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INTERNATIONAL EDITION
December 2015

Tunnels AND TUNNELLING

FINISHING TOUCHES

Years of successful tunnelling wrap up on the largest UK project in a generation

\+

Europe

Unexploded Ordnance

Underground Utilities

WOODHEAD PASS TUNNEL

THE UK is contemplating the pros and cons of constructing the world's longest road tunnel. Not yet named, it would be an improvement of the A628 connection between Sheffield and Manchester, located in the Peak District, a hilly National Park in the North of England. A particular part of this 61.5km road traverses the Woodhead Pass, which because of its elevation and exposure, is subject to high winds and snowfall during the winter months.

The tunnel itself (although it could yet be a series of tunnels) is reported to cost of the order of GBP 6bn (USD 9bn), with a bored length of up to 30km. However, the lower estimate of 20km would see it drop below the length of Norway's 24.5km Lærdal Road Tunnel, which opened in 2000. An interim report observed that the diameter of tunnel bores would be limited to 15m by "present day TBM technology". Geology would largely comprise rocks of the Millstone Grit and Pennine Coal Measures groups, and would be relatively consistent throughout study areas (the Woodhead Railway Tunnel can be considered a precursor project in geological terms). In addition, the topography would mean the tunnel would have to relatively deep.

The report, published last month, concluded that more study was needed, and that a more detailed report would be produced late in 2016. It identified the main benefit: the weatherproofing of the route, as well as getting 30 minutes knocked off the current journey time.

The report also uses the phrase 'Northern Powerhouse' a number of times – which is the current buzzword of the Chancellor of the Exchequer's plans to rebalance the UK economy away from London.

More interestingly, a lot of the details of the tunnel are still undecided. One of the findings of the report was that "the development of a combined road and rail corridor through the tunnelled section could offer some additional benefits, although road and rail would need to occupy separate tunnel bores and we have not yet established the operational case for this type of solution".

So this tunnel really could look much different from a single road tunnel when it comes to the final design, and could end up being quite an ambitious scheme if it goes ahead. Even reaching the remote worksite will be a challenge for teams. But the operational concerns may be the most interesting.

A 30km road tunnel goes considerably beyond anything else the world has seen. At this length, engineers will not only have to consider the usual problems of lighting and ventilation, but also driver boredom, claustrophobia, and fatigue. There are tunnels elsewhere in the world that have large cavern lay-bys for rest stops. However, with the volumes of traffic potentially passing through this route, this could be dangerous. Whether subterranean service stations will be required is also a question that will need to be addressed.

One of the final promises of the report was to commission UK-based research into driver behaviour, and a study of other long road tunnels worldwide

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

Alex Conacher
Editor

Cover
In this issue we look back at the succesfull completion of main tunnelling excavation on Crossrail

Next issue
In the next issue of *Tunnels and Tunnelling* we look at the Canadian tunnelling market with reports on curved microtunnel projects in Ontario, as well as the Port Mann water supply tunnel in British Columbia. In addition, we cover base tunnel operations

This month...

20 YEARS AGO

Four contracts worth over USD 200M have been awarded by the Departement d'Ouvrage of the French State Railways for tunnels on the TGV route from Lyons to Marseilles. The 2.4km Tartaiguille Tunnel near Avignon has been awarded to Quillery. It will be excavated using to Eickhoff 110t roadheaders and Montabert jumbos. The specially built roadheaders will be delivered in January to start work in February. BEC is to build the 440m-long Lambesc Tunnel using two Montabert Robofore computerised jumbos. Mining will take place mostly through limestone and marl.
Tunnels and Tunnelling, December 1995, p.9

30 YEARS AGO

An interesting plan has been designed to increase the supply of potable water to Anchorage, Alaska. Instead of executing another lake-tap into the glacier-fed Eklutna Lake about 55km north of Anchorage, water will be diverted from several hundred metres away from the lake, from an existing tunnel. After tapping into the 3m-diameter headrace tunnel of the 30-year-old Eklutna hydroelectric plant, the Hart-Crowser and Associates plan calls for a 3km-long, 2.5m id tunnel to feed water into a buried pipeline. This new tunnel will be dug through dense to hard overconsolidaed glacial soils consisting of silty sands, gravels and clays. With over half the tunnel lying below the water table. The new system is designed to meet water needs for 40 years.
Tunnels and Tunnelling, December 1985, p.13

Above: ***Main tunnel excavation has completed on London's Crossrail project***

Key people in this issue

SIMON COOKE
In his own words, Simon says that 10 years ago he left the relative safety of a well-paying job armed with a question. That question was simple – namely, how can businesses understand and respond to the threat of Unexploded Ordnance (UXO), in a timely and cost effective manner? Now he is at 6-Alpha, an independent consultancy and project management practice that has independent, with no affiliation to any contractor or manufacturer. Simon gave a presentation on UXO to the March meeting of the British Tunnelling Society, the report of which can be found on page 43

KENNY CLEVER
Kenny is the Small Boring Unit (SBU) product manager at the Robbins Company. He is responsible for all product development, sales and product support for Auger Boring Machines, Small Boring Units and Rockheads worldwide and is based out of Solon, Ohio. In this issue he is interviewed by Tunnels and Tunnelling on some of the latest developments and thinking on SBUs, notably working through an extremely small space in congested ground. Muck extraction by vacuum suction instead of an auger is one of the key innovations. The article starts on page 38

TBM REACHES BRANDENBURG GATE

GERMANY — The TBM mining the U5 extension in Berlin has reached its destination. The 6.67m Herrenknecht Mixshield TBM was launched from the Max Engels Forum in June 2013 and reached the Brandenburg Gate in October. The 1,620m-long parallel drives were constructed with overburden ranging from 5 to 17m, and passed underneath the River Spree, Spree Canal, and Schlossplatz.

Ground was heterogeneous soil, comprising fine sands, stones and blocks of granite, boulder clay and high-pressure groundwater. The contractor was Implenia.

To safely pass under the waterways, the contractor originally planned elaborate ballasting work along the banks of the river and canal, using 400mm-thick steel plates. A Herrenknecht spokesman explained the changes in the final works: "[A change in the original plan] has led to a significant improvement in the ability to use Mixshields for tunnel sections with small overburdens: in some stages the machine was driven using a higher density bentonite suspension (HDSM = High Density Support Medium).

"This meant that in comparison to conventional suspensions, with considerably higher transferable support pressure the penetration depth into the soil ahead of the machine was significantly reduced.

"Thanks to the HDSM used (up to 1.4t/m³), [the machine] was able to safely cross under the Spree... large sandbags lowered into the water near the banks provided sufficient weight. Shipping remained unimpaired.

"The modification of the machine for the HDSM drive was already taken into consideration during design, factory assembly and jobsite assembly. During the advance no further alterations were necessary."

Ongoing work for the Berlin U5

Tunnel explosion caused by paint thinner

SOUTH KOREA — A tunnel explosion that injured 21 people in South Korea was caused by a 3.5t truck carrying paint thinner. The incident took place in the Sangju Tunnel in late October, in the southern city of Changwon.

The driver broke late reacting to a traffic jam, causing his truck to lose stability and topple, spilling the flammable cargo on the road surface, before a spark from the truck ignited the fluid.

According to local media, the tunnel was closed for approximately six hours.

The tunnel cameras caught the incident, and footage is available on YouTube: https://goo.gl/BN7vms

Third Crossrail 2 consultation opens

GREAT BRITAIN — A third Crossrail 2 consultation was launched in late October. This one aims to flesh out more detailed plans for the project. The closing date for comments is 8 January. Responses will be considered to shape proposals for the scheme as they develop. A report will be published in spring 2016.

The first took place in summer 2013, and focused on the "principle of the scheme". The second was in 2014 when TfL asked for views on specific route options relating to Hackney, Kensington and Chelsea and an extension to New Southgate.

The Department for Transport also carried out a safeguarding consultation from November 2014 to January 2015. Safeguarding is a formal process undertaken by the Department for Transport to protect land required for major new infrastructure projects.

A spokesman for TfL said, "Feedback from these consultations, together with further scheme design, has helped develop the proposals for this consultation, which presents new information and invites comments on our proposals relating to: station locations, entrances and exits, shaft locations for the tunnelled section of the scheme, the construction sites required to build and operate the tunnelled section of the scheme, proposed service patterns."

The consultation can be found here: https://consultations.tfl.gov.uk/crossrail2/october2015/consultation.

Walsh's Archer Western leads Atlanta upgrade contract

USA — The Metropolitan Atlanta Regional Transit Authority (MARTA) recently signed a USD 198.5M contract to overhaul and upgrade its tunnel ventilation system (TVS), it announced on November 10.

This major improvement project, which is slated to begin in early 2016, further advances the agency's ongoing commitment to safe and efficient transit operations.

Archer Western Construction, LLC is the primary contractor. Cleveland Electric, R. F. Knox, WSP Parsons Brinckerhoff and up to eight Disadvantaged Business Enterprises (seven of which are local) will participate as subcontractors.

The six-year base contract totals USD 165M with an additional USD 33.5M in contract options that include an extended warranty, hardware refresh, and provisions for long-term system operations and maintenance.

MARTA's TVS covers about nine miles (14.5km) of subway tunnel and underground rail stations, roughly one-fifth of the rail system's total footprint. MARTA has identified the renovation and renewal of its aging system as a top priority to maintain optimal functionality and state of good repair.

MARTA's TVS includes a network of fans and dampers that effectively control and direct air flow during normal rail operations and in emergency situations.

"MARTA is ahead of the curve for dedicating a significant portion of its capital improvement budget to upgrading our tunnel ventilation system," said David Springstead, interim assistant general manager of capital programs and development.

"In the transit industry, this is the largest single contract focused on this type of enhancement."

SECOND AVENUE SUBWAY PHASE 11 DELAYED

USA — Tunnelling for the Second Avenue Subway (SAS)'s second phase will not start by 2019. The MTA cut the proposed budget for the project upon approving its next capital program on October 28. The MTA Board approved the 2015 - 2019 USD 26.1bn Capital Program and is still subject to the Capital Programs Review Board's (CPRB) approval. The program, which totals USD 26.1bn, outlines the next five years' worth of vital investments to renew, enhance and expand the MTA network.

