bearing in mind that a joint venture or firm can apply for more than one contract, I'm optimistic that we'll be able to prequalify a suitable number of professional and experienced contractors on each contract."

Femern stated it will now evaluate the applications in detail and then decide which companies will be prequalified and consequently invited to submit bids. The four civil engineering contracts for the coast-to-coast link are dredging of the seabed and land reclamation; construction of the northern section of the tunnel; construction of the southern section of the tunnel; and construction of the portal structures, ramps and associated land facilities.

The consolidated construction estimate for the coast-to-coast link amounts to EUR 5.5bn (USD 7.3bn) at 2008 prices. Final project approval will be effected by the Danish Parliament's adoption of a Construction Act by the end of 2014. In Germany it is expected that the authorities will approve the project in 2015.

Above: An artist's conception of the land-sea interface of the Fehmarnbelt fixed link project

Worker injured in London power tunnels project

Great Britain A construction worker has suffered head and shoulder injuries at a National Grid site in north London, local news reports revealed. The 24-year-old man was taken to hospital from the site near Haringey where National Grid is tunnelling as part of the London Power Tunnels.

London Ambulance was called to the scene just after 6am. A spokesman for National Grid said the man has received medical attention and his injuries are not believed to be life-threatening. Tunnelling work was temporarily suspended. The Health and Safety Executive has been informed and was investigating as *Tunnels* went to press.

Central bank rates

	Rate (%)
AUD	3.00
BRL	7.25
CAD	1.00
CHF	0.25
CNY	6.00
EUR	0.75
GBP	0.50
INR	7.75
JPY	0.10
NZD	2.50
USD	0.25

Rates are taken on the 12th of each month.

Share tracker

Company	January	February	Change (%)
Aecom (NYSE: ACM)	24.88	29.4	▲ 4.52 (18.17)
Atkins (LSE: ATK)	772.5	832	▲ 59.5 (7.7)
Balfour Beatty (LSE: BBY)	290	273.1	▼ 16.9 (5.8)
BASF Global (XETRA: BAS)	71	71.51	▲ 0.51 (0.7)
Bekaert (BSE: BEKB)	22.16	21.58	▼ 0.58 (2.6)
Bilfinger Berger (DUS: GBF)	72.78	76.77	▲ 3.99 (5.5)
Caterpillar (NYSE: CAT)	95.19	97.22	▲ 2.03 (2.1)
Costain Group (LSE: COST)	261.25	263.5	▲ 2.25 (0.9)
Ferrovial (MCE: FER)	12.06	11.32	▼ 0.74 (6.1)
Hindustan Construction Company (BOM: HCC)	18.9	17.2	▼ 1.7 (8.99)
Hochtief (XETRA: HOT)	46.22	48.69	▲ 2.47 (5.34)
Morgan Sindall (LSE: MGNS)	541	600.77	▲ 59.77 (11.05)
Sandvik (STO: SAND)	104.5	103.6	▼ 0.9 (0.86)
Shanghai Tunnel Engineering (SHA: 600820)	8.83	9.72	▲ 0.89 (10.07)
Strabag (LSE: STR)	19.88	19.62	▼ 0.26 (1.31)
URS Corporation (NYSE: URS)	40.63	42.4	▲ 1.77 (4.36)
Vinci (EPA: DG)	37.1	35.92	▼ 1.18 (3.18)

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

Engineering and services group acquires US water technology specialist

Germany Germany's second largest construction company by revenue, Bilfinger, has signed an agreement to acquire American water technology specialists Johnson Screens, a Bilfinger spokesman announced late last month. The company stated it hopes to become a leading global provider in the water and wastewater business. The two parties have agreed not to disclose details of the purchase price. Bilfinger added that the management of Johnson Screens welcomes the acquisition and will remain with the company.

Johnson Screens, which is based in New Brighton, Minnesota, was founded in 1904 and generates an annual output volume of about EUR 160M (USD 213M) with 1,200 employees and achieves attractive margins. The acquisition allows Bilfinger to double its output volume in the water and wastewater sector to over EUR 300M (USD 399M), but also to further increase the strong profitability in this sector, Bilfinger stated.

Johnson Screens produces mechanical components for the separation of solids from liquids and gases and provides associated services. The products are used for drinking water extraction, in the oil and gas industry and in other industrial sectors for wastewater treatment and resource reclamation. The company's most important markets are North America, Europe and Asia-Pacific.

The acquisition of Johnson Screens will allow Bilfinger to continue its growth in water and wastewater technology. In 2011, the group acquired Diemme, manufacturer of chamber filter presses based in Lugo, Italy.

Chinese TBM supplier launches new international division

China Following the successful factory acceptance test of the first TBM bound for the Kuala Lumpur MRT, Chinese TBM supplier, CREC-TBM, have announced the launch of its new international division, CTE. The company was established in Hong Kong with the purpose of marketing and presenting the TBMs manufactured by CREC-TBM and to provide support for the machines.

Don Hall has been appointed CTE managing director, after leaving infrastructure group, Gamuda, after almost nine years. Hall will initially be based in Kuala Lumpur.

"As a result of several technical meetings, factory and site visits, I became convinced that CREC-TBM had a high quality product and a very good design team, what they lacked was the international factor," he said.

"Consequently, CREC-TBM and myself - along with some other internationally experienced partners - decided to form a new company, CTE, that would manage all of CREC-TBM's interests on the international stage," Hall explained.

Oil price

Values are taken on 12th of each month.

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Photo Competition

Don't forget to enter the Tunnels and Tunnelling Photo Competition if you think you have what it takes to claim the latest in digital camera technology as your prize.

The closing date for entries is 1 July and the short listed entrants will be announced in the September issue of *Tunnels*. The winners will be announced in the Tunnels Awards supplement in the December issue of *Tunnels*.

EGYPT DROWNS TUNNELS

Egyptian forces have flooded smuggling tunnels in the Gaza Strip. The action was part of a wider effort to stamp out supply lines to the region, and local tunnellers feel at risk.

Reporters for news agency Reuters claimed they observed one tunnel suddenly fill with water last month, sending workers rushing for safety, while locals said Egyptians deliberately pumped in water flooded two other tunnels.

An Egyptian security official confirmed the reports. Dozens of tunnels have been destroyed since last August, and an attack that killed 16 Egyptian soldiers. Egypt said some of the gunmen entered the country through tunnels.

Hamas, the governing body of the Gaza Strip said that talks with Egypt aimed at "healing the schism between politicians in Gaza and the occupied West Bank had gone badly but had not collapsed".

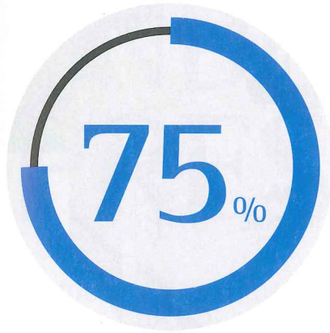
'Ayed', a local tunnel owner, said: "Egyptian measures against tunnels have worsened since the election of [Egyptian president] Mursi. Our Hamas brothers thought he would open up Gaza, I guess they were wrong. Perhaps 150 or 200 tunnels have been shut since the Sinai attack. This is the Mursi era.

"Water can cause cracks in the wall and may cause the collapse of the tunnel. It may kill people."

Reuters estimated some 30 per cent of all goods that reach Gaza come through smuggling tunnels. Israel has imposed a blockade on the region for over seven years. Six Palestinians died in January due to "tunnel implosions", raising the death toll to 233 miners since 2007.

Up to 3,000 tunnels have been constructed under the fence put in place by Israel, which restricts materials that could be used to make or store weapons – such as cement and gravel in this case

A Palestinian man helps a smuggler to ascend a tunnel along the Gaza-Egypt border in Rafah, in the southern Gaza Strip.
SAID KHATIB/AFP/GETTY IMAGES

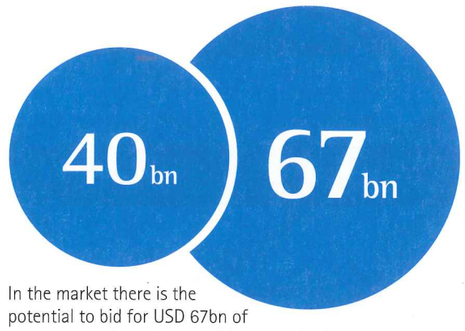


Of the potential projects are expected to have contracts greater than USD 50M

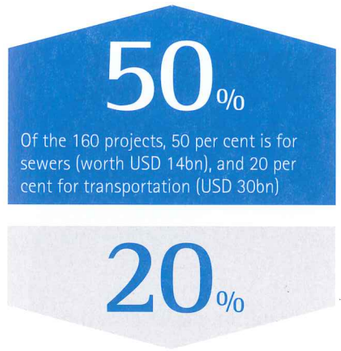
Of the projects are expected to have a contracts between USD 20M and USD 50M

Of the potential projects are expected to be less than USD 20M

IN THE next 12 years there is potential to bid just more than USD 67bn of tunnel work (160 projects) in the US, and USD 40bn of that work is expected in the next five years, according to statistics gathered by industry members and presented by Jeff Petersen of Kiewit at the October 2012 Tunnelling Associateion of Canada (TAC) Conference in Montreal. These numbers are not scientific data, however, as he points out, "we don't have a very good common data source that tracks our industry. But I think I can say our market outlook is strong for the years to come." *Tunnels* looks at some of the specifics the industry does know



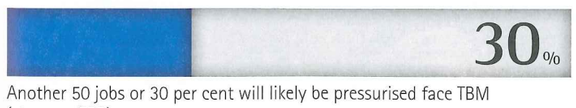
In the market there is the potential to bid for USD 67bn of tunnel work, and USD 40bn of that is expected in the next five years



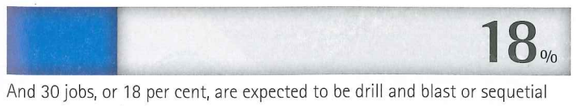
Of the 160 projects, 50 per cent is for sewers (worth USD 14bn), and 20 per cent for transportation (USD 30bn)

About 70 per cent of the market for tunnelling in the US is procured through the design-bid-build method. However, of the 160 jobs expected over the next 12 years

Of the 160 jobs, 30 per cent, or 50 projects, are likely to be excavated by hard rock TBM



Another 50 jobs or 30 per cent will likely be pressurised face TBM (slurry or EPB)



And 30 jobs, or 18 per cent, are expected to be drill and blast or sequetial excavation method

20
Per cent of projects will be procured as design-build

4
Jobs at the least will have design-build-finance, P3 procurement or some sort of finance involved

UNDER PRESSURE

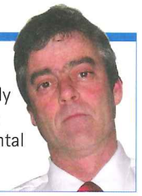
EPB tunnelling near the Port Mann bridge in Vancouver under high pressures has required a customised system. In this article **Keivan Rafie**, **Steve Skelhorn** and **Allen Mitchell** of McNally give a preview of their paper to be presented at RETC in Washington D.C. this June

METRO VANCOUVER is constructing a new water supply main under the Fraser River, just downstream of the Port Mann Bridge. A joint venture of McNally International and Aecon Constructors was awarded the contract for this highly challenging project. When complete, this new water main will help ensure the continued, reliable delivery of clean, safe drinking water to the municipalities south of the Fraser River, and will substantially increase the capacity of the existing main.

The water main will be constructed in a tunnel driven through soil, 35m underneath the riverbed. The 1,000m long, 3.5m diameter tunnel will be excavated under the Fraser River at pressures of up to 6 bar using an EPBM. For this purpose, two shafts will be constructed at north and south sides of the river.

Keivan Rafie
Keivan Rafie has worked on tunnel projects for the last nine years and is currently the tunnel project engineer on the Port Mann Tunnel Project in Vancouver.

Allen Mitchell
Allen Mitchell is a senior project engineer for Metro Vancouver and is the project manager for Metro Vancouver's Port Mann Main Water Supply Tunnel.



Steve Skelhorn
Steve Skelhorn is a project sponsor with McNally Construction Inc. Based in Toronto he has more than 25 years experience in soft ground segmental lined tunnels in the UK, USA and Canada.

Tunnelling in complex geology, exceptional depths and high hydrostatic pressure involves several technical challenges. This paper describes the approaches used in customisation of TBM and tunnelling systems to suit the aforementioned conditions. These modifications were implemented in various areas including but not limited to: design of TBM shield and bulkhead, emergency systems for water ingress, layout of cutting tools and contractors procedures including provisions for high pressure compressed air interventions, specialised launch procedures and TBM removal provisions at the receiving shaft.

The south shaft will serve as the launch shaft for the TBM. The shaft will be sunk using slurry diaphragm walls for primary ground support that are 13m internal diameter and nominally 68m deep. The shaft will be excavated in partially flooded conditions before placing a Tremie concrete base. The shaft will then be dewatered, cleaned and lined with an 11m inside diameter, cast in place, concrete lining. A work slab will be installed at a depth of 51m prior to installation of a TBM launch can. The final lining will then be finished around the launch can to the underside of a buried 7.2m deep valve chamber that will be constructed integral with the upper shaft lining.

Inclinometers will be used throughout the process to ensure ground movements do not exceed design tolerances.

The north shaft will serve as the receiving shaft and facilitate the removal of the TBM. The shaft will be installed using the same procedures as the south shaft, except it will be keyed into mudstone bedrock and potentially excavated in the dry if the permeability and stability of the ground permits.

The tunnel will be constructed using a pressurized-face TBM and gasketed precast concrete segmental liner and the annulus will be backfilled with grout. Segmental liner delivery will be facilitated through the south shaft.

To be effective in controlling loss of ground, the pressure applied to the face by the TBM must be sufficient to support the face and limit ground movement and groundwater flow into the excavation chamber. Fluctuations in the pressure applied to the face will occur as the ground conditions and the composition of the spoil within the chamber changes. Continuous monitoring and careful control of the pressure will be applied to the face during tunnel excavation in order to prevent loss of ground and minimize surface settlement.

EPB TUNNELLING AT HIGH PRESSURES

TBM and cutterhead design

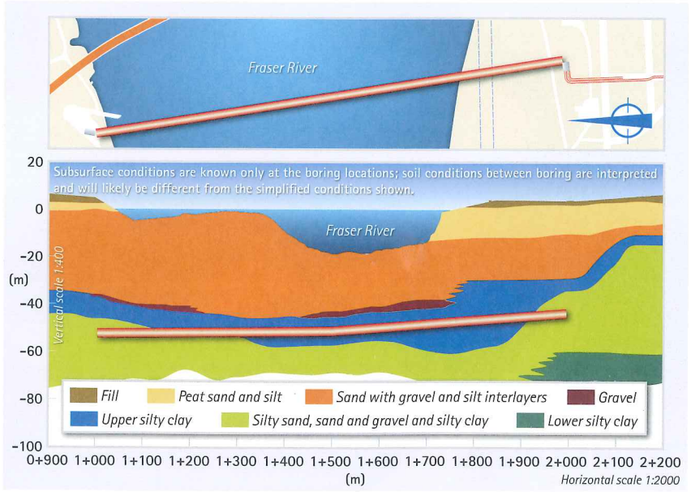
Because of the risks associated with a head entry under the anticipated conditions (6 Bar), the TBM is designed to allow safe hyperbaric entry should it be necessary. Compressed air workers have worked with the TBM manufacturer through the design phase to assure alignment with all components. The TBM gantry is designed to be easily removable to facilitate installation of an in-tunnel airlock as close to the face as practical. The TBM has been fitted with sacrificial skin around the stationary shield to facilitate the sealing operation required in the final stages of the reception process at North Shaft.