MTA reduced the entire program by about USD 3bn, which included USD 1bn in funding for SAS phase 2. Last year's capital proposal called for USD 1.5bn for the tunnel project, and now only USD 535M is allotted.

A spokesman for the authority told local media there will be "visual construction" by the end of 2019, but no tunnelling. The MTA realized it would not secure a TBM by the end of 2019 and have reduced the budget. Tunnelling work would be funded in the next five-year capital plan. There will be a detailed study and environmental review.

Governor Andrew Cuomo, Mayor Bill de Blasio and MTA Chairman Tom Prendergast announced October 10 that an agreement has been reached on the previously remaining funding for the MTA Capital Program. New York State has committed to provide USD 8.3bn, and New York City has committed to provide USD 2.5bn – in addition to USD 11.8bn in MTA funds and USD 6.4bn in federal funds. Cuomo said, "The MTA is the lifeblood of New York, helping millions of people travel throughout the city and the surrounding suburbs, and fueling one of the largest economies on the globe. Our challenge is not only to help the system continue to fuel the region's growth, but to keep up with and respond to that growth as it happens. This MTA Capital Plan is what we need to make the system smarter and more resilient, facilitating major upgrades, expansions and building crucial pieces of equipment so that riders are not forced to accept the failures of outdated infrastructure. This plan will mean a safer, stronger, more reliable transit system for people all over New York, and is crucial in supporting our growing economy. And this program would not have been possible without everyone stepping up to pay their fair share."

First work train traverses the Second Avenue Subway line in New York, USA

Warsaw extension awarded to Astaldi

POLAND — The Astaldi Group has been awarded a EUR 209M (USD 228.75M) contract to extend Line 2 of the Warsaw metro in Poland, the group announced 2 November.

This comes on the heels of Astaldi's construction of the same line's central section, work it completed in March. The new contract calls for the executive design and the construction of the route's eastern section for a total of approximately 3km, from the Dworzec Wilenski Station to the stabling tracks past Station C-18, featuring twin-tube tunnels and three stations.

The tunnels are to be excavated using the two TBMs that have already been employed for the boring of the first section of the line, which allow the tunnels to be bored even as they are equipped for the passage of trains. The contract also calls for building the link with the line's central section, as well as the civil and railway systems, superstructure, and all related works. The works are planned to be completed in 36 months, beginning in early 2016.

Underground space group formed in UK

GREAT BRITAIN — A new group for the intelligent use of underground space has been formed in London. Billing itself as the 'Multi-disciplinary Activity Group for the Use of Underground Space' (Mag2us), it has held two meetings since its formation in September.

Provisional aims of the group, prior to the second meeting, were given as:

- Creation of a 'Use of Underground Space' manifesto, for local authority planning departments and other relevant organisations to help them to make decisions when dealing with underground space
- Round table discussions and workshops between disciplines
- Improve cooperation between disciplines that care about the use of underground space
- Organise lectures and visits
- Stop the 'first come, first served' approach to depleting underground resources
- Create a three-dimensional spatial planning strategy

To launch the group, members of ITACUS, as well as ITA WG 20: Urban Problems, Underground Solutions, convened in London to speak with representatives of the BTS, BTSYM, ITA, ITAYM, the All-Party Parliamentary Group on Infrastructure, Urben (a London based urban planning and design studio), and the British Geological Survey.

The second meeting was due to occur as Tunnels and Tunnelling went to press, so details are unavailable, although the manifesto (or 'position paper') is expected to be released shortly.

ITAYM vice chair Petr Salak explained the justification for the group: "A lot of parties agreed that Mag2us is needed as disciplines do not talk to each other. As this group involves a lot of different parties, it has the potential to really change how we deal with underground space."

Mag2us will focus on the needs of the UK, providing a bridge that international underground space groups would struggle to cross. It will assist underground planning by showing how things can and should be done, give examples of good practice, and suggest improvements in legislation, as well as lobbying.

To mark the formation of the group, a visit to London Underground's disused Down Street Station was arranged with the support of London Underground. Attendees were encouraged to consider the potential uses for existing underground space such as Down Street, which was a useful base of transport operations during the Second World War.

WOJTASIK SUCCEEDS O'MURCHU AS BTSYM CHAIRMAN

GREAT BRITAIN — Mateusz Wojtasik has succeeded Eoin O'Murchu as chair of the British Tunnelling Society Young Members (BTSYM). The handover took place at the group's AGM on 10 November at the Institution of Civil Engineers in London.

Looking back on his time as chair O'Murchu, who works as a senior consultant for IBM, highlighted the tenfold growth of paid BTSYM membership over the last year. This was helped in no small part by the success of the BTSYM Conference, which boasted 100 graduate attendees. O'Murchu's tenure has also seen the group spread beyond London, with attention given to the Midlands and Scotland.

Wojtasik, a geotechnical engineer for Donaldson Associates, has the task of taking the BTSYM forward through the next year. He identified the lack of contractors in the group as something he would like to change in 2016. In addition, BTSYM activities in Scotland will be a focus, as well as relationships with other societies, university representatives, and a new poster competition to showcase the career achievements and ideas of young members.

As Tunnels and Tunnelling goes to press the group is excited for the upcoming UK National Tunnelling Day [3 December – watch this space] during which it hopes, according to a BTSYM statement, to "generate interest in the great number of world class tunnelling projects currently being undertaken in the UK and to promote the industry (and its many professions) to young people and students of all ages. The National Tunnelling Day will become an annual event on the first Thursday of December. It was chosen due to its proximity to the Feast Day of St. Barbara, traditionally seen as the Patron Saint of Tunnellers."

ITAYM leadership reflects on 2015

INTERNATIONAL — The past year has been successful, but not flawless start for the fledgling International Tunnelling Association Young Members (ITAYM). According to a spokesman, one challenge that surprised the group has been the continuing delay in some of the larger countries forming Young Member groups. Italy, Germany and Spain stand out among these as they have a long history and culture of tunnelling.

Another, albeit expected challenge is the high cost of conferences and other official events that ITAYM would like to see addressed to make it easier for young members to attend.

Still, WTC 2015 was a great success for the group, which stated: "The main feedback was just to keep the passion and momentum going and the sky is the limit for Young Members involved in tunnelling worldwide."

Two new Member Nation Representatives joined the group, from Poland and Singapore respectively, and now the focus is on 2016. "The main aim is still to develop the ITAYM internationally and find ways to get as many countries and individuals to contribute to ITAYM. In addition we now want to focus more on integration with the ITA, especially ITACUS and ITACET. In the near future, we would like to see this move into cooperation with all committees and working groups. It will be one of the Steering Board's greatest challenges to identify the needs [of young tunnellers] and make sure its work is relevant. We will encourage young and enthusiastic people to participate both domestically and internationally [...] and we want to make sure age distribution is more balanced in ITA work."

WTC 2016 will be a key moment for the ITAYM. A fresh steering board will be elected, and a past-chair position created to ease the transition.

Akron breaks ground on OCIT projects

USA — The City of Akron began work on the Ohio Canal Interceptor Tunnel (OCIT) – the largest component of the city's court-ordered Long Term Control Plan – with a groundbreaking ceremony on 6 November on the banks of the Little Cuyahoga River.

The city said, of the more than 770 cities nationwide remediating CSOs under the supervision of the U.S. EPA and federal courts, Akron's Long Term Control Plan is the most stringent in the nation. The Consent Decree was entered by the Federal Court in early 2014 at a price tag of USD 1.4bn (escalated).

The OCIT will have a 27ft (8.2m) finished inside diameter and will be 6,240ft long (1,902m). It will begin at the Little Cuyahoga River north of the Mustill Store on the Ohio & Erie Canal Towpath, and extend to Lock 1 of the canal at West Exchange Street in Downtown Akron. The tunnel will control combined sewer overflow at nine separate locations, and will store more than 25 million gallons of combined sewer overflow.

The City has awarded the tunnel construction contract to Kenny/Obayashi JV in august. "Their bid – well below our estimate– gives the City a formidable team to complete this intricate, yet massive, tunnel project," said Fusco. The City Engineer's estimate for the project was USD 252,212,193 and the accepted bid is USD 67M under that. The tunnel is scheduled to be in operation by 31 December 2018.

Phil Montgomery, Akron's Deputy Service Director, said Akron's machine will be named "Rosie." The nomination from Ellet resident Michael Flynn recognizes Mary Rose Jacob and the hundreds of other "Rosies" that worked at Akron's rubber factories during World War II, who turned out material and armaments for the allied effort. TBM launch is expected in 2017.

Toyo Tunnel awarded

COLOMBIA — The Government of Antioquia in Colombia awarded the contract for the design, construction, operation and maintenance of the Toyo tunnel in the Urabá Port to a consortium led by FCC's Citizen Services Group (with a 40 per cent share) and a group of local businesspeople (with the remaining 60 per cent). The contract is worth EUR 392M (USD 429M).

The project, consists of building a completely new road section, 40.84km long in two directions with one lane in each, although there will also be a dual carriageway section with two lanes in each direction. This section will pass through the mountains of western Antioquia, in an area that is difficult to access. This includes 12.3km of tunnels, 9.8km of which will make up the Toyo tunnel. Once complete, this infrastructure will be the longest of its kind in Colombia. The project, located approximately 80km from Medellín, is to be fully executed over 10 years, six of which will be dedicated to the construction phase and two and a half to operation and maintenance. The rest of the time will be spent on the design phase and any necessary pre-construction work.

Other large international infrastructure groups also took part in the tender process.

EURO VISION

The scale and ambition of tunnelling projects in Europe continue to push boundaries. **Keren Fallwell** reports

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

OVER THE past two decades the European tunnelling market has strengthened and expanded, both in the number of projects and technical capabilities.

Although activity in southern Europe has slowed as a result of the recent global economic recession and the Eurozone uncertainty, projects in northern Europe are forging ahead.

In fact, according to BTS chairman and Balfour Beatty tunnelling manager Roger Bridge, it's probably the best it's ever been, in the UK at least.

Ian Gee, director, ground engineering at Atkins, agrees. "These are upbeat and exciting times. We're very excited about what's happening and what's on the drawing board," he says.

Jordi Ferrando Cuadradas, FCC Construction's managing director for Europe, is equally positive. "Infrastructure investment in Europe may still be down on pre-crisis levels but there are a number of high-profile tunnelling projects planned, under way and recently completed that give good reason to be optimistic," he says.

One of the main drivers for tunnelling activity is transport.

Czech Tunnelling Association chairman Ivan Hrdina says that road and rail projects in the EU-15 this year had an estimated value of USD 1.43 trillion. Of that, tunnels and bridges accounted for USD 226bn, and trams and metros USD 95.6bn.

These transport projects are motivated by a need to mitigate the environmental and economic implications of traffic congestion, and the EU's ambition to improve transport connections across the continent.

"With increasing connectivity high up on the EU agenda, tunnelling is playing a big role," says Ferrando.

Some of the projects already under way include the Gotthard Base Tunnel in Switzerland, which will be the world's longest and deepest traffic tunnel when it opens next year, and the Brenner Base Tunnel, the world's second longest tunnel running 55km from Austria to Italy, is scheduled for completion in 2026. Both tunnels are part of the European Commission's Trans-European Transport Network (TEN-T). Aimed at helping to transform the way goods and people move within the EU, the TEN-T will involve the construction of around 2,100km of tunnels in Europe by 2030. The ambitious

***Below:** A seismic joint on the Eurasia Tunnel project in Turkey.* *See feature, p.16*

19km submerged Fehmarn Tunnel, connecting Denmark and Germany under the Baltic Sea, is also part of the network.

FORGING LINKS

Cowi's Chief Specialist Søren Degn Eskesen, who is also the current ITA president, points out that the EU is also prioritising cross-border projects that are part of the United Nations' E20 route which aims to establish transport connections across Europe.

However, he added that challenges of working across borders remain.

"Standards have to be matched. If you're building a railway line you may have different electrical systems so you have to switch from one to another," he says. "There are also different approval processes and environmental requirements. The whole planning and approval process takes longer because you have two national bodies involved."

In addition to the construction of new tunnels, there are many projects upgrading existing road tunnels, especially in the

alpine regions of Austria, Switzerland and northern Italy.

"More than 1,000km of tunnels will have been built for that purpose by 2020," says Eskesen.

To address congestion in some of Europe's large cities, several metro projects are under way.

These include the Grand Paris Express, Copenhagen's Metro City circle line, and the city railway line in Stockholm. The Grand Paris Express is an ambitious project to provide France's capital city with more than 205km of new rail network. The scheme, which combines two projects planned earlier, comprises four new lines and the extension of two existing lines. It will be built in six phases scheduled for commissioning between 2020 and 2030.

Copenhagen's new circle line is a 15.5km twin tunnel route that will, as the name suggests, add a circular transport route around the city, connecting with the existing M1 and M2 metro lines at Frederiksberg and Kongens Nytorv stations. The new system, which is due to open in 2018, will have 17 new stations.

***Above:** Site personnel celebrate the Eurasia Tunnl breakthrough*

***Top:** Workers in a completed section of Crossrail SCL-lined tunnel*

In Sweden, the USD 2.4bn Stockholm City Line, or Citybanan, comprises a 6km-long double rail track, a parallel tunnel and two underground stations. The line, which is scheduled to open in 2017, is the largest investment in Stockholm's rail system since 1950.

In recent years much of Norway's tunnelling work has concentrated on hydro power projects but it is now changing the focus to transport.

"Norway is sitting on a fairly good cash account so it's going to start spending. They want to invest in non-oil and gas infrastructure in a way they haven't done in the past," says Gee. "It's a little bit more prosaic in that it was affected by the downturn but it has particular problems and development objectives which it's trying to resolve with extensions to various schemes such as light rail, metro, have rail, ERTMS and signalling on the heavy rail network."

In March, the joint venture of Acciona Infraestructuras and Ghella was awarded the main tunnel contract for the Follo line, Norway's largest railway contract to date. The 20km, twin tunnel, linking Oslo and Ski, to the south of the capital, is currently the largest infrastructure project in Norway and will be the longest rail tunnel in the Nordic countries. The order for four TBMs has been placed with Herrenknecht and boring will start at the end of next year, following the initial drill and blast phase.

Norway also has long-held plans to develop transport connections along the length of the west coast which involves 1,500km of road and, according to Eskesen, "plenty of tunnels and fjord crossings".

In various European countries tunnels are also being built for flood control

and water stores to deal with the higher rainfall expected as a result of climate change.

"This will generate more projects in the future," says Eskesen, citing 100 small projects planned in Copenhagen alone.

In the UK there is a "slight lull" in terms of site work, says Bridge, as the TBMs have finished on Crossrail and the Bond Street upgrade is coming to an end but there are plenty of projects due to start soon, or in the advanced planning stages.

*Above: **Lifting the Eurasia Tunnel cutterhead***

*Top: **Crossrail's Farringdon Station tunnels***

"We're probably facing the busiest workload we've had for a long time," he says.

UK projects include Shieldhall, Scottish Water's £100m, 3.1 mile-long waste water tunnel in the south of Glasgow, part of the biggest upgrade of the city's waste water network in more than a century; London's major new sewer, Thames Tideway; High-Speed 2; Crossrail 2; London Underground station upgrades; the Northern Line extension to Battersea; the proposed southern extension to the Bakerloo Line; and the lower Thames crossing at Silvertown.

In northern England, the York Potash mine has been granted approval. It will be the first potash mine to be built in the UK for 40 years and will include a 37.5km mineral transport tunnel to carry the polyhalite from the mine near Whitby to the handling facility at Teesside. The long-talked about tunnel under Stonehenge is also being discussed again.

In addition, there is what Bridge calls "the backbone" of smaller projects that are often overlooked.

"People talk about the big schemes but going on day to day are the utility, below the radar projects. They're the backbone that keep things ticking over," he says.

HEADING SOUTH

While the tunnels market is buoyant in northern Europe and the UK, the global financial crisis and uncertainty in the Eurozone have taken their toll in some countries and, as a consequence, on some projects. Eskesen says the Lyon ring road project would have made better progress if it were not for the financial crisis. The road, designed to reduce congestion on the two highways that run through the centre of France's third largest city, has never been completed on the western side.

Projects in countries such as Spain and Ireland, which in the past benefited from large sums of EU funding, have also fallen victim to the financial downturn. In Dublin, the two-line metro and the EUR 4bn (USD 4.3bn) DART underground – the latter involving 7.6km of twin tunnels – have been put on ice and Gee doubts they will be realised in the next five to 10 years.

"There was a great enthusiasm for those capital projects in the heydey of European investment in that country but that's stopped. The Irish economy is starting to turn around and there are a couple of tunnelling schemes coming up in water supply and waste water in Dublin but the really major tunnelling projects are mired at the moment," he says.

As some markets have slowed, especially in southern Europe, more companies are now looking for work in northern Europe, especially in the busy Scandinavian region. The result is a more competitive market.

"Norway has invited them to come because they have so many projects and they want to have a competitive tendering process," says Eskesen. Many Italian and Spanish contractors are entering the market and Copenhagen's Circle Line is being built by "mainly Italian contractors", he added.

LABOUR GAP

All this work in Europe going on at the same time as there are large projects in the Middle East and across the globe raises the question of whether the industry has the labour resources and expertise available to match the demand.

"The issue is engineering resources and the mobility of people to deliver these projects," says Gee.

"Some clients in the UK who traditionally think it's someone else's problem are starting to think about engineering resources and the amount of work being programmed. It's giving some concerns for capacity although contractors will invariably say 'it's not a problem; we will deliver it'. Yes, it might be delivered, but I think an acute demand for skills will develop between 2016-2017, particularly in the UK."

Roger Bridge also acknowledges the potential pressure on labour and skills but says historically the industry has managed the peaks and troughs of work. With commodities markets declining mining engineers would be available for work, and contractors and clients would also need to work together "on reasonable expectations for competency".

"It would be very easy for a client to be quite demanding on the competencies of the workforce and find it very difficult to achieve," says Bridge. "On some jobs all sprayers have to be EFNARC accredited. That takes three years so if you bring in trainees they can't spray shotcrete on that project. It's balances like that that have to be achieved and considered in a reasonable manner."

The long bidding and development process for these major projects slows down the tunnelling sector, says Ferrando, although it is not surprising, given the scale of investment required – and there are rewards.

"On the back of Crossrail, projects like HS2 and Thames Tideway will require huge amounts of expertise to deliver and they represent a healthy pipeline for the UK market."

Many of the projects in the starting blocks will push new boundaries and tackling these is helped by industry collaboration and lessons learned from previous jobs.

"Collaboration has almost become the norm. Projects are now larger and there's an expectation that most projects of GBP 100m-plus will be delivered by a joint venture," says Gee.

"In terms of developing the state-of-the-art there are specifics in terms of technology but a lot of it comes from a body of knowledge and experience vested in individual companies. You only have to look at the people queuing up for the large amount of work in the UK – it's everyone under the sun."

In learning from past projects, Eskesen believes the industry has not only honed its technical abilities but it is also better at managing risks.

The ITA has several committees working on technical guidelines in order to have new ideas accepted by the market more quickly and Eskesen expects technical advances to continue.

"We are now building tunnels that we wouldn't have been able to years ago," says Eskesen. "Nearly every year we see a new record in terms of diameter or links or depths of tunnelling projects, and I think it will continue."

He says the Fehmarn Tunnel will "definitely break a new record and be technically challenging".

Gee identifies the Follo line as a potential game-changer for tunnelling in northern Europe.

"It's introducing hard rock TBM technology to a market that's more familiar with drill and blast," he says. "I think the client decided he wants an international standard railway with a segmentally lined bored running tunnel. It's ruffled a few feathers in the market by choosing that as opposed to what is northern European custom and practice of unlined hard rock tunnels."