Face stability

By definition EPM provides control of ground movement ahead of the TBM during mining. Initial parameters concerning the selected EPB pressures will be established from the data provided within the GBR and GDR.

Ground movement due to the formation of an annulus outside of the segmental lining will be controlled by using a pressure and volume balanced system of grouting to maintain a full annulus as the TBM advances.

Under full EPB, areas of highly saturated flowing ground may only be apparent due to the condition of the material within the screw. In such areas, it may be necessary to inject



Below: Figure 1, The EPBM for the 3.5m diameter tunnel

The TBM has been fitted with **sacrificial skin around the stationary shield**, to facilitate the sealing operation

polymer based ground conditioning agents in order to maintain the plug formation within the screw. Polymer will be pre-mixed and injected ahead of the face through injection ports. In extreme cases (ground with minimal fines), it may be necessary to add pure polymers to the screw conveyor.

As an added precaution, a bentonite holding tank will be maintained on the TBM back up system. This will contain a supply of pre-mixed bentonite and will allow injection to the head to modify the soil and provide sufficient fines for plug formation. The bentonite system consists of a dedicated pump and holding tank which will be recharged from the surface.

Controlled discharge and water ingress

To properly dissipate the EPB pressures from 6 bar to atmospheric to allow for safe and efficient extraction of muck from the working chamber, the total length of screw conveyor has been extended and a double screw system has been used on the Port Mann TBM.

Several ports along screw have been provided for injection of soil conditioning material to control the excavated material and to facilitate consistent muck removal.

The full length of the drive at Port Mann will be excavated downhill at grades of up to 1.48 per cent, and it will be necessary to control and collect water ingress at the face during tunnelling. In case of an emergency, both screw conveyor sections (front and rear) are equipped with an independent guillotine door. The estimated time to close the guillotine doors using the main bank power is 10 seconds and while under emergency power is 20 seconds.

Water ingress through a breach in the tail seals will be managed by injection of additional tail seal grease and grout. Should water flow not diminish, thicker emergency grease will be pumped through the tail tubes. If this fails to stem the water, a decision to inflate the emergency seal or to inject polyurethanes will be made.

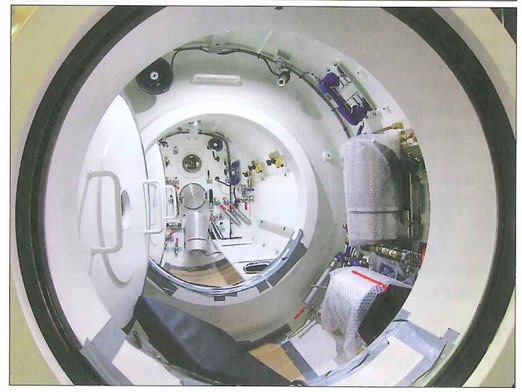
HYPERBARIC INTERVENTION

Airlock concept

For the purpose of applying compressed air to the tunnel, an in-tunnel airlock will be installed. Setting up the system in this way eliminates compromises associated with TBM mounted airlocks and also improves safety. With a TBM mounted airlock, only around 6m³ of air is compressed, which could be insufficient in a blow-out. By using a tunnel mounted lock, the buffer of air is far greater and the logistics of intervention are substantially improved. However, there are risks introduced in applying high pressure air to the tunnel such as fire hazards and detrimental effects to TBM equipment that require specific procedures to mitigate.

Design considerations for tunnel bulkhead system

The bulkhead has been designed to withstand the maximum anticipated internal pressure developed by the compressed air plant. Specifically, the bulkhead and airlock will pressurise to a maximum of 8.8 bar corresponding to 7 bar maximum working pressure with a temporary overpressure of 1.8 bar.



Above: The hyperbaric intervention system

1.48
Per cent down hill grades for excavation

8.8
Bar to which the bulkhead and airlock will pressurize.

Design of rolled tees

The bulkhead system will be anchored to the existing Port Mann segmental tunnel lining via the circumferential caulking grooves. Several rolled structural pieces will be inserted into the groove to form a ring and subsequently welded to circular steel pipe sections. Since the series of four rolled tees may not be loaded evenly (tees closest to the pressurized hyperbaric condition will experience higher forces than the tees located behind), the design conservatively considered only the first two rolled tees actively resisting the maximum thrust with the remaining two rolled tees installed only for redundancy.

Design of welded steel pipe

To house the compressed air bulkhead, three steel pipe sections with each section corresponding to a 1.0m tunnel lining ring will be welded in place. Only one of these pipe sections will actually house the compressed air bulkhead, with the remaining two sections to enable redundancy in the rolled tee anchorage system, and also to increase the barrier to pressure leakage through the segmental lining.

The steel pipe sections (or cans) are

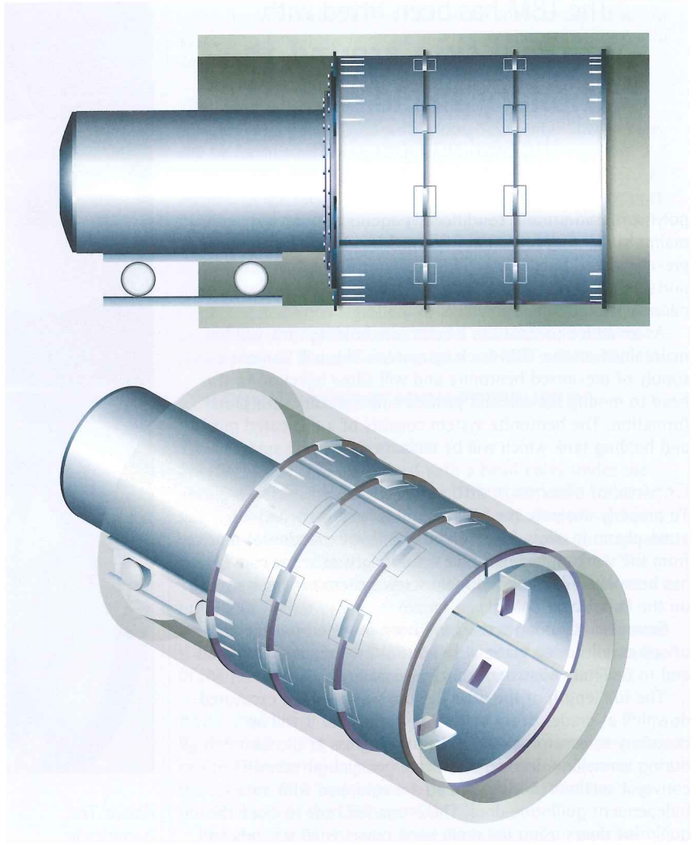
designed according to ASME Pressure Vessel Code design methodology. The grouted annular space between the segmental lining and steel pipe, as well as the presence of the tunnel lining and external soil and groundwater pressure will all further restrain the steel lining.

Design of steel bulkhead

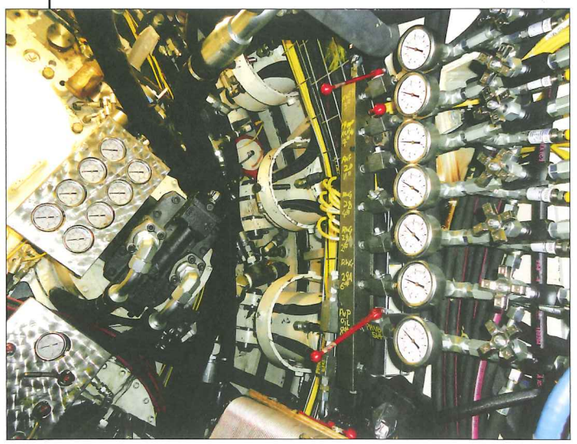
A steel bulkhead (flange) with a large central circular opening is required to secure the rail mounted airlock in place. The bulkhead will bolt to the airlock flange and will be welded to the interior of the steel pipe. Due to the larger bulkhead area, initially a bulkhead consisting of thick pressure grade steel plate was designed. The bulkhead will essentially act as a ring cantilevering away from the interior of the steel pipe with a concentrated ring load being applied along the circular centerline of the airlock mounting bolts. This results in a large steel plate thickness bulkhead. A second design consisting of a thinner steel plate reinforced bulkhead with steel brackets spaced at 30 degree centres along the bulkhead perimeter was evaluated, which proved to possess adequate capacity.

TBM LAUNCH AND RECEPTION

Due to high hydrostatic pressures at the bottom of launch and reception shafts, the TBM must break-in and out of the ground through specialised procedures. The intent of these methods are to balance the 6 bar pressure outside the shaft slurry walls to ensure the integrity of the shaft and tunnel are not compromised. Hydrogeological conditions at the project area are controlled by combined influences of local topography, a complex geological setting and the Fraser River tidal cycles. The water table below the upland areas is elevated approximately 40m to 50m above the river level and ground water generally flows toward the River. Artesian piezometric levels measured at the south shaft are on the order of 5.1m above ground surface. The TBM will be launched from the south shaft which is located about 220m south of the south bank of the Fraser River.



Above: Figure 2, Diagram of the airlock



Below: Interior components of the machine

The existing ground surface in the vicinity of the shaft is relatively level at about elevation +3.7.

To successfully launch the TBM into the challenging ground conditions behind the slurry walls, several provisions have been made. Firstly, a 7m by 6m ground replacement zone (concrete block) has been constructed at the tunnel horizon using slurry wall installation techniques to provide protection for the first few metres of tunnel excavation. Further, a launch can has been designed to encapsulate the TBM and allow for manual pressurisation of the TBM working chamber up to 6 bar to balance the hydrostatic pressures expected behind the slurry wall. This pressure will be provided to the TBM working chamber by introducing bentonite to a "launch can" sealed using Bullflex system. The TBM will be received at the north shaft located about 35m north of the Fraser River's north bank. Initial support of the shaft was done with slurry diaphragm walls with a nominal ID of 8m and a depth to bottom of Tremie slab of 65.7m. A 5m ID, reinforced, cast-in-place concrete structural shaft, will be constructed within the slurry wall shaft. Similar to the south shaft, a 3m by 6m ground replacement zone (break-in block) was constructed at the tunnel horizon using slurry wall installation techniques

NORTHERN EXPOSURE

While Seattle is known for its grey drizzly days, the climate for tunnelling is all blue skies. Sound Transit will bid another major tunnelling contract for its regional mass transit system this March, **Nicole Robinson** reports

SHOULD SEATTLE become home to another professional sports franchise anytime soon, one might suggest they adopt a TBM mascot. A number of machines have been busily mining beneath the city streets, and the mammoth Alaskan Way Viaduct is expecting its 17.5m Hitachi Zosen EPBM to be fully assembled this year.

With TBMs completing their work on the University Link, or U-Link, tunnels, Sound Transit is ready to bid the twin bore tunnel construction contract for its next extension, to Northgate. At the far northern end of Seattle, this urban center has one of the region's shopping malls, multi-family housing and a community college. It's also adjacent to the Interstate Five corridor.

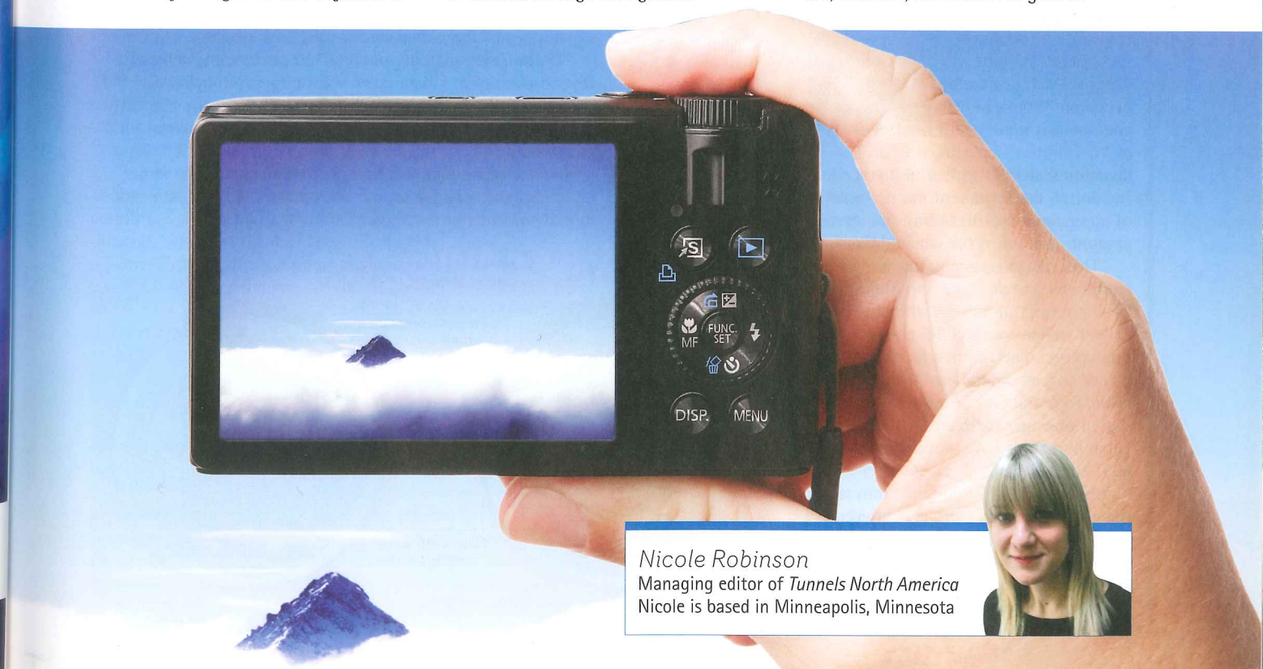
"It's a very busy area of Seattle and it sees a lot of transit ridership," says Don Davis, executive project director with Sound Transit for the North Link. "This is probably the best ridership segment in our current program, and we're expecting about 62,000 daily boardings on this link."

The Northgate Link, or North Link, component of Sound Transit's 23-mile (37km) north-south regional mass transit system is a 4.3-mile (7km) light rail extension. Connecting the University of Washington to Northgate, via the densely-populated Roosevelt neighbourhood, the alignment is mainly in tunnels through soft ground with the last mile elevated as it reaches Northgate's shopping mall.

This corridor is currently served by an extensive bus system, but it's already very congested, explains Davis.

From the University of Washington Station (part of U-Link), the North Link alignment continues north, underground to the U-District Station (previously called Brooklyn), then to the Roosevelt Station, also underground. The tunnel will end at a portal and the remaining mile or so will be elevated to the third station, Northgate.

With a number of similarities between the two projects, Davis and colleagues are optimistic about this next step. There are, however, differences in ground



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

conditions, and the U-Link experience has shed some light on what's to be expected up north.

EXTENDED FAMILY

Sound Transit will advertise the tunnel construction contract this month and it includes all of the TBM tunnelling, the portal at the north end of the alignment, cut and cover excavations for the two underground stations and cross passages. The current estimate for contract is in the range of USD 500M.

Two separate contracts will finish each underground station. Another contract will construct the remaining elevated mile of light rail.

Several other contracts include utility location and systems work, among others. Jacobs Associates is the engineer responsible for all of the tunnel design and design for support of excavation for the stations.

Shannon & Wilson is involved on the project for geotechnical work, and Parsons Brinckerhoff is the lead designer for the aerial guideway and the aerial station at Northgate.

As an extension, the twin bore tunnels will be the same dimension as the U-Link and Central Link projects. Finished tunnel diameter will be 18ft, 10in (5.7m), and at minimum the TBM diameter will need to be around 6.5m.

"As far as the tunnelling itself goes it's very similar," says Davis. "We have basically the same tunnel section in the Northgate segment as we do in the University segment. The difference, is of course is the geology."

The two stations will be between 80ft and 90ft (24.4m and 27.4m) deep, and the deepest part of the alignment is underneath the University of Washington's campus, with an approximately 150ft (45.7m) invert. Near the portal, the alignment has an invert of approximately 40ft (12m), the least amount of cover in the whole drive.

"There are the same geologic conditions prevalent right through the U-Link project and the Northgate Link in that we have a variable sequence of interlayered glacial, interglacial and non-glacial soils as we did on U-Link and also on Central Link," says Isabelle Lamb, design manager for Jacob Associates. Lamb and Davis have worked on both light rail projects.

On the North Link alignment there are numerous contacts between hard cohesive soils and then variable permeability non-cohesive soils, such as sands and gravels, as well as boulders and shears. "So it's similar in the environment [of] the University Link. But the big difference here on Northgate Link is we have a lot more of your sands, the non-cohesive soils," she explains.

"On U-Link a majority of the U-220 contact, which went from University of Washington station to Capitol Hill, was predominantly the cohesive silts and clay—the really hard silty clay type. And through that material we had channels of sand cut through.

On Northgate Link, we have a predominate of the more granular, non-cohesive sandy soils and fills. So it's just a real mix of soil."

Geology

- **Engineered and non-engineered fill:** Includes granular and cohesive fill
- **Recent granular deposits:** Loose to dense silt and sand with gravel; includes normally consolidated alluvium, beach deposits, reworked glacial deposits and recessional ice-contact deposits
- **Recent clay and silt:** Soft to very stiff clay and silt with fine sand beds and variable gravel; includes normally consolidated lacustrine, wetland recessional lacustrine and ice-contact deposits
- **Till and till-like deposits:** Dense to very dense, mixture of silt, sand and gravel, and hard, silty clay with sand and gravel; cobbles and boulders are common in these deposits, but are highly variable spatially. The spatial variability of the till-like ESU makes it difficult to correlate between borings. This unit can be adjacent to and transitional in nature with, cohesionless sand and gravel. Also includes glacially overconsolidated till, subglacial meltout till and lacustrine diamicts
- **Cohesionless sand and gravel:** Very dense sand and gravel to sand with variable silt; cobbles can be found in these deposits; includes glacially overconsolidated fluvial and glacial outwash deposits
- **Cohesionless silt and fine sand:** Very dense silt, silty fine sand and fine sandy silt with trace of clay; predominantly cohesionless; includes glacially overconsolidated lacustrine deposits
- **Cohesive clay and silt:** Very stiff to hard, silty clay and clayey silt with trace of sand and gravel; scattered cobbles and boulders can be found in these deposits; includes glacially overconsolidated lacustrine, peat and paleosol deposits. Where hatched, these deposits contain primarily peat or wood.

Below: Figure 1, Dimensions of completed tunnels

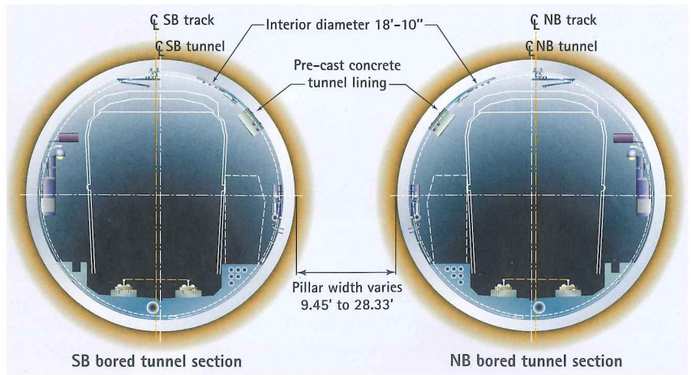


Table 1. Project comparison

U-Link	North Link
3.15-mile extension	4.3-mile extension
Two stations	3 stations
20 cross passages	23 cross passages
Three TBMs	Up to 3 TBMs
18ft finished diameter	Same
15ft Minimum overburden	40ft Minimum overburden
Two tunnelling construction contracts	1 tunnelling construction contract

Source: Sound Transit

DRIVING APART

The total TBM drive will be approximately 18,391ft (5,605.5m), with a 4,773ft (1,454.8m) reach between the University of Washington station and the U District station, 5,530ft (1,685.5m) between U District and Roosevelt station, and from there, another 8,088ft (2,465m) to the portal. The cut and cover U District station and Roosevelt station are going to be approximately 400ft (121.9m) and 490ft (149.4m) long, respectively.

TBMs will be launched from the Roosevelt station, and Sound Transit anticipates a total of three machines will be used on this contract. Two EPBMs will complete the drives south to the U-Link's University of Washington station, past U District station, approximately 10,303ft (3,140m) each. A third machine, either EPBM or slurry, will do both drives between Roosevelt station and the portal.

"The potential for use of a slurry machine is because of the granular, non cohesive soils that we anticipate for that northern end," explains Lamb.

A retrieval shaft will be built at the north end of University of Washington station. The TBMs will drive into the shaft and be extracted from the station.

Shannon & Wilson has been helping with groundwater modelling for the station excavations, looking at discharge flows and interpretations of the ground conditions. For the TBM launch and retrieval at Roosevelt station the contract will call for pre-excavation jet grouting. While for the U District station, because of the proximity of structures, the design team is looking at dewatering rather than pre-excavation grouting.

"We also have pre excavation grouting proposed for some of the cross passages where we believe the groundwater conditions would make straight SEM excavation a little difficult," explains Lamb.

One of the project's biggest challenges is its 23 cross passages, however the ground conditions will be different from the U-Link project where one particular cross passage required dewatering activity.

As well, the groundwater pressure head is lower further north. At the alignment's deepest point beneath the university there is a maximum pressure head of 2.9 bars, explains Lamb. "On University Link, in comparison, the pressure head was approximately 5.2 bars. As we go to the north the pressure head gets much less, and it's less than 2 bars."

Few differences can be distinguished between the projects beyond the ground conditions. "We're passing under the University of Washington's central campus and that has requirements with respect to noise and vibration, and long term vibration impacts from the operating system," Davis explains.

He later adds, "We had some rather significant challenges on University Link passing under a ship canal and passing under the I-5 freeway with very minimal overburden on the tunnel. We had only 15ft (4.6m) of cover when we passed under the freeways. We don't have those same challenges on Northgate Link.

"It's different challenges, different geology and different kinds of development. But it's very similar. It gave us the opportunity to look at the University Link and look at any of the issues they ran into on University Link and take into account as we progress on Northgate Link."

For example, on U-Link's Capitol Hill station, when the soils were not as expected, the project team re-did the dewatering design, explains Lamb. "It's a bit of a learning experience. We are now seeing how the soil behaves so we are very optimistic about how the ground will behave on North Link"

Right: Figure 2, The North Link alignment

18
The diameter in feet of the finished tunnels to connect with the U-Link

23
Cross passages will be built as part of the North Link tunnel contract

40
Approximate number of feet for the invert where there is the least amount of cover

TUNNEL ENVIRONMENT

Environmental monitoring is getting an increased focus from tunnel clients, designers and contractors. **Alex Conacher** speaks to a variety of the parties to find out some of the main concerns, and what developments are being made in thinking and technology

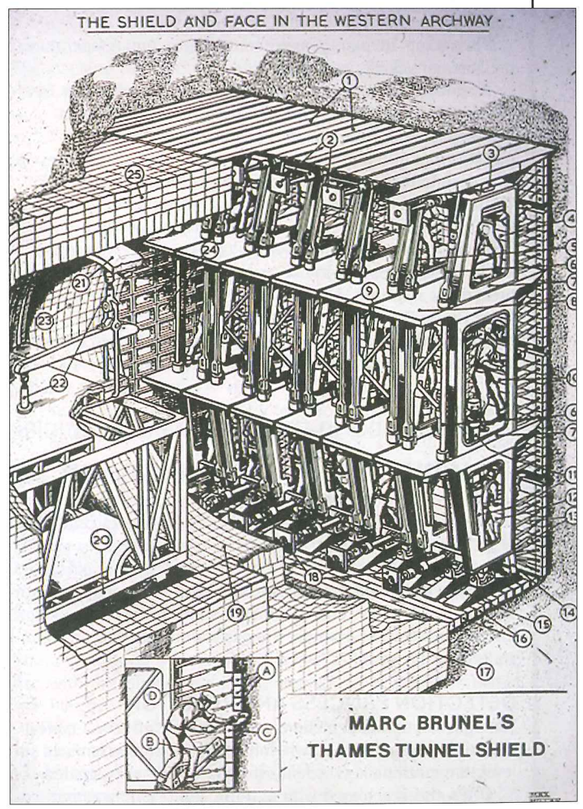
Alex Conacher
The *Tunnels* features editor has been with the magazine since 2010

THE ORIGINAL Thames Tunnel Project (1825-1843) was driven with the first ever tunnelling shield design, and resulted in the deaths of seven men. One of the major floods injured and nearly killed Isambard Kingdom Brunel himself, purportedly as he was saving several others. In addition to the regular water inflows and marsh gas ignitions, the project "driven from a depth of 60ft [18m], by a capacious apparatus, denominated the shield" had only cost GBP 120,000 "notwithstanding difficulties and accidents", according to the Thames Tunnel Office in a report from 1835.

The shield acted, as the report puts it, as a kind of horizontal cofferdam, and protected the workers. To an extent. "Working in the tunnel the air quality was appalling with the workers frequently being dragged senseless up to the surface to recover in the fresh air. The River Thames was no better than a sewer, and the sewage entering the tunnel gave off methane gas which was frequently set alight by the candles that provided a dim light for the workers – there were no miner's safety lamps in the Thames Tunnel," – Brunel Museum.

(The Thames Tunnel celebrates its 170th anniversary this month, see news story p.8).

In modern times, the view is that health and safety concerns are strong enough to ensure a protected and pleasant working environment. Perhaps the occasional catastrophe from the mining sector, or the daily human cost of mining in China is the exception to this. ❱



Right: Figure 1, The first tunnel shield used in the 1800s

Above: A traffic light-style warning system for methane gas in the Appenines

OPTIONS

Although the primary causes of accidents in tunnels are slips, trips and falls, and many would have the safety focus on these, there are passive measures that can be put in place to ensure a non-toxic working environment. As evacuation is always the preferred means of worker protection, monitoring systems are key to protection in the tunnel environment.

The factors frequently monitored are gas, fire, temperature, pressure, air velocity and dust.

A spokesman for monitoring equipment manufacturer Trolex tells *Tunnels* that typically a project will demand a complete system from a manufacturer, rather than cherry picking from different suppliers. The spokesman emphasises that despite this, flexibility is important to make sure a customer does not have to make any compromises.

Although it is not usually a requirement to provide individual components of a system to a construction project, the best examples of bespoke systems are actually the permanent solutions. The spokesman gives the 'National Grid Head House Gas Systems' in the UK as an example. "This incorporated our gas sensors which went back to a PLC panel that was built by Trolex, and utilised other suppliers parts. This panel also gave digital outputs to the head house main control system, which allows end customer systems to be integrated into our system, for example if a gas alarm goes into an alarm state then the local PLC will also be alerted."

If people in the street would complain about it,
why should it be okay on worksites?
But often it is hard to place liability

DETECTION PROCESS AND REACTION

With gas (methane) detection, as an example of how a typical monitoring system works, when it reaches a pre-determined level, the machine is switched off and the tunnel evacuated.

Often this is achieved with a 'traffic light' style warning system and the appropriate responses are taught in regular health and safety meetings (see photo to the left).

DUST

On certain issues, some people think the industry is not going in the right direction. Dust can come from a number of sources: pneumatic breaking of concrete, shotcreting works and moving spoil, among others. Keith Bowers, engineering professional head for tunnels at London Underground (LU) says dusty worksites are a significant concern of his right now.

"My perception is that we are not making as much progress as we could be as an industry. When I started as an engineer using dry mix, dust was a real problem. I think people may have become less sensitive to the dust issue because we are still noticing dust on site.

"It's an ethical question: if people in the street would complain about it, why should it be ok on worksites? Responsibility for managing dust is shared throughout the supply chain. For example, plant should be designed to protect the operator in the tunnel environment, and the contractor should be using plant correctly for the safety of the operator.

"The contractor has direct responsibility for the safety of the workforce, but we must also recognise that the design of the works and the design of the plant will have an influence, so all parties must have some responsibility."

Roger Bridge, tunnelling manager at Balfour Beatty somewhat disagreed with Bowers, "I can only comment on my own worksites, but it is just important to make sure severe dust exposure doesn't happen. This is perhaps harder these days as we have more heavy mechanical breakers and sources of dust generation, but we are more environmentally aware."

Bridge added, "My work at the A3 Hindhead tunnel project [in the UK] is a good example of this. New, stricter requirements were brought into force post-award with EH40/2005 and HSE regulations. The revised limits brought the maximum number of particles down from 0.3mg/m³ to 0.1mg/m³ for respirable crystalline silica dust.

"We used dry de-dusters to deal with the particulate matter from the excavation in sandstone. It was a very clean site, though it is the invisible particles that can enter capillaries and cause lung issues. We looked at a drum cutter for heading excavation, but in the end we adopted a ripper bucket so we weren't breaking the rock into such fine pieces. Adopting a conveyor belt meant trucks were not generating dust or fumes within the tunnels."

Bridge discusses the common practice of personal exposure detectors. But points out that even these, and the in-tunnel dust stations, require laboratory analysis for measurements to be fully understood. There is no way it seems to get an accurate, instantaneous measure of dust exposure.