The demands of working at high pressure will also drive innovation, says Gee. "Thames Tideway has attracted the sort of contractors who can work at unusually high pressures of ground water, in deep tunnels in pretty demanding circumstances. I think there will be a lot more of that," he says. "I think the potential demands of working in excess of 3-4 bars pressure will continue to drive innovation."

Every project has its challenges and "if they were easy they would have been done before", says Bridge, and the next phase of UK tunnels will be no exception. "Work in and under London is always challenging with the structures you have to interact with and the ever-growing use of the underground space. It will be an interesting challenge if there's an overlap in projects – the Northern Line extension, Thames Tideway, Silvertown. If they're all trying to use river resources then the logistical support of those schemes will create a challenge," he says.

Outside London HS2 will also present logistics issues with the length of some of the tunnels and the challenges of working on rural sites. While none of them will be an easy project, says Bridge, they will receive their "fair and due attention and the problems will be overcome" and they are indicative of the healthy appetite for infrastructure and tunnelling. "It's a good time to be a tunneller," he says

STRAIT TALKING

The Eurasia Tunnel under the Bosphorus is a major engineering feat and a symbolic milestone. **Keren Fallwell** reports

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

WHEN THE TBM on Turkey's Eurasia Tunnel broke through on 22 August there was double cause for celebration.

Not only did it mark the moment that the two continents of Europe and Asia were joined by a road tunnel for the first time, it was also the crowning achievement for one of the world's most challenging tunnelling projects.

Boring the tunnel, which runs across the south-eastern end of the Bosphorus strait, linking Kazlicesme on the European side of Istanbul with Goztepe in Asia, involved working at nearly 12 bar of water pressure in fractured rock and soft ground.

And making it even more remarkable is that it will be completed and opened ahead of schedule.

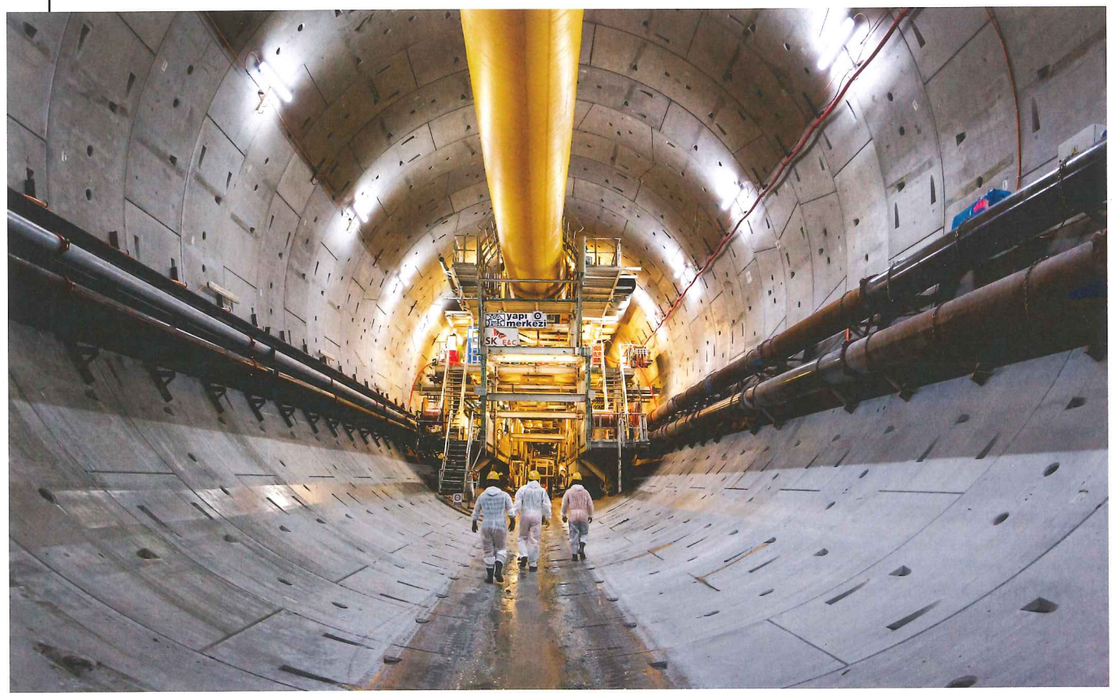
Located about 1.5km south of the Marmaray subsea rail tunnel, which opened in 2013, the 5.4km-long twin-deck Eurasia Tunnel will reduce the journey time between the two continents from 100 minutes to just 15 minutes and ease the pressure on the two existing bridge crossings further north.

It will have two lanes on each deck, a toll plaza and an administrative building on the western side and ventilation shafts at each end. The tunnel is part of a 14.6km route which will carry an average of around 100,000 cars and light vehicles a day, providing an additional 20 per cent capacity across the Bosphorus and aiming to reduce Istanbul's notorious congestion. In this year's Tom Tom Traffic Index Istanbul topped the congestion list of 146 countries, with a 30-minute commute taking around an hour, adding an extra 110 hours a year to the time people spend in their cars. The survey found the congestion level on highways was 79 per cent, and 50 per cent on non-highways.

The TBM named Yildirim (meaning lightning in English) began boring the 3.4km subsea section on the Asian side of the waterway and at its deepest it was 106m below sea level and never less than 26m. The maximum depth of the seabed is 62m along the route of the tunnel.

Project summary

- **Tunnel length:** 5.4km
- **Excavation diameter:** 13.71m
- **Inner diameter:** 12m
- **TBM length:** 120m
- **Contractor:** Avrasya Tüneli Isletme Insaat (ATAS)



The excavation diameter was 13.71m, allowing an inner diameter of 12m with a 600mm-thick lining – making it the sixth largest diameter tunnel in the world.

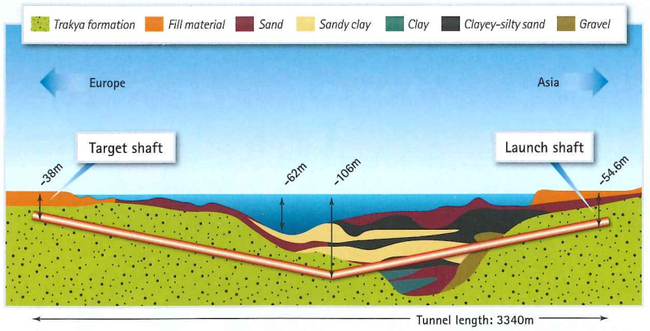
NATM and cut and cover were used along 1km of the connection tunnel sections on each side of the sea crossing. The Asian side transition box, allowing for the parallel traffic to be stacked in double-deck configuration to enter the TBM tunnel, provided the launch shaft for the 120m-long TBM, while the longer cut cover section on the European side provided the machine's retrieval.

In addition to building the tunnel, the project has involved widening the approach roads on both sides, constructing bridging intersections, an overpass and a total of 10 pedestrian crossings.

Despite the complexities of the tunnel crossing, Basar Arioglu, chairman of Avrasya Tüneli Isletme Insaat (ATAS), the joint venture between Turkey's Yapi Merkezi (leader) and Korea's SK Engineering & Construction, says a bridge across the strait at this point was never an option.

***Above:** Location of the tunnel relative to the Marmaray project*

***Below:** Geological section of the tunnel alignment (not to scale)*



"A bridge would have obstructed the view of the historical city when entering Istanbul by boat. No-one wanted to build a bridge there," he says.

Going under, rather than over, the stretch of water that connects the Black Sea to the small Sea of Marmara and the Mediterranean, has entailed dealing with the extremes of fractured rock – the Trakya Formation – on either side of the channel and soft, marine sediments in the centre section.

"It was very complex geology. About every 50m we hit rocks with volcanic intrusions essentially shooting up from below," says Arioglu.

To cope with these two extremes of hard rock and soft sediment, and the high pressure, Herrenknecht supplied a mixshield (slurry) TBM.

The face had both hard rock disc cutters, mounted on six radial arms, scrapers and buckets and openings between for supply support and spoil removal.

Atmospheric pressure was maintained for the working conditions inside the TBM, and a key element of this was the changing of the disc cutters through accessible cutterhead technology.

"We used a sophisticated system to

allow the disc changing directly from within the cutter arms at atmospheric pressure," says Werner Burger, head of engineering at Herrenknecht.

The design approach was first used on a machine in Hamburg but not one of this size or at this depth. The 19in double-edge discs were removed from the face, along with their housing, and a new cutter-housing unit was installed, all without losing pressure. The operation took about two to three hours – a huge time-saving compared with the days it would have taken for divers to complete the same task.

Arioglu estimates that during the TBM's operation the discs were changed more than 400 times and the scrapers more than 200. Arioglu believes this technology will become a 'must-have' on big TBMs in the future.

Carrying out hyperbaric intervention at this pressure is also problematic and fortunately only three were required, the shortest lasting one day and the longest 10 days.

"Because of the high pressure it's hard to do any intervention at the front of the machine but we did it three times, one at 10.8 bar pressure," says Arioglu. "Our team and our machine were well prepared for this kind of operation and as a result the interventions were very quick and very safe."

For these operations, the railway that transports the carrying trolley and lifting equipment for the disc cutters was also used to move a diving pressurized transfer shuttle into place. The pressurised shuttle fitted onto an airlock at the top of the bulkhead, lifted up by a scissor platform at the end of the rail. Prior to the intervention the saturation divers entered the pressurised living chamber on the surface where they compressed to 9 bar pressure before entering the pressurised shuttle and transferring to the TBM. After they finished their daily work inside the slurry chamber of the TBM, the divers returned to the pressurised living chamber and rested until the next working day. This cycle had to be repeated for every working day between the surface and TBM. Once the intervention was completed, the divers entered a decompression phase in the living chamber where they had to remain for up to 10 days after a dive. Sometimes two teams of divers were used, each working around seven hours at a time.

Finance model

Not only has the Eurasia Tunnel pioneered technical developments, it was also the first time a private company in Turkey had received a loan from the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD).

The project has used a build-operate-transfer model to bring together private investment and project experience with the support of international financial institutions.