KEEPING THE ROOF UP

In his paper, 'Innovations and improvements of technology and data management systems to monitor large scale tunnelling works', Jon Scott, managing director of UK-based geotechnical monitoring specialist Itmsoil, describes recent advances in technology that have allowed monitoring to become a critical element of tunnelling projects.

Four main factors have driven down the cost of monitoring. The automisation and miniturisation of sensors makes them quicker to install and far less obtrusive in an environment where space is at a premium; they are also "virtually immune" to temperature and RF interference.

In addition, data collection methods are more stable than before, and can be reliable over mobile phone and Wi-Fi through other portable devices. Software has also advanced; easing data acquisition, database processing, presentation and user access.

With sizes reducing from centimetres and inches to a matter of millimetres (and sometimes a cost reduction factor of 10), Scott adds that the vast increase in the number of sensors sees data transmission take on a greater importance than ever before. While a handful of sensors can be each connected to a data logger by individual cables, the number of modern sensors would make this costly, time consuming and hazardous.

Scott cites a recent project where cable installation and protection took three times as long as sensor system installation. The benefits of modern wireless technology are obvious.

Finally, he points to energy harvesters. These small devices can harness vibration or thermal energy and convert it into electricity, which is small but usable. All of these advances have brought monitoring from the periphery of a project into being a mainstream consideration, Scott concludes.

1.5
Seconds a signal is sent from the battery to a receiver

3.5
To four years of battery life for the RFID system being used on one of the Crossrail drives

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PERSONNEL MONITORING

Bernhard Wimmer, managing director of Austria-based tunnelling and mining equipment distributor Durstmueller tells *Tunnels* of a less typical type of monitoring that just came into tunnelling, with a first case of use at Crossrail C300/410 in London, UK.

The basic idea is to provide active radio frequency identification (RFID) tags, roughly the size of bank cards, to certain tunnel workers. The tags have a built-in lithium battery that sends out a signal every 1.5 seconds at 433MHz to receivers wherever an operator would like to place them. The maximum range is approximately 100m depending on the type of antenna that is used.

The readers are linked to a computer that processes the data, which can render a real-time visual status display and can also switch components and systems on or off.

The RFID tags can keep tabs on where workers are, or how many, or who is in the underground environment. But they can also enable rig proximity detection. The placement of readers in rugged housings at key points on drilling rigs (or any plant) can create an unbroken worker detection zone around the machine. The potential uses are well demonstrated by the Crossrail case.

"We have installed the very first system on a Robodrill (formerly Montabert) drill rig," says Wimmer. "Our system interfaces with the drill rig and we have arranged different 'classes' of users: pilots, copilots and (normal) workers.

"In general the workers should be protected against the dangers of a rock drill under operation. Depending which class [of worker] a detected transponder is related to, the drilling will be influenced accordingly."

Wimmer adds that, for example, if a 'normal' worker is detected in the vicinity of the rock drill, drilling will be stopped. If a co-pilot is detected, drilling will be stopped unless the co-pilot is in the basket and presses a special pedal there. The machine will continue drilling then, but with a reduced speed. If the co-pilot is in the baskey and closes all windows such that the rock drill cannot harm him, drilling can continue at full speed, despite his detection by the system the person is being detected.

"There are several combinations of 'what if' scenarios programmed for the best safety and protection of employees," he says.

Wimmer adds on reflection, "A very good combination is to add [complete] personnel (and eventually object) tagging and tracing system. If all the employees on site are equipped with a tag, this is just the logical next step for more safety. It can automatically be displayed how many people there are, and where they are underground. Even if people are moving inside vehicles like cars, trucks or trains."

The battery life is around 3.5 to four years. A limitation of the system is if a miner does not wear, or has a defective tag.

REFUGE CHAMBERS

Finally the refuge chambers of the mining industry are more and more common in tunnelling. The latest (2011) update of BS6164 requires a refuge chamber in tunnelling. Standards see them able to withstand pressures in excess of 15psi and can support eight to 24 miners for several days when disconnected from surface power.

Companies such as Trolex with their refuge chamber partner Strata Worldwide were involved, as well as others such as Mine Arc, with the mining world's requirement for refuge chambers/safe havens.

There are systems available to provide readings and data on the internal and external environment. The actual control of oxygen supply and CO2 control is already part of the integral chamber operations, and not part of a separate system

SEGMENT MOULDS SPECIFIED

In this technical review, engineers on the Sparvo tunnel project take us through the complete process of segment design and casting on-site to handling and finally installation. **Alex Conacher** speaks to **Alain Préaut**, sales director for segment mould and system manufacturer CBE to get the other side of the coin

TUNNEL RING designs are getting more complex for facing new tunnel challenges, which were insurmountable 10 years ago. They require a new generation of connecting devices, gaskets, fibres and concrete mix, says Alain Preaut, CBE sales director.

Having said that, moulds are not only an assembly of welded steel parts; [manufacturers] try, by their design, to bring some extra capabilities which will make the clients' operation easier and thus more cost effective. These include faster vibration, easy cleaning and curing monitoring.

Most our technical efforts spent during the past five years have been focused on engineering and R&D issues to speed up the mould design process currently performed with 3D software. Then, we have reduced our delivery time and increased the precision of shop drawings programs involved in laser cutting and CNC machining.

In such a way, and by reducing the error factor (or margin), we have also sped up the final assembly process. Our fitters can focus on mould accuracy and tolerances instead of the mechanical performances that are guaranteed by our model and crosschecked by our R&D department. The investment in 3D laser tracking some years ago in order to control accuracy and tolerances has significantly improved lead-time and performance in the fabrication process.

DEMANDING

Contractors are expecting a very tight level regarding tolerances and 3D checking with 3D-laser scanners are getting more and more common. That could make the difference especially for large size moulds involved in large tunnel projects. Those expectations do not let any room for approximate skills and poor references.

The legal risk involvement is also pushing our engineering survey and studies, mainly about geometrical tolerance conservation, mould deformation and stress applied to moulds during concrete pouring phase.

The German (STUVA) and British (BTS) standards are among the most exigent in terms of tolerances. Our success in these countries is the best proof of the expertise we have reached.

The size of the project can be a challenge too: three double carrousels for Emisor Oriente in Mexico supplied within just 12 months, the two lots of C300 and C305 supplied the same year.

The location is also sometimes not easy, we have installed a carrousel in Russian Manchuria during winter and the same year another one in an Indian Tiger Reserve in summer.

NEWER TECHNOLOGY

We truly believe that the cast-in ('anchored') gasket is real progress, though the benefit does not go to CBE so much. The machining of moulds side requires a more complicated process and tooling, we do not charge this to the client.

Actually, the gasket gripping on segments is much better, the working conditions are much better for the operators who do not have to use a solvent base glue, this is also better for the environment, and the precaster is not obliged to store flammable products in his factory yard any more.

Since [the first use at] the Lee Valley project (see *Tunnels International*, October 2011 pp.52-54), we have supplied four other projects using this technology: Spurs National Grid in the UK, Bridlington in the UK, Blue Plains in the USA and Vélizy in France.

Carrousels

Automatic precast yards, the so-called carrousel systems, represent more than half of all CBE segment projects per year.

Automated 'turnkey' factories are still located in high labour cost areas but the growing demand in the BRIC group of countries, connected with high inflation are in favour of productivity gains.

It is quite usual for us to make comparative pre-studies between static and carrousel process at the quote stage. We provide also factory layout drawings, as a free service, which will help the client to make his decision.

Reputation, experience and expertise remain the key. The industrial model required by this market is now so exigent that I consider it as exclusive as long as the market player, client and competitors are reasonable: tunnel safety is involved.

Even in China, where some new and unknown companies without any references are claiming they can make moulds at half price, I am sure entering the market remains very difficult

The German (STUVA) and British (BTS) standards are among the most exigent in terms of tolerances. **Our success in these countries is the best proof of the expertise we have reached**

LARGEST SEGMENTS

The largest operational EPBM in the world is currently excavating the south bore of the Sparvo highway tunnel project in Italy. The outstanding size of the 15.615m Herrenknecht machine and complex geology has required 700mm thick segments with a high level of steel bar reinforcement. This paper is written by **Maurizio Pepino**, **Gianluca Comin** and **Alfonso Di Cara** of main contractor Toto Costruzioni Generali

SPARVO TUNNEL forms part of the Variante di Valico project in Italy. A 65.8km motorway link, the project is intended to upgrade the Apennines section of the motorway between Sasso Marconi and Barberino di Mugello in the undulating Emilia-Romagna region, and ease travel between the cities of Bologna and Florence.

Autostrade per l'Italia, Italy's national road operator, divided the project into 13 lots. Contractor Toto Costruzioni Generali won four of these, including lots six and seven – the Sparvo Tunnel section. The project is noted for being the latest project to boast the world's largest TBM, a 15.615m EPB manufactured by Herrenknecht.

DESCRIPTION OF THE PLANT

To ensure acceptable production, and to have enough space for the necessary storage, an area over 20,000sqm was chosen. It is located 2km from the southern entrance to the Sparvo tunnel. Toto performs the entire segment production process with 93 employees divided into three shifts, with 24-hour operation, six days per week.

Despite the high initial cost, a carousel system was selected to increase the rate of production. Four different sets of moulds are used, with each one 'turning' on tracks of the carousel. Euroform designed this system with the assistance of Toto specialists. An average daily production equal to 80 segments per day is assured, corresponding to eight complete rings.

After the completion of the first tunnel, Toto's precast plant manager Gabriele Trovarelli decided to improve the carousel system by installing a hydraulic power pack to increase its translation speed. This modification permits a maximum production of 90 segments per day, due to the increase in power. The plant comprises three separate units for a total exploitable area equal to 5,800sqm.

Welding

The production starts with the manufacture of the steel reinforcement. In a 1,800sqm area there are nine workstations. A different cage is assembled in each workstation through the welding of steel bars supplied by Sofer Carpenterie.

To maintain a healthy environment, mobile aspirators of noxious gas are installed, and a series of welding machines are fed gas by a centralised plant. Each shift has 15 employees.

Air Liquide provided all the welding machines, gas distribution plant, and the aspiration system. The Stargon gas is supplied by Rivoira.

Placement

The reinforcement is later placed inside a mould at the start position of the carousel system; this last area takes up 2,800sqm and is arranged as an assembly line. Workers operate from fixed, protected positions while the equipment is moving:

- 1st position: segment de-moulding with a vacuum system and safety grabs;
- 2nd position: cleaning and disarming;
- 3rd position: dimensional control of the mould with a micrometer rod;
- 4th position: installation of the steel reinforcement;
- 5th position: general check, mould tightening and lateral closing;
- 7th position: is a soundproof cabin with a 5m³ casting bucket; near the cabin there is the control station where all casting stages are managed with the help of some cameras and a PLC malfunction detection;
- 9th position: complete closing of the mould (fresh concrete has no contact with the air).
- 6th and 8th positions are in case of extra operations.

At the 2nd position, in order to ease de-moulding and to ensure the long-term usability of the moulds, the application of a chemical release agent, BASF Rheofinish 216, is constantly applied at the beginning of each cycle, following careful cleaning of the internal surface of the moulds.

After the 9th position, the closed mould is moved by the carousel to the entrance of the curing oven. The curing oven at 1,200sqm is a third of the total area of the plant. The opening

of the oven bulkhead fixes the start of the thermal cycle.

THERMAL CYCLE

The oven is divided into three sections with gradual temperature increases. In the first the temperature range is between 20-25°C, in the other two sections the temperature range is between 55-60°C. It's regulated by a low-pressure steam injection system and contains three sets of moulds. Ten moulds are always on the workstation line while the remaining 30 are below the thermal cycle.

This permits a faster concrete curing through a temperature monitoring system; it has a minimum duration of nine hours. The thermal cycle is divided into pre-aging (one-and-a-half to two hours), the thermal rise phase (one-and-a-half to two hours) and the aging phase (four hours at constant temperature). Precast elements are initially manufactured through a pre-aging phase with a constant temperature equal to 20°C in order to get a minimum strength, to avoid micro-cracks. During the thermal rise, or heating phase, the temperature in the oven is increased following a thermal gradient equal to 15-20°C per hour. Then, when the temperature is 55-60°C (maximum 65°C) it must be kept as consistent as possible for four hours.

As with the heating phase, the post-aging must be gradual in terms of concrete cooling to limit any cracking from uncontrolled shrinkage. Besides this, segments must be protected against concrete surface drying, and the core must also not exceed 50°C.

Close to the carousel system inside the plant, there is a temporary segment storage point where segments are immediately placed after removal from the oven and subsequent de-moulding. This manoeuvre avoids a thermal shock. The minimum curing time at this stage is 24 hours, then each segment is lifted and moved to toppling equipment where EPDM gaskets and guide bars are installed.

A large area of approximately 7,000sqm around the precast factory is used for segment temporary storage. A maximum of six elements are stacked with the intrados facing upwards. In this way the capacity of the storage area reaches around 2,500 segments (250 complete rings). The Cifa concrete mixing plant takes up a 500sqm area.

SEGMENT LINING DESIGN

Mix design

The tunnel lining is created through the assembling of a precast concrete, segmental ring with the use of a vacuum erector. Segments are to connected each other with steel bolts, while the longitudinal joints between adjacent rings are maintained by bi-block system. The hydraulic sealing of the ring is achieved with the application of EPDM gaskets on the external perimeter of each segment.

The tunnel design, due to the variable geomechanical and geological conditions, defines two different types of segments in terms of a 28-day concrete cubic strength. This is equal to 50MPa and 45MPa, respectively for types one and two. The fire resistance of precast segments was assigned as R120, while exposure class is relative to a 'moderately aggressive environment' XA2.

The mix design imposed the use of a pozzolanic cement and minimum three aggregate classes in accordance with UNI 8520/a with a maximum diameter as 20-25mm. The cement is supplied by Cementirossi while aggregates are supplied by Granulati Donnini. A consistency S4 is needed immediately before casting (measured by an Abrams cone, UNI EN 12350/2), and a water-cement ratio equal to 0.42 is advised. It's of utmost importance to use a super plasticiser, with a common dosage of 0.8-1.5L per 100kg of cement. This reduces the need for water and produces a high quantity of hydration heat being based on modified polycarboxylic ether.

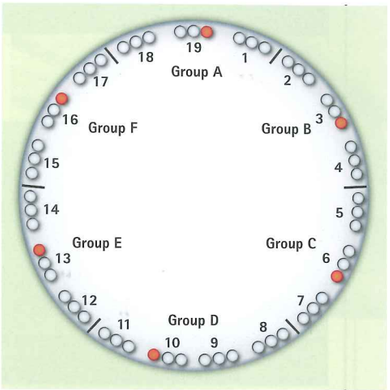
Steel reinforcement

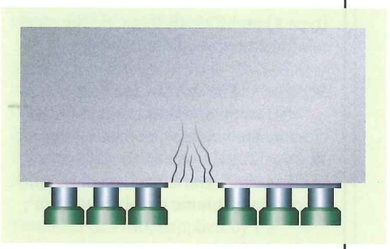
As described, two classes of segments are produced by the precast plant: C40/50

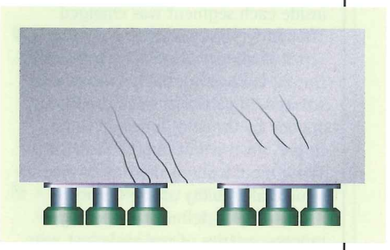
Right: Figure 1, Thrust cylinder layout

Right, below: Figure 2, Graphically rendered result of the symmetrical load tests

Right, bottom: Figure 3, Graphically rendered result of the asymmetrical load tests







700
The thickness of the Sparvo Tunnel project's precast concrete segments in millimetres

Table 1. Concrete makeup				
Raw materials	U.M.	Concrete strength classes f(Rck)		
		Rck 45	Rck 50	Rck 50 (new mix)
Rubble 12-22 mm	[kg]	570.0	530.0	570.0
Rubble 22-32 mm	[kg]	300.0	300.0	300.0
Sand 0.8 mm	[kg]	860.0	840.0	860.0
Sand 0.2 mm	[kg]	120.0	140.0	100.0
Super plasticizer Glenium ACE 40	[L]	4.2	4.6	4.3
Beton 42.5 pozzolanic	[kg]	390.0	430.0	410
Water	[L]	150.0	155.0	153.0

Note: The quantities are valid for 1 cu.m of concrete.
Source: Toto

(type 1) and C35/45 (type 2). The steel reinforcement requirements are:

- Type 1: Diameter of the bars at 18-16mm, and a rated steel weight/concrete volume equal to 110kg/m³;
- Type 2: Diameter of the bars at 18-16mm, and a rated steel weight/concrete volume equal to 90kg/m³;

Steel reinforcement distribution inside each segment was changed after early TBM advances due to a series of abnormal cracking processes. During excavation, the segments were stressed by particular load conditions applied by thrust cylinders in order to prevent the lowering of the TBM. These modifications did not involve the structural stability of the tunnel.

In order to define the cracking process, a series of real scale test were carried out with high pressure on thrust cylinders group D (300 bar equal to 24,938kN). Two loading configurations were applied to the segments: a symmetric load, and an asymmetric load applied respectively by the same thrust group (group D), and by two adjacent triple group of different thrust groups (group D and C or E).

All symmetrical tests showed the formation of a cracked area in the central part of the segment, between two thrust cylinders groups. This cracking process is due to an increase of the tensile stress between thrust groups.

For the asymmetrical load, a cracking zone appeared in the unloaded part of the segment due to high tensile stresses. In some cases cracks even appeared beneath the most loaded thrust cylinders shoe. To analyse the stress state of the segments a finite element model (FEM) was defined. In the symmetrical case (500 bar for each thrust group equal to 20,790kN) the model showed a high compressive stress under each cylinder

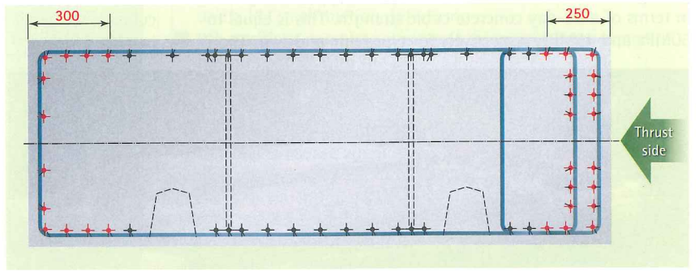
Above: Steel cage bars for the segments had to be reduced in diameter to increase reinforcement

Below: Figure 4, Steel reinforcement was modified with additional bars at segment edges, shown in red

and a tensile stress in the central area of the segment, this area extends up to 250mm from the edge of the segments. The FEM even detected a traction area at the segment edge opposite to thrust side. Its width is 300mm.

Showing steel

Following the previous results, steel reinforcement was thickened - reducing the diameter of the individual steel bars from 22mm to 16mm (without any modifications in terms of steel strength area/reinforcement effect) to control the cracking from unavoidable thermal shrinkage. During the concrete curing, simply due to the outstanding dimensions of the segments for the Sparvo project, temperature differences between the core and the external surface were greater than 20°C. Moreover, additional steel bars were also added in order to bear all tensile forces induced by the thrust cylinders. Some 18 bars of ø16mm in the first 250mm of the thrust side of the segments, and 12 bars of ø16mm inside



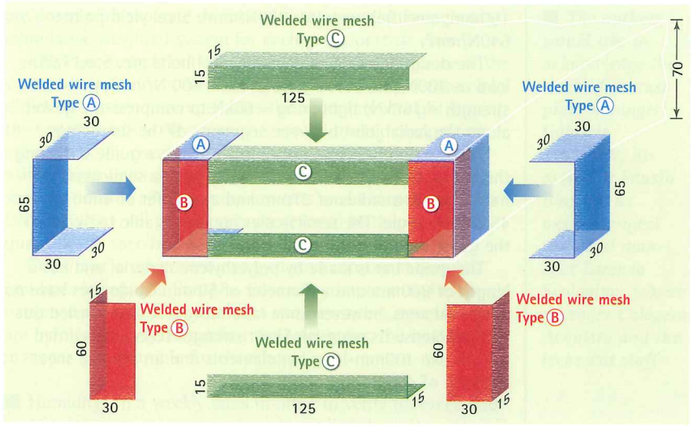


Table 2. Segment statistics	
Attribute	Value
Segment length	2m
Segment thickness	0.7m
Segments development	4.73 m
Ring conicity	± 18.8mm
Ring weight	157,22t
Segments weight	16,55 ton
Key Segments weight	8.27 ton
Ring weight	157,22 ton

Source: Toto

Above: Figure 5, welded wire mesh applied to the concrete segments

Above, right: Segments stacked with the concave facing upwards

Below: Figure 6, The bi-block system in use on the Sparvo project

the first 300mm on the opposite side of the segments.

To limit the spalling phenomena, the concrete cover was reduced to 30mm at the edge of the segments, and a series of welded wire meshes ø5mm, 100mm by 100mm were installed. The same arrangements were carried out on the type two segments. Using the steel reinforcement as described, no more cracks were observed on the segments.

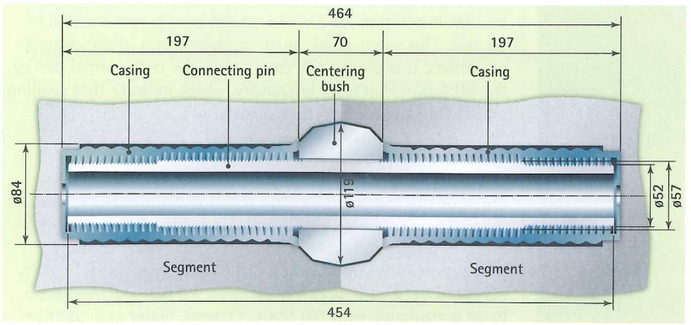
CIRCUMFERENTIAL AND LONGITUDINAL JOINTS

Longitudinal

The longitudinal connection between segments of adjacent rings is achieved with the bi-block system. Each segment is connected by four steel pins, while the key only needs two, making the total for each ring some 38 elements. Bi-blocks

15.62

The diameter in metres of the Sparvo earth pressure balance TBM supplied by Herrenknecht



are easier and faster to assemble than bolts as they are put directly into their threaded PVC housing on the segments before being handled by the erector.

The positioning of each segment is more accurate than with the screwing of longitudinal bolts because the connector itself acts as a centering system. This means more safety for the employees, fewer misalignments and less time required to perform a ring build.

The bi-block system used in Sparvo Tunnel is BZ-160, supplied by FIP Industriale and consists of:

- A n°2 threaded PVC casing embedded in concrete and placed among the reinforcement bars with a specific guide reinforcement. The casings are made in Nylon PA-6 a plastic material impact-abrasion resistant with high elastic properties.
- A connecting steel pin (S235JR), inserted into its casing just before the segment loading on the segment feeder;
- A centering polypropylene bush (BE170M0).

The project requires pullout strengths greater than 185kN and shear strengths greater than 130kN.

To evaluate the mechanical performance of the bi-block system, the manufacturer carried out a series lab tests from July to September 2010. This involved the casting of cubic samples with a perfect coupling of steel pin, casing and concrete. Pullout and shear strength tests showed strength characteristics higher than the designed values, a pullout strength of 211kN and shear strength in excess of 250kN.

In accordance with the wishes of Spea Ingegneria Europea, the division of Autostrade per l'Italia Group responsible for supervision of works, the Structures and Material Testings Laboratory of the Department of Civil Engineering at the University of Rome Tor Vergata performed a second series of tests to

Table 3. Component tolerances	
Material	*Value*
Cement	± 3%
Water	± 3%
Total aggregates	± 3%
Additives	± 3%
Source: Toto	

confirm all results provided by FIP and even to check special work conditions of these elements to simulate some assembly errors.

In detail, the second testing series covered shear strength tests; pull-out tests with the steel pin not fully inserted into the casing; pull-out tests with the steel pin not perfectly aligned in the casing but slightly inclined and pull-out tests with a greasy steel pin.

The strength tests carried out with these special conditions confirmed the reliability of this connection type. Average strength values were slightly lower than those ones in standard conditions. The maximum percentage difference among pullout strength test results was approximately 20 per cent, and it was recorded for a case where the steel pin was incorrectly inserted into the casing, however this result was still higher than the designed value.

Circumferential

The circumferential connection between adjacent segments in the same ring is achieved using special bolts; each joint is fixed by two steel bolts, for a total of 20 bolts in each ring.

FIP Industriale also manufactured these (TE28) steel bolts as a temporary circumferential joint. The technical specifications of the TE28 are: shank length: 727mm; shank diameter: 25mm; thread diameter: 28mm; thread length: 160mm; steel failure point: 800N/mm²; Steel yield point: 640N/mm².

The design requirements of the steel bolts are: Steel failure load > 700N/mm²; steel yield point > 400 N/mm²; pull-out strength = 160kN; tightening = 60kN to compress the gasket along the radial joint between segments of the same rings.

To ease ring building, the segments have a guide bar along the radial joints, so their contact faces have a semicircular housing with a radius of 27mm and a chamfer of 4mm with a 45 degree angle. The semicircular housing is able to 'receive' the guide bar and ease its slide into it.

The guide bar is made by polyethylene material and has a length of 800mm and a diameter of 50mm. Guide bars have no structural aims, however some laboratory test were carried out to characterise its material. Shear strength tests were carried out on two 100mm-long bar elements and an average shear strength of 400kN was reached.

Table 4. Production tolerances	
Aspect	*Value*
Segment radius	± 1mm
Segment thickness	± 1mm
Planarity contact areas	± 0.2mm
Gasket housing depth	± 0 - 0.3mm
Segment width	± 0.5mm
Internal surface deviation	± 1mm
Segment envelope	± 0.5mm
Angles	± 0.3°
Biblock holes position	± 0.5mm
Other elements position	± 1mm
Source: Toto	

Construction details

The segment lining is a universal type. Each ring is made by nine segments and one key that are 700mm thick and 2m long. The weight of each segment is in excess of 16t, while the key segment is more than 8t. The total ring weight reaches 157.22t. The outside ring diameter is 15m and the maximum internal diameter is 13.60m. It is the biggest and heaviest precast lining for a TBM in the world.

Water sealing gasket

To waterproof the tunnel, rubber seals are installed on the segments. The gaskets in use at Sparvo are FIP T184 EPDMs and it is applied along the entire perimeter of each segment (extrados side).

The geometrical characteristics of the gaskets are: base width 44mm, height 20mm (11mm housed and 9mm outside housing), EPDMs are characterised by a hardness (DIN 53505) in a range 70± 5 Shore A3, a failure load (DIN 53504) greater than 10N/mm², an ultimate elongation greater than 300 per cent and a residual strain (24h/70°C; 25 per cent) less than 15 per cent. The gaskets have been tested at the same laboratory of the University of Rome mentioned previously. Watertightness and squeezing tests were carried out using the corner of a gasket to simulate its behavior in contact with the edge of the segment. Watertightness tests, performed in accordance with the STUVA 'Recommendations for the use of gaskets for sealing segmental lining' yielded the following results:

- Gap 3mm and offset 20mm: sealing pressure 50 bar;
- Gap 4mm and offset 20mm: sealing pressure 21 bar.

The safety factor applied on gasket sealing pressure is two, in order to consider its long-term life and a possible detensioning of the EPDM rubber. Squeezing tests showed a maximum reaction load of the gasket on the corner equal to 29.2kN. This value avoids spalling phenomena of the concrete of corners. It is also in agreement with the tests carried out by the MPA Bau Hannover laboratory, which indicate that spalling occurs for values higher than 230kN/m.

Tolerances and quality control

The quality control of the segments starts with an accurate check of the concrete mix. The concrete is produced with an automatic electronic control programmable logic controller (PLC) of aggregates, cement, additives and water during all production cycles, following a quality control plan to be daily accepted by Spea Ingegneria Europea. All raw materials must be in accordance with ISO 9001. Cement, water and additives

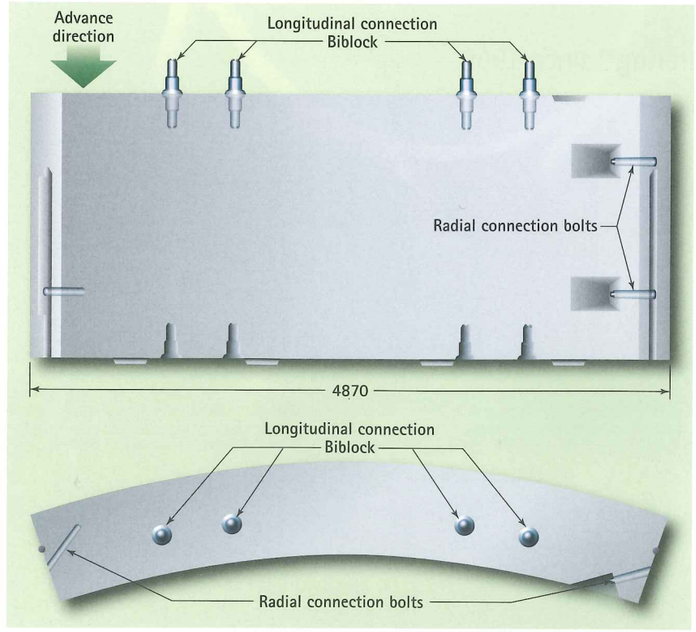
are dosed with separate devices while aggregates through a cumulative weighted system for each granulometric class.