In 2008 Turkish contractor Yapi Merkezi (leader) and Korean contractor SK Engineering & Construction formed the ATAS, a special purpose company for the investment with 50-50 shares. The same companies formed the YMSK joint venture with 52 per cent and 48 per cent shares respectively to build the project as contractor. ATAS will also be responsible for the tunnel's operation and maintenance for just under 26 years. After that period, the facility will pass to the Ministry of Transportation.

The project has a total cost of USD 1.245bn. YM and SK are investing USD 285m as equity and a USD 960m, 18-year loan has been underwritten by the EIB and EBRD, the Korean Exim Bank and Korean Export Insurance Agency, and commercial banks Standard Chartered, Sumitomo Mitsui Banking Corporation, Mizuho Bank, Garanti Bankasi, Türkiye Is Bankasi, Yapi Kredi Bankasi and Deutsche Bank.

Another first for the project was a disc cutter monitoring system in the TBM's control cabin. Designed by VMT, the system measured key values such as rotation and temperature. The results were displayed on a screen where healthy units were shown in green and abnormal discs as a yellow or red alert.

Arioglu says this feature also proved its worth. "When we saw the cutterhead coming out after the breakthrough, it was almost intact and worn uniformly," he says.

Another feature on the TBM was extra 'chisel' grill bars across the slurry openings in the face. These allowed for the heavily fractured quality of the Trakya Formation which meant large blocks coming away from the face. The large blocks were kept in front of the cutting wheel until the TBM action reduced their size sufficiently to allow them through the spoil grill into the jaw crusher and then the slurry line to the surface.

The TBM, launched in April last year, made average daily progress of 7m, installing 600mm-thick lining segments behind it. The five per cent incline of the alignment was another challenge, especially considering the heaviest of the segments weighed 15 tonnes, but Arioglu says the operation went without incident.

"The lining segments were carried into the tunnel on an MSV – fully loaded carrying 130 tonnes. The machine carried very heavy segments safely and without any accidents," he says.

While the varying geology was a challenge, another was the tunnel's proximity to the North Anatolian fault line. The tunnel is designed to withstand a 7.5 (moment) magnitude earthquake and to mitigate movement two rubber and steel seismic joints, manufactured by Japanese company SEIBU, have been installed in the lining at the transition from hard rock to the soft sedimentary deposits on either side of the tunnel. The joints were installed by the segment erector and temporary supports were required to ensure that the huge forces pushed by the TBM did not compress the joint. The seismic connections allow movement of 75mm in contraction, 75mm in expansion and 50mm shear.

"The joints ensure watertightness but also give the lining the flexibility in the transverse and longitudinal directions," says Arioglu. Fireproofing will be applied on the tunnel segments. Emergency stairs are located every 200m along the tunnel and they are accessible through fireproof emergency rooms, equipped with CCTV monitoring for those unable to use stairs. Safety lanes are positioned at 600m intervals for breakdowns in the tunnel. The upper deck of the tunnel was the first to go in, cast in situ behind the TBM and advancing around 12m a day, while the lower deck is being manufactured offsite and will be installed at a rate of around 100m a day.

Despite the challenges the project has faced – the complex geology, the high atmospheric pressure, the hyperbaric interventions, and the difficulties involved in building infrastructure in a large, densely populated, working city – the TBM broke through two weeks ahead of the 72-weeks programmed.

The tunnel is expected to open in December 2016, three months earlier than the original opening date of March 2017.

The ability to change the discs inside the cutterhead and the success of the hyperbaric interventions helped operations but Arioglu also attributes much of the smooth-running of the project to the planning afforded by the long lead-in time.

"The joint venture was awarded the project in 2008 and the finances were agreed in March 2013 so we had more than four years to prepare," says Arioglu. "Four months after the finances were agreed I was in Germany taking over the TBM, which had been ordered even before the financial closure. We took some risks but they, and all the preparation, paid off"

Next step

Months before the TBM broke through on the Eurasia Tunnel, Turkey's Prime Minister Ahmet Davutoglu announced plans for another ambitious tunnel under the Bosphorus, the 6.5km Grand Istanbul Tunnel – a three-level structure – said to be the world's first – for road and rail.

The 6.5km-long, 16.8m-diameter will also be a PPP project and a build-operate-transfer model.

The USD 3.5bn tunnel is expected to be completed by 2020.

***Right:** Artists concept of the operational tunnel*

Winning project

Even before the Eurasia Tunnel has opened it has been stacking up awards. The project's finance arrangement has certainly been attracting interest. In 2012 the project won Euromoney's European Deal of the Year Award for its finance arrangement. The award recognises outstanding investment deals in terms of diligence, effectiveness, innovation and scale.

In the same year it won EMEA Finance magazine's award for the best public-private partnership and Infrastructure Journal's Deal of the Year – Transport.

In May this year it received another accolade when the tunnel project's sustainability practices were recognised through the European Bank for Reconstruction and Development's Environmental and Social Best Practice Award. The project was chosen ahead of 27 other candidates.

Seok Jae Seo, general manager of ATAS JV, said a holistic and sustainable approach had been employed since day one of the project. "This holistic approach considers and cares for all aspects including technical, environmental, social and safety, as well as the benefits of all stakeholders, especially the citizens of Istanbul. We aim to build a long-term sustainable asset for Turkey," he said.

The project has now been shortlisted in the Major Project of the Year (more than EUR 500M) category in this year's ITA Tunnelling Awards.

A CROSSRAIL MILESTONE

Sally Spencer
Sally joins the Tunnels and Tunnelling team as a contributing editor this year

Project managers **Roger Mears** and **Greg Reichmann** look back on three years of successful tunnelling at Crossrail. **Sally Spencer** reports

EUROPE'S LARGEST infrastructure project, Crossrail, is moving closer to its phased opening in May 2017, leading up to full opening in December 2018.

When that happens, Crossrail will connect Reading and Heathrow in the west with Shenfield and Abbey Wood in the east. Crossrail will add 10 per cent capacity to London's rail network, will serve 40 stations – 10 of which will be new – and will carry an estimated 200 million passengers each year.

This monumental project will have a profound effect on the way millions of people visit or transit through London every day, so it's all the more remarkable that, for the average man or woman in the average street in the UK, it's been pretty invisible.

There are exceptions, of course. In 2014 an excellent three-part BBC documentary profiled the project and some of the individuals working on it. And earlier this year the Prime Minister David Cameron and Mayor of London Boris Johnson featured in the news as they celebrated the completion of tunnelling following the final breakthrough at Farringdon station.

The fact that this huge endeavour has caused relatively few ripples is a great source of pride to the teams responsible for its construction, particularly as asset protection has been at the top of the agenda.

Roger Mears, project manager for the C305 eastern running tunnels contract and Greg Reichmann, project manager for the C300/410 western running tunnels, agree that third party asset protection both above and below ground has been fundamental to Crossrail's success.

Among the many infrastructure obstacles thrown up, Mears cites having to tunnel under the Canning Town viaduct as an example. Here, the Dragados Sisk joint venture (DSJV) implemented a very sophisticated system of jacking and monitoring to compensate for ground movement.

Existing utilities also posed significant challenges: "We've bypassed a number of large diameter sewers by a very few metres so we've had to carry out sewer lining operations, which are challenging scopes of works in their own right," said Mears. "Trying to agree what the nature of the mitigation is and then installing it ahead of the TBM passage generates a whole new package of works."

Further west, concerns from "a very important stakeholder" were of an altogether more cultural tone.

"We tunnelled under the Barbican Centre and they were very concerned about the noise impact on their concert halls from both the tunnelling and the subsequent railway operations," said Mears.

"They were quite nervous during the days, weeks and months prior to us tunnelling under, so much so that we understood when the New York Philharmonic Orchestra was going to start performing. Their fear was that concert goers would be able to hear the underlying rumblings of a huge TBM in the gaps between the beats in the music, which would be a terrible disruption."

The team was so confident that noise would be minimal that, in fact, the programme of works wasn't altered. "What we did do was change to a different type of track bed both for the construction railway laid behind the TBM and for the permanent works," said Mears. "A section of track slab will be on bearings which will damp down any vibration and prevent noise from the railway operations.

"For C305 we built the full track bed and the construction railway as we tunnelled and used a different sleeper design and we've had no complaints

from the Barbican Centre throughout our works."

Quite the opposite, in fact. The Barbican Centre was so impressed with Crossrail they commissioned their own artwork to mark the passing of the TBM underneath the estate (this can be viewed at http://blog.barbican.org.uk/2015/04/pipe-dreams).

Underneath the western running tunnels the infrastructure included 18th century wells at Tottenham Court Road and Bond Street stations. "If they had been charged with water and been in a slightly different location they could have been a really big issue from a structural stability point of view," said Reichmann.

"But our processes and tunnelling excavation sequences and methods take account of those types of obstacles and we only go forward at 1-1.5m at a time in those advances so that, if we do come across something, we haven't suddenly exposed a large section of unsupported ground."

Culturally significant buildings are very thick on the ground in this part of London. In Soho Square, for example, one of the capital's oldest buildings, the Grade 1 listed House of St Barnabas, had to be closely monitored for ground settlement. And access for vintage cars worth many hundreds of thousands of pounds had to be maintained at Bonham's auction house in New Bond Street.

Both of these challenges were highlighted by the BBC documentary – as was the captivating tale of 'the eye of the needle' at Tottenham Court Road station where the Northern Line and Central Line of the London Underground intersect. Crossrail needed to link to this hub and negotiate sewers, pipes, cables, the Northern Line platforms and two escalators. The only option was to drive the 900 tonne TBM 850mm above the live running tube line and 350mm below the escalators.

*Above: **Completion of Stepney Green SCL cavern***

*Above: **Break through at Farringdon by Elizabeth***

However, Reichmann and Mears are modest about these more publicised achievements.

"The Tottenham Court Road location was tighter than you would want but in terms of managing the TBMs alignment to get it to where you wanted it to be within normal tolerances, the guys have got the competence to do that," said Mears. "They are able to steer the TBM very precisely, assuming the laser surveying technology works – which it has done."

"The BBC picked up on the things they could dramatise easily but there were so many smaller white knuckle moments that didn't come with the same drama to other stakeholders," added Reichmann.