The PLC controls both the mix and the load sequence of the concrete components. Depending on the humidity measured by different sensors, it compensates the aggregates weight varying the water quantity. All scales and the volumetric equipments are periodically checked/calibrated by qualified centers using Italian Calibration Service (SIT) standards. Technical specifications of all dosing equipments are in accordance with UNI EN 206-1. All percentages are referred to the required quantities as specified in the concrete recipe.

Tests/checks are carried out by Toto Costruzioni Generali and Spea Ingegneria Europea. Concrete components, fresh/hardened concrete characteristics and measuring equipments are monitored daily. Regarding the aggregates, the quality manager is responsible for checking:

- Humidity, on a weekly basis in order to verify no exceeding of tolerances;
- Sieve analysis (above all passing 0.075mm), done each 1,000m³ of material using UNI sieves (in accordance respectively with UNI EN 933-1 and UNI 8520-7);
- Imbibitions coefficient and volumic mass, done at the first delivery for new supply in accordance with UNI EN 1097;
- Sand equivalent and blue value have to be SE > 80 and VB < 0.6 cm³/g carried out each 8,000m³ of material in accordance with EN 933-9 and EN 933-8;
- Presence of reactive minerals, each 8,000m3 of material in accordance with UNI EN 8520-4 and EN 932-3;
- Presence of sulphates (SO4 < 0.05%) and soluble chlorides (Cl < 0.05%), tests carried out in case of doubts and each 8000 m3 of material in accordance with EN 1744-1;
- Presence of organic substances, tests performed in case of doubts and each 8,000m³ of material in accordance with UNI 8520-14 and EN 1744-1;
- Alkali reactivity, tests are done each 8,000m³ of material in accordance with UNI 8520-22;

The authors would like to acknowledge the work of precast plant manager Gabriele Trovarelli, his assistant Fausto Blasioli, as well as project technical manager Lorenzo Scolavino; jobsite manager Calogero Acquista and the technical staff



Below: Figure 8, Bi-block system on concrete segments showing radial connection bolts

Additives and cement are checked at each delivery in terms of quality in order to confirm the label and CE conformity. Water is tested through chemical analysis to check the contents of organic substances and chlorides, for the first use of non-potable water, and in case of doubt (in accordance with UNI EN 1008). Concrete is qualified through a complex control plan:

- Fine aggregates humidity, in order to estimate the dry mass of the aggregates. For each delivery the humidity is checked with probes on a weekly basis, or with more frequency depending on the climatic conditions by drying tests;
- Coarse aggregates humidity, in order to estimate the dry mass of the aggregates by test of drying weekly, or with more frequency depending on the climatic conditions;
- Water content of fresh concrete to evaluate the consistency of the concrete. This test is carried out daily with an Abrams Cone in accordance with UNI EN 12350-2 or -3, -4, -5;
- Fresh concrete temperature, each 300m3 of mix. The temperature must be more than 10°C;
- Compressive cubic strength of concrete (28 days) is monitored daily, withdrawing a series of cubic specimens during the casting phase in accordance with UNI EN 12390-3 to evaluate its correct failure.

Scheduled controls are performed by instrumentation able to discretise 0.1mm. Each mould is checked daily, providing correction if needed.

ADVANCE IMPROVEMENTS

During the advance of the excavation of the Sparvo tunnel, due to particular work conditions, four Elastomat load spreading pads of 400 by 500mm have been installed on each of the segments on the side in contact with the ring previously mounted. This avoids spalling phenomena. The pads are made by elastomerised bitumen, with the addition of SBS rubbers and polyester reinforcements. Their aim is to protect the concrete of the segments during the ring build. In addition, at the four corners between the EPDM gasket and the extrados, four 800mm-long stripes of bentonitic seals (Bento-FIP TMZ) were installed. These additional seals, which expand up to four times their original volume upon contact with water, create an elastic and compact shield, which waterproofs the tunnel in case of splintering at the corners

PIPE DREAMS

Diana Pfeff
Diana is the product manager for Herrenknecht's direct pipe technology, with an R&D history

THE DIRECT Pipe method, which was developed in the scope of a research project sponsored by the German Federal Ministry of Education and Reseach (BMBF), was successfully deployed for the first time in 2007 for a Rhine crossing in Worms. Since then, 18 projects have laid a total of more than 9km of pipeline in Europe and the US (status June 2012).

In this second of a two-part series **Diana Pfeff** of Herrenknecht focuses on project implementation of Direct Pipe, from start to finish with case studies around the world. For part one, see *Tunnels* February

The now established process is characterized by the fact that it is suitable for direct laying of larger diameter product pipes. In specific project framework conditions, Direct Pipe offers benefits compared with older established laying methods, and is thus a useful alternative in many cases.

The first article in this two-part series was printed in (*Tunnels International* February 2013, pp.33-37).

PLANNING ASPECTS

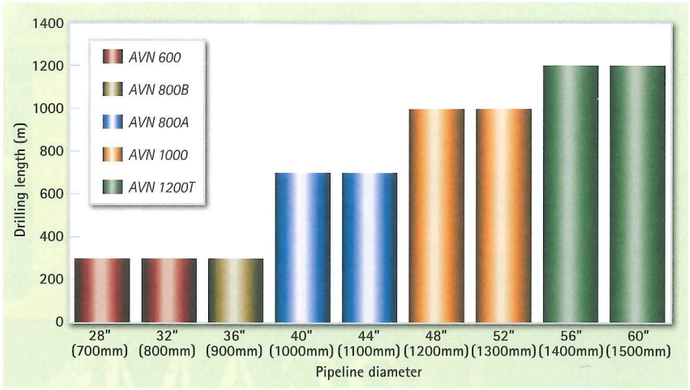
In contrast to the HDD method, where the opposite relation applies, in applications using the Direct Pipe method the maximum drilling length increases with the pipe diameter. Figure 1 reflects a fairly conservative estimation of potential drive lengths. The experience of the past few years has shown that drives of up to 1,400m (Ø=48in) are possible. In the future, the application scope can be expected to expand continually.

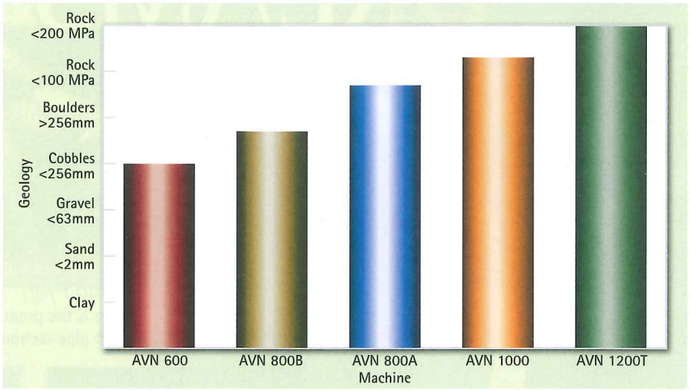
Figure 2 shows that the minimum pipe diameter is currently 28in (OD=711mm). The AVN machines deployed for this very small diameter cannot be equipped with a power unit for lack of space. This leads to a drilling length restriction of approximately 300m for pipeline diameters below 40in (OD= 1,016mm).

GEOLOGY

Detailed analysis of the geological characteristics provides important reference material for selecting a suitable laying method during the planning phase of a project. Planners can also assess whether the desired pipeline diameter can be laid directly in the existing geology, or if laying in stages is required. In case of homogeneous conditions, this assessment is always easier than in conditions with a mix of geologies. The important influencing parameters are, for example, the sieve corn analysis and the consistency of granular soils as well as the compressive strength, tensile strength and the abrasivity of the rock.

Because the Direct Pipe method involves thrusting the pipeline into the ground in sync with drilling the bore hole, it substantially reduces the risk to the terrain compared with the HDD method. This means that the pipeline can be laid directly, even in unstable geologies, such as rough grained or similarly graded sand or gravel, without the bore hole collapsing. With HDD, this typically necessitates the use of a casing. If the entire drilling route does not traverse stable geology, the pipe thrusting method alternatively uses a larger concrete pipe as protection. Direct Pipe offers an alternative for these cases.





Above, top: Figure 1, drilling diameter and lengths

Above, bottom: Figure 2, Direct Pipe in various geology

Figure 2 illustrates the geological application scopes of the various Direct Pipe machines. One explanation for the levels shown is the increasing torque that becomes available as the machine diameter increases.

As described in part one of this series, stone and rock chips are crushed in the crushing chamber.

The reason for the levels shown in rock is the application scope of the cutting tools on the smaller AVN machines. They are designed or usable for a maximum specific compressive strength. The larger the cutterhead, the more space there is for larger disc cutters.

The contact pressure required to loosen chips from the rock formation needs to be transferrable to the disc cutter bearing without causing damage to it. As a general rule, it can be said that as the hardness (compressive strength) of the rock increases, the diameter of the machine must also increase to ensure economic drilling.

CUTTING TOOL CHANGE

In the course of choosing the method or machine, it is important to assess as accurately as possible if and how often the tools mounted on the cutterhead will need to be changed due to wear during the drive.

As the **hardness of the rock increases**, machine diameter must also to ensure economic drilling

In Direct Pipe the cutting tools are changed above ground for all pipeline diameters of less than 56in (OD=1,400mm). To allow this to happen, the machine is pulled out of the bore hole along with the pipeline. After replacing the tools, the machine is pushed back into the same bore hole along with the pipeline. In the meantime, the bore hole is filled with high-viscosity bentonite. In contrast to thrusting smaller concrete pipes, the Direct Pipe machine is directly welded onto the pipeline. All machine parts are joined captively to withstand pulling force.

As of a pipeline diameter of 56in, access to the rear of the cutterhead is possible below ground. The AVN1200T deployed for this application has a door ('T' stands for the German word for door = 'Türe'). The special backloading system makes it possible to change worn tools in layers that do not contain groundwater. If it is necessary to change in groundwater conditions, the machine has to be pulled out of the bore hole because the use of an airlock lock is not permissible for these small diameters.

Figure 2 shows the guide values for economic deployment of the various machines in loose stone and rock with compressive strength of up to 200MPa, independently of the length of the section. If longer distances with even harder, or very abrasive rock are expected, it makes sense to deploy a larger machine with an airlock to be able to handle frequent disc cutter changes underground without any difficulty.

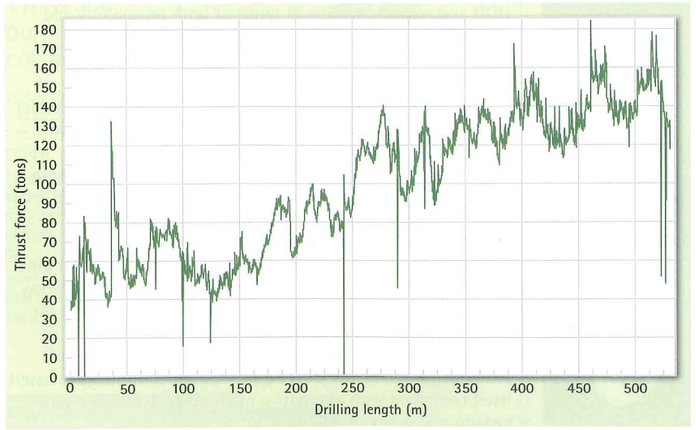
THRUST FORCE

The Pipe Thruster pushes the machine and the pipeline into the bore hole. In addition to the contact pressure required to act on the cutterhead, the friction between the lubrication bentonite or the bore hole wall and the pipeline needs to be considered. The radial overcut of approximately 50mm is completely filled with lubrication bentonite. Although the pipeline ideally floats in this, the friction grows with increasing laid length. However, experience shows that the thrust forces required for Direct Pipe are relatively low compared with standard pipe jacking. A representative example of the thrust force required by the pipe thruster is given in Figure 3.

An evaluation of nine of the 12 projects implemented thus far with a diameter of 48in (OD=1,220mm) reveals the following range of friction values or thrust forces. In the case of three drives in clay, the friction was so low that a thrust force of just 0.11-0.33t/m of 48in pipe (=0.03–0.09t/m²) needed to be applied. The length of the PE coated gas pipelines was between 370m and 590m. Historic values in sand and gravel with PP coated gas pipelines of lengths between 370m and 1,400m are 0.35-0.45t/m of 48in pipe (=0.06–0.15t/m²).

50
Approximate millimetres of radial overcut is filled with bentonite

9
Total kilometres of pipeline have been laid up to mid-year 2012 in 18 projects



Below: Figure 3, required thrust force

A Dutch institute has now developed a mathematical model that allows the required thrust forces to be computed. The model is based on a FEM. It was combined with historic data from various projects.

PROJECTS

Up to mid-year 2012, a total of 9km of pipeline had been laid in 18 projects. Five drives are described in more detail in the following case studies.

PILOT PROJECT WORMS 2007

A 464m 48in steel pipe was laid under the Rhine (48in casing pipe for various lines with an OD=1,219mm). The reasons for choosing this method were the partly unstable geology on the one hand and the cramped conditions on the other. It was impossible to lay the pipe in a single section on either bank of the river, thus making HDD impossible, or at least extremely risky.

The fact that the machine was thrust into the small target pit in Worms harbour with a thrust force of just 80t and in just 13 days shows the enormous speed on the one hand, and that the new technology has minimal thrust force requirements on the other. Microtunnelling with concrete pipes would have taken longer and thus also cost more.

THE NETHERLANDS

The first gas product pipe laying task took place in the Netherlands. In 2010 and 2011, a total of six projects were completed. The drives of between 360m and 1,400m below small rivers or rail tracks were part of a 500km north-south route. The pipeline with its diameter of 48in will transport gas throughout Holland in the future.

The 540m crossing below the very deep Hartelkanaal in Rotterdam used by vessels at Rotterdam's Europoort harbor in the summer of 2010 was one of the most unusual projects due to the required passageway depth of 30m below the surface. The cramped space available, which meant that the crossing had to be planned to be as short as possible, led to very sharp launch and exit angles of 10 and 12 degrees (approximately three to five degrees had been typical thus far).

In a geology of sand and silt, the entire pipeline was laid successively in 10 pipe sections of 54m each within some two weeks.

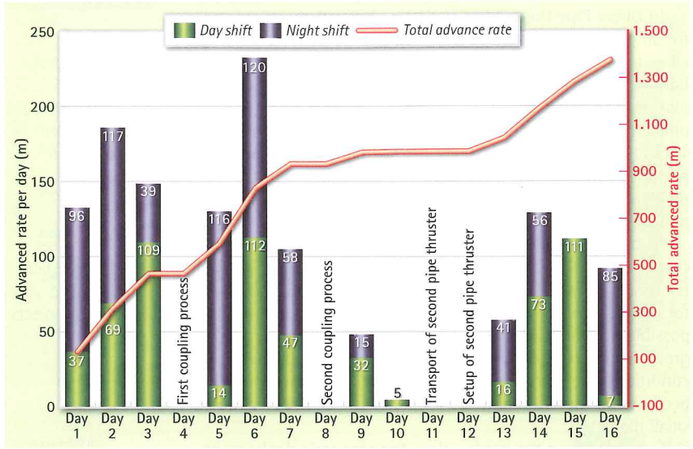
The Netherlands Society for Trenchless Tunneling awarded the client and the construction company the No-Dig Prize 2010 for the successful use of this alternative laying method.

Laying a 1,400m 48in gas pipeline is currently the record holder in terms of drive length. The pipeline was laid out in three pipe sections of 500m each. With two pipe changes, the thrust duration from launch to arrival of the machine at the target was just 16 days (Figure 4). The maximum advance in a 24-hour period was 232m.

Those 16 days include setting up a second Pipe Thruster, after advancing approximately 900m. The feed force of 500t was insufficient at approximately the 900m point. After installing the second machine, the remaining pipe was pushed into the target pit within just four days by the two Pipe Thrusters.

This is equivalent (with an effective working period of 11 days) to an advance performance of around 125m per day.

With a pipeline of this large diameter, this kind of laying speed would definitely have been impossible to achieve using any other method.



Above: Figure 4, Advance rates laying a 1,400m gas pipeline (48in)

FLORIDA GAS PIPELINES

Direct Pipe successfully celebrated its first outing in the US in August 2010. The three gas pipeline projects in Florida used diameters of 30in and 36in (OD=762mm and 914mm), compared to the 48in pipelines laid in Germany and the Netherlands. The drive lengths were between 119m and 226m.

One special feature in the first American Direct Pipe project was its curved route. In contrast to the previous routes, the pipeline had to be thrust under Highway 70 not just with a vertical curve (R=914m) but also with a horizontal curve (R=1,828m). The gyroscope-based navigation system and the electronic hydrostatic hose balance kept the machine safely and precisely on the required curved trajectory.

After just three days of drilling (12-hour shifts), the on-site team had laid the 215m gas pipeline in a single section and precisely on target.

In early 2011, the third project in the US involved retracting the Direct Pipe machine and 36in pipeline using the pipe thruster for the first time. After a drive of 102m the machine was pulled above ground in just one day; the cutterhead was changed and the machine then pushed back into the bore hole. The cutterhead change was made necessary by an unforeseen rock horizon that was impossible to pass without disc cutters. The remaining 124m pipeline was then laid within three days.

WASTEWATER PIPELINE IN ENGLAND

The Direct Pipe method was assessed as being low-risk for an 860m-long crossing below the River Ribble in England. Due to the anticipated coarse gravel and boulder strata, use of the HDD method was assessed to be too difficult and risky.

The route of the two waste water pipes to be laid led through rapidly changing layers of various soil layers. Long sections in clay with various sand and gravel content necessitated the use of a centrifuge.

From a shared launch pit, the two parallel 56in pipelines (OD=1,422mm) were laid at a distance of just 3.5m apart. The two pipes acted as a casing for two waste water lines (DN900) later installed in them.

In contrast to most of the projects realised previously, whose target pits were near to the surface, the machine had to be recovered from a 15m deep target shaft in this case. The navigation system deployed (gyroscope and water levelling system) allowed for precise targeting of the reception seal installed in the shaft.

CONCLUSIONS AND FUTURE

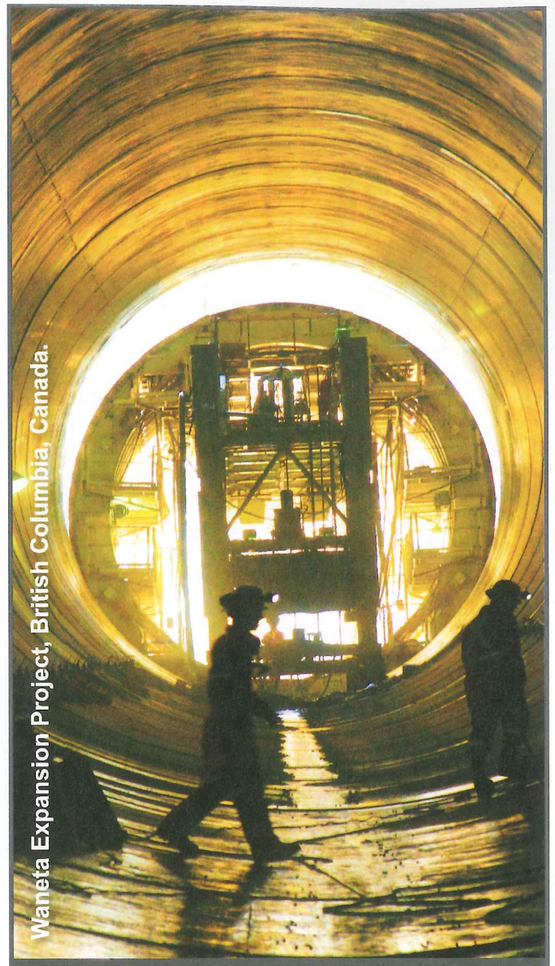
As the first 18 projects have shown, Direct Pipe achieves fast laying speeds. This makes the method an alternative to HDD and microtunnelling in terms of both technology and economics.

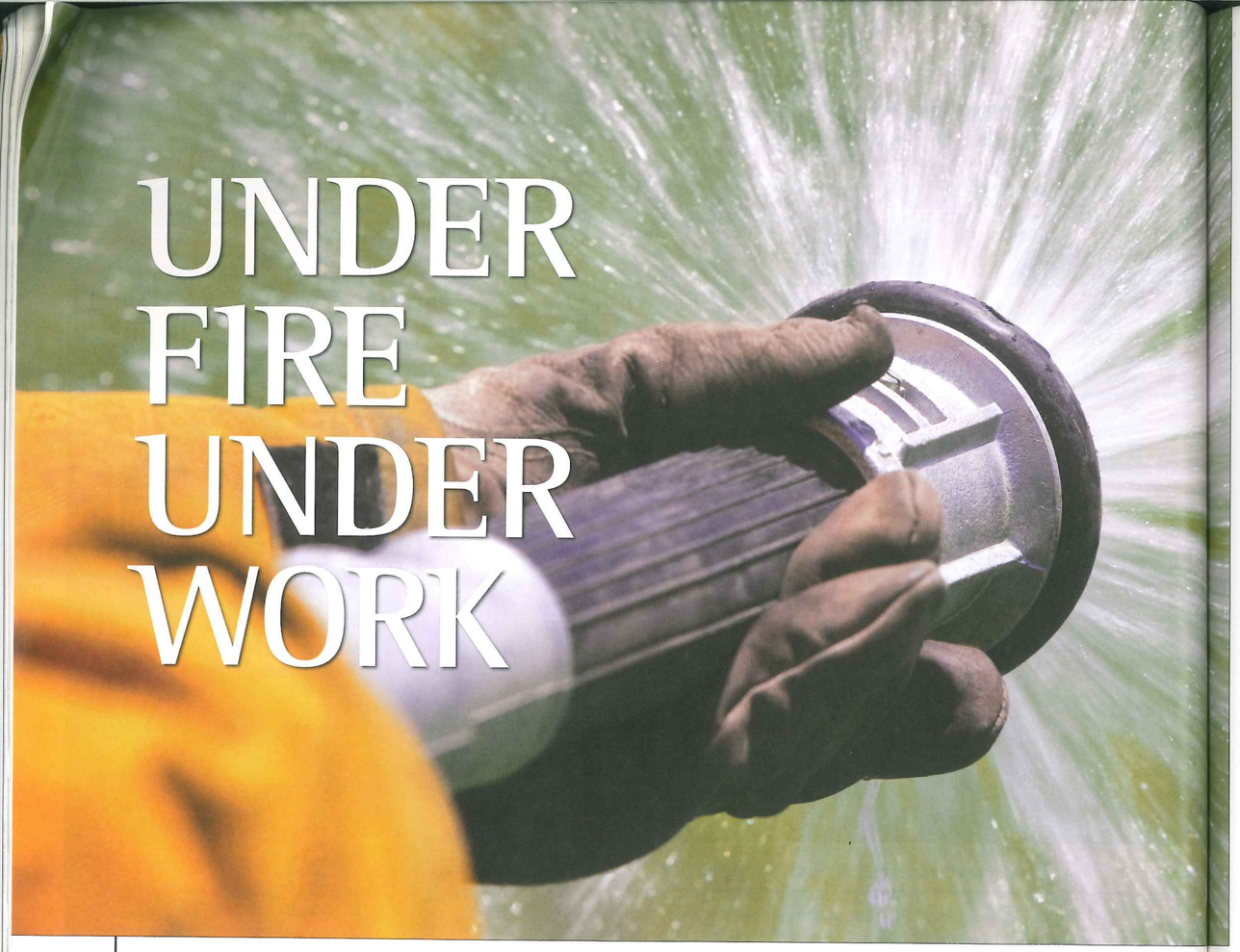
The drives completed thus far suggest the feasibility of increasingly long distances, given the right geology, that are only restricted by the smaller defined diameters of the product pipes and thus the limited accessibility of the machine for cutting tool changes.

Improved laying safety in difficult terrain—compared with HDD—and the economic benefits compared with standard microtunnelling and or pipe jacking, make the method extremely competitive.

The safety aspect of being able to recover the product pipe and the machine, and that of 'minimally invasive' passageway below habitats or obstacles, are decisive selection criteria for purchasers and official sponsors.

The benefits and applications described in this series of articles will lead to the Direct Pipe method continuing to assert itself compared with alternative methods such as HDD, pipe jacking and segmental lining





UNDER FIRE UNDER WORK

THE RISK of a fire in a tunnel under construction is minimised by good planning, coordination with the emergency services, procurement of equipment with fire-safety in mind, and awareness of procedures and documentation.

STORBELT TUNNEL FIRE

The contract involved two bores, 8km-long, 7.7m ID, 75m below sea level, using four Howden EPBs. The TBMs incorporated twin track within the gantries, and were considered to have advanced fire-fighting provisions, including two water curtains, AFFF fire suppression systems controlled by a central control panel housed in a non-fireproof container, and 10 fire reels. The control panel was not in an explosion proof container, so it was not connected to the emergency power supply.

On the morning of Saturday 11 June 1994, around 7.30, just after handover from nightshift to dayshift, there was a large flash around the shove rams. Within seconds the TBM methane alarm, set at 25 per cent LEL and 50 per cent shut-down of power supply, cut the mains power to the TBM. Emergency power systems were activated, and thick black smoke engulfed the TBM.

The well-drilled crew donned MSA sets and gathered at the permanently-available man-rider at the back of the TBM. The TBM engineer and foreman went to the fire control panel but this was inactive as it was connected to the mains supply. They were thus unable to activate the sprinkler system.

Four trained members of the crew donned breathing apparatus (BA) sets and operating as two teams carried out a search of the upper and lower levels of the TBM. Once satisfied all were accounted for, the crew evacuated the TBM. Those working on adjoining cross passages and the second tunnel drive also evacuated to the surface.

The risk of fire in tunnels under construction can be reduced in several ways. At the November 2012 BTS meeting **Barry O'Donoghue**, Mott MacDonald site contract manager; **Francois Pogu**, Vinci's Lee Tunnel project director; **Dave Bulbrook**, London Fire Brigade group manager; and **Donald Lamont** of Hyperbaric & Tunnel Safety reviewed the Storbelt and A86 Socatop tunnel fires, protocol for working with fire brigade and current legislation required for contractors

Above: Figure 1, The A86 Socatop tunnel located in Paris, France

The fire crews tried several times on the day of the fire to enter the tunnel. They also attempted to introduce CO2 into the tunnel air mains to contain the fire, but this failed due to freezing. During the day of the fire the ventilation system was shut down. Entry was only possible towards the end of the second day, where it was apparent that extensive damage had occurred to the tunnel lining with up to 200mm spalling of the 400mm thick concrete tunnel lining.

The initial fuel source of the fire was put down to hydraulic oil atomising from a hydraulic ram. The source of ignition was never established.

There were no injuries. The crews were well drilled in emergency procedures. There had been a fire on one of the adjacent machines the previous year, which had resulted in extensive review of procedures. Emergency drills were also emphasised due to the risk of flooding, particularly from cross passage excavation, which was being carried out at the same time as TBM excavation.

Extensive repair work was required following the fire. The site took the precaution of constructing two water-tight bulkheads at the portals prior to repair work, and a third bulkhead to enable compressed air to carry out these repairs.

The fire extended the contract by nine months, and cost USD 33M.

A86 SOCATOP TUNNEL FIRE

The 10km A86 Socatop 11.5m ID tunnel was being excavated in 2002 using a TBM capable of working either in EPB or slurry mode; at the time of the fire, it was in EPB mode. This unique tunnel to the west of Paris was part of the circular road being constructed around Paris. The tunnel was split into three horizontal levels, which were created during construction. Two horizontal slabs were concreted to split the tunnel into three separate chambers: the upper part for the conveyor and ventilation, the lower part for TBM traffic. The tunnel train was approximately 70m-long and was powered by diesel engine. The tunnel concrete separation slabs were being constructed using timber and plywood, which was being installed as the tunnel was being excavated.

During the planning stages extensive review of fire scenarios were prepared, including fires occurring at any of the three levels within the compartmentalised tunnel. The TBM was equipped with a manlock to gain access to the cutterhead; there were fire detection and fire suppression systems, water screens and sprinklers. In addition, the Paris fire brigade was involved with the project, and monthly inspections and training drills were carried out.

On 5 March 2002, at 22.30, one of the diesel locomotives caught fire when situated under the tunnel timber formwork. Four trained men tried to fight the fire. The TBM crew was informed. The TBM crews activated the rear fire-curtain and went to the front of the TBM. As the fire blazed, the tunnel ventilation collapsed.

Communications were lost and the ventilation was switched off. The Paris fire brigade tried but was unable to gain access to the TBM.

Nineteen operatives on the TBM were trapped for nine hours. They did not panic but remained in the TBM manlock as required by their emergency procedures. Within the manlock was water and fresh air. It had subsequently been calculated that there was 48 hours of breathable air supply available to them. Once the fire brigade managed to get through to the TBM, all 19 operatives were safely removed over a three-hour period. There was one injury to a fireman due to falling down through an opening between first slab (ankle sprain).

The 400mm-thick concrete tunnel lining was damaged due to the fire. It had behaved as the designers had predicted if a fire had occurred, with up to 100mm of spalling.

The cause of the fire in the diesel engine was put down to an oil leak to the turbo. Following the fire all diesel locos were changed, the fire suppression systems were improved, and the durability of the tunnel communication systems were improved. The fire plan was revised, training was reinforced, and goggles were supplied with the tunnel MSA re-breather sets.

Fire and smoke suppression systems on the TBM were improved.

9
Months added to the Storbelt tunnel contract after the fire in 1994

19
People were trapped on the A86 Socatop tunnel TBM for nine hours

THE FIRE BRIGADE

The purpose of the fire and rescue service in law is a responsibility to plan for operational incidents, to carry out a preventative function, and fundamentally to respond to emergencies. In addition to this, following a fire, to carry out investigations into the causes.