"There were things like getting a Thames Water main monitored and secured before a TBM went under it, or getting the approvals from external stakeholders and asset owners before we started excavation of a new section of tunnel. Those one-off interfaces are very intensive in terms of the amount of time and human capital spent on trying to resolve issues.

"And working in the middle of Mayfair, where you have residents and businesses to keep happy is a challenge because the residents don't want you working at night and the businesses don't want you working during the day, so we've had to employ practical means to make sure we don't impact either.

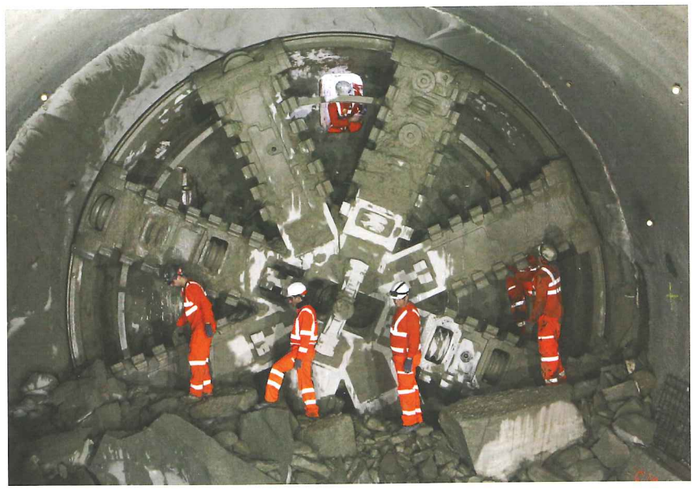
"Stakeholders are rightly concerned about their assets and overcoming those trust hurdles is as demanding as the physical works."

This is where the unsung heroes in the background have really come into their own, said Reichmann.

"Take our compensation grouting team as an example," he said. "There are five grout shafts at Bond Street, seven at Tottenham Court Road and one at Fisher Street [there are 22 in total]. The fact that you didn't hear much about their work was because it was a success. It's those types of activities that can stop a project if they go wrong."

Reichmann and Mears agree that Crossrail's smooth progress has also largely been down to the "really high-spec" TBMs employed on the project.

"Crossrail wrote the specs for the TBMs and gave those to the contractors to adapt and procure," said Mears. "There was no debate about leaving them to try to find the lowest possible cost solution – it was a case of 'this is what you need, this is what you are going to get'. That has been a good lesson."



HEADLINE GRABBER

While the eight TBMs have undoubtedly been star performers, both project managers point to the SCL work as being perhaps the most rewarding when it comes to a sense of achievement.

"The running tunnels tend to be the prizewinners when it comes to getting media attention because they're big," said Reichmann. "The TBM purists of the world will kill me for this but I find the SCL is a lot more demanding from a technical perspective."

The largest SCL caverns for Crossrail were built at Stepney Green where two drives meet – the Z drive that goes out to Pudding Mill Lane, near Stratford, and the Y drive that leads on to the drives that run down to Abbey Wood.

The caverns are 17m at their widest point, twice the diameter of the running tunnels, and have an access shaft for ventilation and emergency access and egress.

"This was a very challenging piece of construction work because it couldn't be done in a single drive," said Mears. "It was done in a double side wall drift, so the left and right central sections of the tunnel were advanced to a certain point and then the central heading was brought up to enlarge it to its maximum."

Forming the tunnel lining at the point of application, as opposed to building a concrete ring in factory conditions created different challenges.

"You have got to be really spot on and the materials have to be perfect," said Mears. "The SCL is a sensitive chemical mix including retarders and accelerators that can be affected by the ambient temperature, storage of the accelerators, the wetness of the aggregates, where the cement has come from and so on. It's a really delicate balance and takes a lot of control and competence to make sure you have the right product and the right workforce who know how to apply it.

"The caverns were built in about 18 months, which is quite remarkable and, again, a big success story".

Crossrail has provided a showcase for SCL and Reichmann pointed out that the project has pioneered different profile and excavation control techniques that have been used in the past but have been improved.

"The technique of using beamers to control excavation on the King's Cross project has been improved and all the contractors are adopting that technology to improve the product they can offer," he said.

"There is much to learn from the materials that are being used on Crossrail, as well," continued Reichmann. "This is the first time that a sprayed waterproof membrane of this magnitude has been used in this environment. And just spraying a secondary lining of this scale after we've already installed a primary lining that will last tens of years without any settlement is remarkable."

Mears points to another example of new techniques being applied to old methods, this time where SCL turned out not to be the preferred option.

"On C305 we built our cross passages using SGI segments rather than SCL. There was a lot of debate about it but DSJV wanted to go with segments because of the surety of the products – they felt more confident in the programme if they could advance the heading knowing another segment was waiting for them.

"This presented another challenge in terms of manhandling these very large segments, so they worked with their supply chain to design and build an erector structure that sits in the cross passage. I've seen films of London Underground construction where the men had to lift the segments on their backs and force them into place but now that process has been mechanised. I've never seen it done before."

Facts and figures

- Construction began on 15 May, 2009.
- Tunnelling commenced in May 2012 and ended in May 2015.
- More than 10,000 people are currently working on Crossrail, including 485 apprentices.
- Eight Herrenknecht TBMs have bored 10 tunnel drives and 42km of new 6.2m diameter rail tunnels under London.
- The TBMs had a total of 18 breakthroughs.
- Tunnelling progressed at a collective average of 38m per day.
- The fastest day of tunnelling by a single machine was 72m by Ellie on 16 April, 2014.
- The deepest point in Crossrail tunnels is 42m at Finsbury Circus, near Liverpool Street station.
- The type of ground bored through included London Clay, Lambeth Group, Thanet Sands and chalk.
- There are 10 cross passages on the eastern tunnels, six on the western tunnels and four on the Thames tunnel.
- Five portals were built – Royal Oak, Pudding Mill Lane, North Woolwich, Victoria Dock and Plumstead.
- Crossrail's tunnels are made up of more than 200,000 concrete segments, each weighing 3.4 tonnes.
- Ten new world-class stations are being built. Typically they will be 250-300m in length and have been constructed at depths to tunnel crown up to approximately 30m below street level.
- A total of 3.4 million tonnes of material was excavated by the TBMs and a total of 7 million tonnes will be excavated during the entire construction. Ninety-eight per cent of all excavated material will be re-used – 3 million tonnes of it is being used to create a new wetland nature research at Wallasea Island in Essex.
- Crossrail is being delivered by Crossrail Ltd, which is a wholly owned subsidiary of Transport for London. Crossrail is jointly sponsored by the Department for Transport and Transport for London.

Mears and Reichmann both pay tribute to the contractors they've worked with on their respective contracts – DSJV for the eastern running tunnels and Bam Ferrovial Kier (BFK JV) for the western.

"DSJV have done a really excellent job – and I'm sure Greg will say the same about BFK JV in the west," said Mears. "They've been really collaborative and innovative in working out ways to build the job as efficiently as possible.

"They haven't just done the bare minimum, they've been open to looking at taking on whatever challenge sits with us as a client's risk, as opposed to a contractor's risk and have worked hard to help us mitigate those. They've really stepped up to the plate for the good of the job and it's the main ingredient in the success of the project."

Mears and Reichmann also agree that, in many respects, the knottiest challenges have arisen at the interfaces between the many different contracts and sub-contracts that have made up the mammoth Crossrail project.

"The western package was originally

Above: Tunnel entrance at Paddington

Left: Some of the spoil is being used to create the new Wallasea Island bird sanctuary

two contracts," said Reichmann. "C300 was the running tunnels and C410 was the station platform tunnels and concourse tunnels. BFK JV proposed bringing those contracts together in a solution that was beneficial to Crossrail and from a programming perspective.

"There was a lot of planning at tender time to make sure those interfaces worked but, as with any construction project of this scale, as time goes on programmes change and suddenly some of the elements that used to fit, don't any more.

"The big, ongoing construction challenge is making sure those elements dovetail – such as starting work on the Bond Street and Tottenham Court Road platform tunnels at the same time as you're trying to strip out a TBM.

"You work together to make sure you can accommodate any changes but, again, like any project, if you were doing it again there would be things you would change and improve to make sure those interfaces were really rock solid," said Reichmann.

"The interface between contractors is challenging," agreed Mears. "A lesson learned for everyone on Crossrail and definitely for myself is that you have to make sure you minimize those interfaces and have them at sensible points in three-dimensional space.

"It obviously makes it very difficult when you have to transit a TBM through a box that was built by someone else. It's easy to say with hindsight that maybe we could have structured some things differently but take your mind back to the when the job was first let – it was a difficult time in the industry and Crossrail was conscious it didn't want to burden one contractor but wanted to spread the work evenly among companies who were capable of doing the work."

Of course, there is still an enormous work to be done before passenger trains start running through the Crossrail link but there is a sense that now the tunnelling is finished, from a risk perspective at least, the most challenging part of the project is complete.

And, with that, comes a huge sense of pride in the achievement thus far.

"Some of the platform construction is complete and the platform edge screen doors are going in so it's all coming together," said Reichmann. "Seeing that is when you think 'we were a part of that, we created the space to allow this to

happen'. It's very rewarding."

"Crossrail is remarkable in the amount of tunnelling that has been carried out through this densely populated city with many historic assets without any serious impact on any railway operations or buildings," added Mears. "We've done it without any serious ground failures or collapses or any issues working with TBMs or SCL. We've excavated more than three million tonnes of central London and sent it out to Wallasea in Essex [where a wetland nature reserve is being created] and it's all been done in three years."

While Crossrail construction hasn't caused any major ripples in the public consciousness, the project has raised the profile of the tunnelling community.

"Crossrail has done an excellent job of making sure we have a positive image," said Mears. "And the BBC documentary was brilliant – the number of people who now ask me about my job and say it sounds really interesting and that what we're doing is great is terrific."

And, of course, while the British public may have improved their knowledge about tunnelling, the learning experience for those actually working on the project has been second to none.

"Thousands of people have now worked on Crossrail and it's been like a university of construction professionals," said Mears.

"Crossrail has really championed apprenticeships, which has got to be the way forward for this industry. And, as for myself, it's really accelerated my learning. I've learned an infinite amount of how to build these complex tunnels, from dealing with technical challenges such as settlement and ground water, to managing contracts. It's been fantastic, incredible."

With the Crossrail experience bolstering their skill sets, many of the workforce have now moved on to other projects. Several have moved to the Middle East to work on Riyadh and Doha metro projects while others have stayed closer to home and are already working on the Thames Tideway scheme – Greg Reichmann included.

Above: Platform tunnels at Farringdon Station

There is also the prospect of High Speed 2 (HS2), the rail link between London and the West Midlands, to look forward to and, perhaps, Crossrail 2, which, if it goes ahead, will provide a north/south route across London.

And, looking at this wider picture, the success of Crossrail to date should ease the way of other major infrastructure projects, both in the UK and elsewhere.

"Big infrastructure projects in the past have had a tarnished reputation of being late, over-budget and of not really delivering on the vision they were meant to at the start," said Reichmann. "But in London we've had Heathrow Terminal 5, the Olympics and now this. It gives so much credence to the likes of Crossrail 2 and HS2 because we've got the skills, the reputation and the knowledge to go and do them. There is a lot more confidence about putting money into infrastructure now – and that's a big positive."

Mears, who has spent five years of his 12-year career on Crossrail, is in full agreement. "The start of my career was a time when civil engineering projects were late, over budget and filled with acrimony between client and contractor," he said. "To date, all our contracts have been settled amicably and the project is going to be delivered on time and on budget, so that is a step change," he continued. "This is how a tunnelling job through a city should be"

EAST MEETS WEST

Eight Herrenknecht TBMs turned in exemplary performances during tunnel excavation on the Crossrail project. **Sally Spencer** reports

Sally Spencer
Sally joins the Tunnels and Tunnelling team as a contributing editor this year

MAY 23 2015 will go down in history as a landmark date not just for Crossrail but also for Herrenknecht. It was on this day that TBM S-720 – Victoria – broke through at Farringdon at the end of an 8.3km drive from the Limmo Peninsula.

A successful break through is always a cause for celebration but this one was different. Not only did Crossrail's 18th break through join the eastern and western tunnels but when Victoria's job was done three days later, after progressing into Farringdon station, it marked the end of three years and 42km of tunnel excavation underneath some of the most valued – and valuable – real estate in London.

The three joint ventures working for project owner Crossrail Ltd on Europe's largest infrastructure project – Bam/Ferrovial/Kier (western tunnels), Dragados/Sisk (three sections of the eastern tunnels) and Hochtief/Murphy (Thames tunnel) – specified eight TBMs between them. And Herrenknecht supplied all eight.

The first order was received at Herrenknecht's Schwanau factory in early 2011 and the first TBM – Phyllis – was completed in October the same year. The factory had ample capacity to manufacture all eight at the same time but this wasn't necessary.

"They were rolled out at intervals, although the timing of the delivery of the first TBM was fairly critical as the portal at Royal Oak had already been completed so the contractors were ready to start," said Roy Slocombe, director at Herrenknecht International Ltd (Great Britain). Boring work commenced at Royal Oak in May 2012.

The TBM shopping list comprised six earth pressure balance (EPBM) shields for the construction of the eastern and western tunnels through London clay, sand and gravel; and two Mixshields for the Thames tunnels, which were excavated at depths of up to 15m below the river bed.

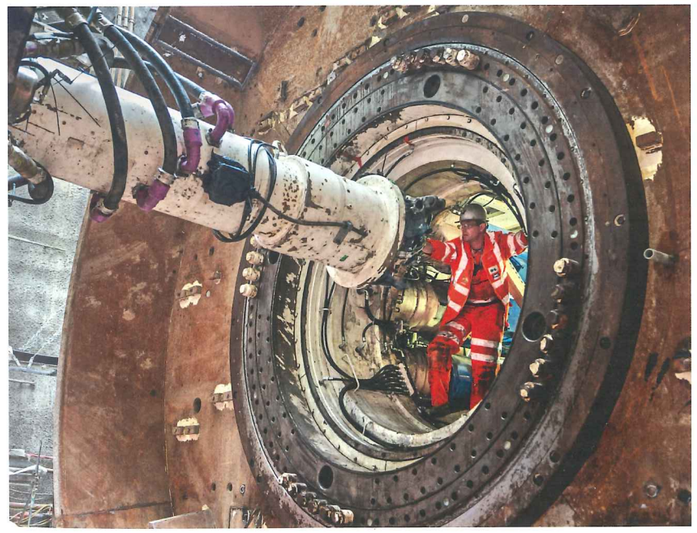
"The slurry system was selected mainly because of the flints in the chalk under the Thames," said Slocombe. "The flints are very abrasive and have caused problems with some tunnels in the past but both we and the Hochtief/Murphy joint venture were able to draw on our experience of working on the Channel Tunnel Rail Link tunnels beneath the Thames and, as a result, the Mixshields coped very well."

The eight machines had shield diameters of 7.08m, were up to 147m long, weighed up to 1,100 tonnes and had a power drive of up to 1,920kW.

Guiding these beasts through London's crowded subterranean infrastructure called for millimetre-precise steering and all eight machines were equipped with laser-guidance navigation systems from Herrenknecht subsidiary VMT.

New features on the TBMs included the provision of refuge chambers in accordance with recommendations in the 2011 revision of BS 6164 (Code of practice for health and safety in tunnelling in the construction industry).

"These were the first machines in the UK to be equipped with a refuge so that if there was a fire in the tunnel behind the TBM, the crew could take cover in a safe haven that was supplied with scrubbers and an air supply," said



Below: TBM S-722, named Ellie, was deployed by Dragados/Sisk on the drive from Pudding Mill Lane to Stepney Green

Machine data

Machine type: six EPBs, two Mixshields
Shield diameter: 7.08m
Drive power: 1,600-1,920kW (EPB); 1,120kW (mixshield)
Torque: 5,850-9,800kNm (EPB); 3,709kNm (mixshield)
Total weight: 850-1,100 tonnes
Total length: 109-147m

Slocombe.

Another key amendment was to the belt weighing equipment. "Crossrail wanted to monitor ground settlement as carefully as possible so the belt weighers, weighing the amount of material extracted in every ring, were to a higher standard than had previously been used."

Finding a route through existing infrastructure meant that the ability to follow tight curves as well as straight lines was paramount and the machines had double articulation to enable them to follow curves as they were needed.

SETTING UP

In terms of assembly on site, each contract was handled in a different way, depending on site conditions and programme requirements.

"For example," said Slocombe, "the portal for Contract C300 [the western tunnels between Royal Oak and Farringdon west] was sandwiched between main railway lines and the Westway overpass, so the two machines, Ada and Phyllis, for Bam/Ferrovial/Kier, were assembled some metres away and then rolled into place on heavy transport ready for the launch."

"The TBMs launched from Limmo by Dragados/Sisk (Elizabeth and Victoria) for the eastern tunnels were assembled in a small launch adit at the bottom of the shaft and the shields themselves were fully assembled on the surface and then lowered down in one big lift."

Jessica and Ellie, which were deployed by Dragados/Sisk on the drive from Pudding Mill Lane to Stepney Green and Sophia and Mary the mixshield TBMs used by Hochtief/Murphy for the Plumstead to North Woolwich leg under the Thames, were assembled in the portal area and launched complete.

The TBMs were required to work around the clock, seven days a week and they were guaranteed to be operational 90 per cent of the time. In fact, Herrenknecht surpassed that, achieving 95 per cent TBM availability.

This was down in no small part to Herrenknecht's team, which provided the service and maintenance requirements of the machines and kept a ready supply of spare parts at all the Crossrail worksites in London throughout the course of the project.

The machines were maintained on a regular basis and the cutter tools were replaced as necessary. When the machines passed through the previously constructed stations, the opportunity was taken to check the wear protection on the cutterheads.

The TBMs' performance was

exemplary, said Slocombe. "They were up to the specification and all the machines did everything that was expected of them. The fact that S-722 [Ellie] was able to advance 72m – 45 segmental rings – in just 24 hours is quite an achievement and not just for the machine but for the team that was operating her."

The machines were operated by 20 men per shift, with 12 on the TBM and eight on the gantry. And Herrenknecht also played its part from an operational point of view by training TBM operators, accompanying them on the machines and giving advice during the drive. This typically included changing small parameters in the control system, such as air pressure, water or foam level where the ground was wet, sandy or chalky, to make the drive more efficient and safer.

FIRST STOP

Elizabeth's first port of call, 2km after launching from Limmo en route to Farringdon east, was the newly constructed box for Canary Wharf station. This marked Crossrail's first breakthrough into an existing structure and had to be executed with millimetre precision. Once through, the TBM had to cross the 250m-long station before it could continue on its way to Whitechapel, Liverpool Street and its final destination, Farringdon.

Tracks were laid, consoles were welded to the machine's shield and moving skates were placed underneath. For the back-up, engineers in Schwanau designed special shunting units and in this way, over the course of seven days, it was possible to shunt the entire 150m-long TBM through the station. This solution avoided costly and time-consuming disassembly and re-assembly.

Victoria was transported through the Canary Wharf station box in the same way, just after Elizabeth.

The redeployment of Jessica and Ellie saved the purchase of another two TBMs and also recouped some time from the original plans.

"At the time of the contract it hadn't been decided what to do about the short G drives [Limmo to Victoria Dock portal] but then Dragados/Sisk elected to re-use Jessica and Ellie, which had come in from Pudding Mill Lane to Stepney Green on the two Z drives," said Slocombe.

The two machines were dismantled and transported on heavy trucks to the Limmo portal and relaunched in order to tunnel the 930m to Victoria Dock.

The original plan was that Ellie would be assembled in the auxiliary shaft while the back-up would be lowered through the main shaft at Limmo. However, because Jessica finished her work at Limmo faster than expected, there was enough space to lower and assemble all of Ellie through the auxiliary shaft. This freed up the main shaft for other work.