The brigade acknowledges that the circumstances when dealing with a fire in a tunnel under construction can often involve additional challenges to its more normal mode of operation when dealing

with a fire in the conventional-built environment.

If a fire occurs in a tunnel environment, communications are vital, as is water supply. The lack of ventilation and long travel distances in a tunnel fire places additional stress on a fire fighter. The manual handling consideration can also cause significant physiological effects. For example a single 20m length of water hose weighs 100kg. This is cumbersome, and if a number of lengths are required, will result in a significant resource impact to commence a fire fighting attack, in terms of personnel and BA. Construction sites present challenges, which can be overcome with proper planning, preparation and communications, particularly on arrival.

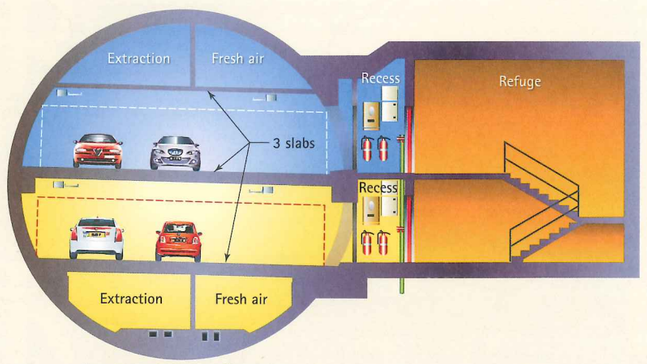
A fire fighter in full gear relies on BA and on integral communications, which are intrinsically safe for hazardous environments. In the past, contractors have wanted to issue hand- radios to the fire fighters. This presents problems. It takes away one of their hands for a start. Heat stress can have detrimental effect and thought processes become more difficult. Tunnels are enclosed and in an emergency situation can be very stressful. A dedicated radio channel for the emergency services does involve additional cost, but it is fundamental to how the emergency services are able to operate efficiently.

Water supply is also crucial, and history has shown that if enough water is available, the fire will eventually be put out. It is also important to minimise the amount of combustible material permitted within a tunnel environment. The heat that can potentially develop in a confined space is immense, and can make conditions intolerable for human activity if combustible materials are not properly managed.

It is vital that upon arrival the fire service are given current, accurate information. This includes the number of people involved, the best access to the incident, including any newly construction points of access, newly constructed shafts and cross passages, smoke curtains, fire suppression systems, the location of any refuges and bridgeheads. This information can make a crucial difference to decisions that need to be made by the incident commander.

A key requirement is a responsible person who meets the fire crew on arrival, and can assist the incident commanders in making decisions, based on a dynamic risk assessment. The better the information made available, the better the decisions that are made. If there are lives to be saved, a higher level of risk will be taken by the Fire and Rescue Service, but without lives at stake, less risk will be taken.

During the planning stage it is important for the contractor to work with the Fire and Rescue Service. It ensures information is given to local fire stations so site-specific plans



One tunnel: 11.5m diameter

Questions from the floor

Online: Is there a formal contract between the contractor and the fire brigade?

David Bulbrook: there is no formal contract. The fire brigade are obliged to provide advice to the contractor on how they will respond, and it is in their interests to provide this information.

Nigel Valvona, Thames Tidal Project: For very long tunnels, how many refuge chambers should be installed?

Donald Lamont: You should give some thought to where the fire is likely to occur. For a long tunnel, you will be looking at protection around the TBM. In between the TBM and the pit bottom, possibility only the train and the locomotive are a potential fire source. Bear in mind that for a tunnel fire, the ventilation will drive the smoke out of the tunnel. Self rescuers will also be available, and there may be a requirement to provide stockpiles of selfrescuers along the tunnel, to provide escape to the surface.

Clive French from Alliance Insurance: You mentioned the Fire Brigade has a statutory right or duty to investigate after a fire incident has occurred. How long would such an investigation last after the event has happened?

Dave Bulbrook: that it depends on the complexity of the fire, and that if the fire involves a serious injury or death, the investigation will take longer. It is a very difficult thing to quantify exactly how long the investigation will take; it very much depends on the circumstances of the fire. There is no simple answer to this question.

David Hobson from Jacobs: There has been a lot of work been carried out in London on Crossrail and Tideway developing good fire plans, and looking at the risk assessment. Is there any possibility of getting such plans onto the BTS website so that others can use them as examples of good practice?

Damian McGirr: That this may be a possibility, if the plans are made available.

Top left: The characteristics of a tunnel fire

Top right: A86 Socatop tunnel section showing three layers

Above: A firefighter's breathing and communication equipment

can be prepared and initial plans are in place. This gives the fire crews a vital head start when they arrive at an incident. This should be considered an on-going process where any significant change to access or response facilities should be communicated the service.

The overall responsibility for the rescue does sit ultimately with the brigade's incident commander, but incident management is a team response and the responsible person has an important role to play.

Also vital is how many people are within the tunnel. Increasingly more complicated systems are being used to record the number of people underground. How readily available is this information? Is it kept at a central location? Can it be made immediately available to the incident commander? If lives are at risk it makes a huge difference to decisions the incident commander has to make.

On large contracts, it is a good idea to have one point of contact within the brigade, as the person who will develop fire and rescue policy. On larger projects it is a good thing to have a standardised policy for levels of fire protection, and also controls to be put in place and emergency procedures when dealing with an incident.

Flammables and cylinders present particular issues. The brigade no longer close down large areas of London when a cylinder is alight, but acetylene in particular will lead to an area being closed down, due to the risk of explosion. It is recommended that a tally system is put in place when cylinders are in use, and in the event of an evacuation, to try and get the cylinders out.

One other observation is the human element of barriers between contractors. The brigade will try to overcome these personality issues, but where they cannot, they will escalate the issue to the client. The brigade is always keen to develop good relations.

The fire and rescue services have a national incident command system. The contractor's responsible person will be an equal partner in this system. On arrival, the brigade requires quality information to base their decisions on. This contractor's responsible person should be easily indentified, so the brigade can trust the level of information being supplied. This person then forms part of the brigade's response team.

DONALD LAMONT - ANIMATEUR ITA WG5

There are three things that have to come together to make a fire; oxygen, ignition and fuel. In tunnelling the only thing you can control is the fuel. In a tunnel fire the flames will hit the crown of the tunnel and move along horizontally. A plume of smoke will also travel horizontally. Initially the smoke is hot, buoyant and turbulent. In certain tunnel fire situations there may well be a separation in the tunnel between both smoke and flames in the top half, and fresh in the lower half.

In terms of heat output, it is important to appreciate just how much radiant heat can be generated from a vehicle fire. The heat from a car on fire will be somewhere between 2 and 5MW. A large vehicle fire could generate between 10 and 20MW of heat. You cannot get close enough to this heat source to fight this fire with hand-held extinguishers.

It's not just the radiant heat that you need to look at, but also toxic smoke. In a tunnel environment that toxic smoke will travel along the tunnel, and can affect both your breathing and eyes if you don't have a pair of goggles.

There are lots of fuel sources in tunnels: Vehicle cabs, rubber tyres, hydraulic fluids, lubricants, grease, diesel, hydraulic hoses, cables, lubricants, cables, conveyor systems. They all can burn in the event of a fire.

Good housekeeping is particularly

EN 12336/16191

Clause 5.12 – Fire prevention and protection

- 5.12.1 - Tunnelling machinery shall be designed to avoid the risks of fire (see EN 13478+A1).
- 5.12.2 - All tunnelling machinery shall be equipped with fixed fire extinguishing systems

In terms of heat output it is important to appreciate just how much **radiant heat can be generated** from a vehicle fire

important. Rubbish is fuel. Store it in fire-resistant containers and remove the rubbish as soon as possible.

Electricity at 3.3kV to 11kV has a high potential for sparking to form a source of ignition. Other sources include internal combustion engines, friction, impact, and hot work. Another concern is smoking, which is banned in tunnels, but occasionally traces can be found. Fires do occur underground.

CDM regulations part four sets out requirements for the contractor to take in to account. Designers should also be aware of the requirements, so designs can be tailored to make it easier for the contractor to comply. Reg 38 talks about preventing risk from fire. Reg 39 talks about the need for emergency procedures, Reg 40 the need for emergency egress routes, Reg 41 fire detection and fire fighting requirements.

In terms of the policy from the HSE, fire has low probability but high potential consequence. Fires don't happen very often, but when they do, they have high impact. Fire fight to save life only, don't commit when lives are not a risk. Don't put fire fighter's lives needlessly at risk.

The principal object is prevention of fire occurring; the second objective is not to put lives at risk needlessly.

One of the characteristics of a hydraulic oil fire is the rapid build up of heat and smoke. The tunnel owner should impose a fire risk reduction strategy. All significant items of underground plant, either mechanical or electrical, should have an onboard fixed fire suppression system. You hit the button, and then you go. You don't stay and fight the fire.

Hydraulic oil should be low flammability hydraulic fluid. Note that its fire resistant properties decrease with time. Don't forget the local plant hirers. Make this requirement known to them. It is good practice to run a system where vehicles must be authorised before they are allowed in to tunnels. This may be controlled by the use of vehicle signage.

In terms of European Standards, the current requirement, EN12336 will be replaced by EN16191 in 2013. They both have requirements on fire protection. Tunnel machinery shall be designed to avoid the risk of fire. Also, all machinery shall be equipped with fixed fire suppression systems.

In addition, portable fire extinguishers should be distributed along the TBM, with a water curtain at the rear.

BS 6164, section 13 deals with fire and smoke. 13.4.3 refers to fire extinguisher systems. All underground machinery should have fire extinguisher systems covering engines and tyres. BS 6164 also talks about conveyors (low flammability materials), cables (again low flammability), and electrical systems, which should have fire extinguisher systems.

Section 14 deals with response to emergency: the need for emergency control rooms, rescue capability, communication systems, accounting for underground personnel, alarm systems, self rescuers, refuge chambers and for emergency exercise drills. It's all very well making emergency plans, but they need to be tested in a planned manner.

Refuge chambers have all of a sudden become very popular. There is a clause in BS 6164 and also in EN 16191 but they give relatively little detail on the requirements for chambers. Where the risk assessment shows the refuge chamber to be necessary, then it has to be provided. However the ITA is drafting much more detailed guidance that is due to be published in the spring of 2013. This will explain that the requirement for a refuge chamber will be based upon risk assessment. The presumption will be that you provide a refuge chamber during tunnel construction, unless the risk assessment shows it to be not necessary.

It is to be emphasised that a refuge chamber is not an alternative to escape to the surface. The first preference is escape to the surface. A refuge chamber does not provide protection from fire or flood. It doesn't provide protection against collapse either. It is not a structural chamber.

A benefit of a refuge chamber is accounting for personnel without committing surface personnel entering the toxic atmosphere to carry out a rescue; the personnel are accounted for and are in communication with the surface rescue teams.

There are three operational modes; standby – no incident has occurred, the chamber is unoccupied, but is ready for immediate use; externally supported – an incident has occurred, the chamber is occupied, and the chamber is supplied from a surface air supply, via a tunnel compressed air line. Effectively you then have an infinite supply of breathable air, as long as the surface air supply and the tunnel air line are maintained; standalone mode (the trickiest mode) - an incident has occurred, the chamber is occupied, and external power and/or external air has been disconnected, and now the occupants rely on the chamber for life support.

This includes a breathable atmosphere, air cooling, lighting, communications and water. The ITA guidance will require the refuge chamber to be able to operate for a minimum of 24 hours in this mode.

Refuge chambers are complex to operate, particularly in standalone mode. Personnel could die in the chamber if it is not operated correctly.

The chambers can heat up and the levels of CO and CO2 can build up

■ *Rapporteur: John Corcoran*
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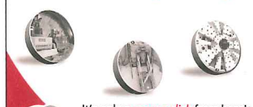

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BRITISH TUNNELLING SOCIETY

What's on

2013

Bauma Munich
15-21 April 2013
Munich, Germany
Back for the 30th time the world's largest construction show, Bauma Munich focuses on all sectors of the construction industry.
www.bauma.de/en

The 12th International Conference "Underground Construction Prague 2013"
22-24 April 2013
Prague, Czech Republic
The ITA-AITES Czech Tunelling Association under the auspices of the ITA-AITES International Tunelling and Underground Space Association is organising UC 2013. The Czech Republic is implementing and preparing significant underground structures.
www.ita-aites.cz/en/conference_underg_constr/conference-uc-2013

Tunnel Expo China
28-30 April 2013
Shanghai, China
The sixth China International Underground Engineering & Tunnel Technology Exhibition will showcase the latest products, cutting-edge technology. It will be held in Shanghai World Expo Exhibition & Convention Center (SWEECC, Formerly Shanghai World Expo Theme Pavilion).
www.chinaexhibition.com

World Tunnel Congress
31 May - 7 June 2013
Geneva, Switzerland
The technical highlight of the conference calendar, the show includes WTC and the 39th ITA General Assembley.
wtc2013.ch

Construction Expo
5-8 June 2013
Sao Paulo, Brazil
Dedicated to both construction and infrastructure, this trade show will represent such sectors as materials, services and equipment providers for industries including roadways, airports, seaports, bridges and metros in a country currently seeing a boom in infrastructure development.
www.constructionexpo.com.br

Strait Crossings Conference
16-19 June 2013
Bergen, Norway
Organised by the Norwegian Public Roads Administration, the focus is on extreme crossings and new technology.
www.sc2013.no

RETC
23-26 June 2013
Washington D.C., USA
The Rapid Excavation and Tunnelling Conference is the largest North American tunnelling show. This year Washington plays host to the show and is expected to attract nearly 2,000 tunnellers from around the country and overseas. Tunnels will have a stand at the show so be sure to find us there.
www.retc.org

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

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

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

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

2014

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

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

British Tunnelling Society

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

Tottenham Court Road Upgrade – Central Line Overbridges
21 March 2013
London Underground's Tottenham Court Road station is currently being upgraded to accommodate projected increases in the passenger numbers. The works include the construction of additional passenger tunnels to improve passenger circulation. The talk will also look at construction methodology.

Tunnel Operators Forum
17-18 April 2013
The twice yearly UK operators forum. Hosted at the IMechEng.

Harding Prize Competition
18 April 2013
The Competition is open to all aged 33 or under at the end of 2012. Entrants submit an original paper relating to any aspect of tunnelling which they consider of interest to those in the tunnelling industry. The evening consists of presentations of shortlisted papers by the authors, following which, the winner will be announced.

Contact us

Jon Young

Nicole Robinson

Alex Conacher

Jim Moore

Head Office

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

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

www.tunnelsonline.info
editor@tunnelsonline.info

Editorial

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

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

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

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

Production

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

Technical Illustrator
Nick Stenning

Sales

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

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

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

Marketing

Marketing Manager
Barbara Carcangiu

BTS - Editorial Advisory Board

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