"The whole process took three months and the change in plan saved the contractors a week and could only have been achieved with input from Herrenknecht," said Roger Escoda, Dragados/Sisk tunnel manager.

"They knew the details of the machine and were able to tell us whether and how our plan was technically feasible," he said.

"It's not a unique situation but we had extra people involved so that if anything needed refurbishment it could be done as the TBMs were reassembled," said Slocombe. "And, as they had only run 2.7km they didn't require any major repairs."

Once they had finished their drives, the TBMs had differing fates. In chronological order, the cans and cutterheads of the first machines that came in from the Paddington direction – Phyllis and Ada – were buried at Farringdon.

"By electing to do that it meant that Farringdon station was freed up for other construction to proceed there," said Slocombe. "The back-up was taken back in the tunnel, although not all the way out as by that time there was other construction going on, so they came out in smaller pieces at Fisher Street."

The two Mixshields, Sophia and Mary, were dismantled in the open at North Woolwich. The next two to be dismantled (prior to being redeployed), were Jessica and Ellie, which were removed at Stepney Green. Here the shaft was so narrow that the back-up had to be lifted out at an angle and, in order to facilitate this, Herrenknecht engineers in Schwanau designed stiffeners, which were then welded on to the equipment on site. Finally, Elizabeth and Victoria were dismantled underground. The cutterheads were cut into small pieces and removed via the shaft at Farringdon, while their trailers were removed from the tunnel via the shaft at Stepney Green.

Many of the major components will be remanufactured and will be used again in new projects. "Martin Herrenknecht is very proud to have supplied all eight machines for this prestigious project," concludes Slocombe

Eight TBMs and 10 drives

Royal Oak to Farringdon (Drive X): Phyllis (S-705) and Ada (S-706) were delivered to Westbourne Park, just west of Paddington, in early 2012 where they were assembled and tested ahead of launch in May and August 2012 respectively. Each TBM tunneled 6.8km towards Farringdon, completing their journeys in November 2013 and January 2014 respectively.

Limmo to Farringdon (Drive Y): Elizabeth (S-719) and Victoria (S-720) were delivered to Limmo Peninsula in London's Docklands in summer 2012 and launched in November and December respectively. They constructed 8.3km of tunnels between Limmo Peninsula, near Canning Town station, and Farringdon, finishing their work in May 2015.

Pudding Mill Lane to Stepney Green (Drive Z) and Limmo to Victoria Dock Portal (Drive G): Jessica (S-721) and Ellie (S-722) constructed the 2.7km tunnels from Pudding Mill Lane portal, near Stratford, to Stepney Green, completing their work in February and June 2014 respectively. The machines were then dismantled, lifted out of the shaft and transported to Limmo where they were relaunched to drive the 0.9km tunnels from Limmo to Victoria Dock portal. Jessica relaunched in June 2014, finishing in August, while Ellie relaunched in September 2014, finishing in October.

Plumstead to North Woolwich (Drive H): The two mixshield TBMs Sophia (S-731) and Mary (S-732) were used to construct the 2.9km-long Thames Tunnel between Plumstead portal in south-east London and North Woolwich portal on the north side of the Thames. Sophia launched in January 2013 while Mary launched in May 2013 – both machines completed their work almost exactly a year after their respective launches.

CENERI: A LINK IN THE CHAIN

Sally Spencer
Sally joins the Tunnels and Tunnelling team as a contributing editor this year

THE SOON-TO-BE-COMPLETED Gotthard base tunnel at 57km is the world's longest rail tunnel. But without its little brother, the 15.4km Ceneri base tunnel, the Gotthard Alp Transit Project would not be able to achieve its ambition of creating a continuous flat rail link between Zurich and Milan and reducing the journey time between the two cities from 4 hours 10 minutes to 3 hours.

The Ceneri base tunnel is Switzerland's second largest tunnel currently under construction and, along with Gotthard and the already completed Lötschberg base tunnel, forms part of the New Rail Link through the Alps (NRLA). Ceneri tunnel is being built by AlpTransit Gotthard AG, under contract from the Swiss federal government, as is the Gotthard base tunnel. The estimated investment for the Ceneri base tunnel is CHF 2.58bn (USD 2.69bn).

It is anticipated that 270-340 trains per day will be able to travel the new route – up substantially on the 220-260 that were able to run on the previous mountain route. Trains will be able to reach up to 250km per hour. Also, once the NRLA is complete, 2,000 tonne loads on goods trains will be able to travel non-stop through Switzerland, without the addition of a pushing locomotive and freight transport capacity will increase from around 20 million tonnes per year to 50 million tonnes per year.

The Ceneri base tunnel is an integral part of the New Rail Link through the Alps. **Sally Spencer** reports

Ceneri base tunnel is in the Swiss Canton of Ticino and passes under Monte Ceneri between Camorino in the Magadino Plain and Vezia, near Lugano. At the request of Ticino, a Locarno-Lugano link is also being implemented to serve regional traffic – travel between these two destinations will reduce from 55 minutes to 22 minutes.

A 5.5m diameter, 3.1km-long exploration tunnel near Sigirino was driven via drill and blast between 1999 and 2003 to gain geological data, with orthogneisses and other gneisses being

Cifa concrete pump operating near Camorino portal

the predominant finding. This exploration tunnel as well as an extensive geotechnical investigation was used to determine the definitive horizontal route of the twin, single-track tubes.

The routes of both the Gotthard and Ceneri base tunnels are curved – a fact determined not just by geology but also by geography, such as the position of dams, access routes to construction sites, depth of the overlying rock and land use.

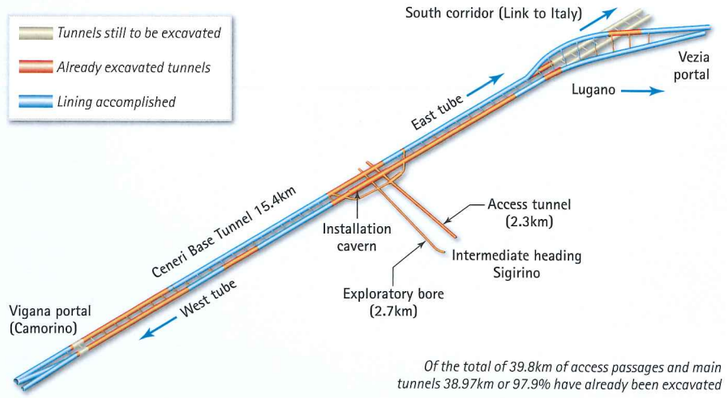
DRILL AND BLAST

The decision was made that the Ceneri base tunnel would be excavated entirely by drilling and blasting – with one exception. In 2008 an access adit tunnel, also at Sigirino and running parallel to the exploration bore, was dug using a Robbins TBM.

This 9.7m diameter, 2.3km-long tunnel joins up with approximately the halfway point of the main rail tunnel bores and is dimensioned to accommodate the conveyor belt system, site vehicles and construction ventilation. A system of chambers was constructed at the junction with the main tunnels, the largest of which houses the concrete production plant. Space at the access portal is very constricted and locating part of the construction site inside the mountain mitigates noise pollution for local residents.

*Above: **The access tunnel at Sigirino***

*Below: **Layout of works required and progress***



Of the total of 39.8km of access passages and main tunnels 38.97km or 97.9% have already been excavated

The TBM method was chosen largely for noise abatement reasons with respect to the nearby municipality of Sigirino and excavation of the adit tunnel was achieved in 10 months and with the use of 30 cutter rings (daily advance rates averaged 18.5m). Robbins found the geology of the tunnel alignment to be good for TBM boring, with no squeezing ground or large water inflows encountered.

However according to AlpTransit project manager Paolo Vicentini, the foreseen geology of the main drives did not lend itself to the use of a TBM through the whole length.

"It would only have been possible to excavate about 4.5km of the southern drive by TBM," he said. "The main contractor, Consorzio Condotte Cossi, offered both excavation methods but the drill and blast was more economical and the bid included a guarantee that the completion time goals we had set would be reached.

"And, indeed, the breakthrough at the south was achieved in March this year, almost a year ahead of the original schedule."

Work on the two main tunnel tubes began from the intermediate chamber system in 2010, with the majority of the excavation being carried out simultaneously in both directions. However, to minimise time and costs, inward drives from portals at Vigana/Camorino and Vezia are also being excavated.

Restrictions have been observed in order to reduce transmitted vibrations and noise, especially in the south drives where there is thin cover and near the portal where it is densely populated.

Blasting has been controlled by reducing explosive loading and fragmenting the detonations and, at the two portals, it was forbidden to work at night and during the weekend.

In addition, during excavation of the trench for the cut-and-cover track of the south portal, the main blasting and excavation activities were only allowed during the summer months in order not to disturb a nearby school.

The north portal is located in the Vigana/Camorino area and here, in loose rock, the tunnel had to pass just nine metres underneath the A2 motorway. A monitoring and alarm system was installed to warn of any unexpected subsidence in the road surface.

Shortly after this portal, both tubes feature branch-off caverns, which will allow the crossing of the Magadino Plain at some point in the future.

Provision is also made for future extensions near the south portal, which is at Vezia. Around 2.5km north of this portal – and still inside the mountain – there is a branch off at Sarè, which will allow the future extension of the tunnel south to Chiasso and Como.

*Above: **Sealing work ongoing in October 2012***

*Below: **Tunnel east from Vezia portal***

Driving in the solid rock here was performed with minimal amounts of explosive in order to protect populated areas and buildings nearby – such as the 18th century Villa Negroni.

Protective construction methods were also called for further on where the tunnel passes just four metres above the new Vedeggio-Cassarate road tunnel of the Lugano bypass.

SPOIL SITUATION

As the majority of the Ceneri base tunnel is being excavated from the mid-way point, the material preparation and storage facilities are located at Sigirino. The transfer tower in front of the portal of the access tunnel, silos connected to the works track, conveyor belts and the installation for producing the rock aggregates for concrete production were set up between 2007 and 2009.

The dump for the excavated material can hold 7.5 million tonnes and accommodates spoil from both Vezia and Vigana portals, as well as Sigirino. An estimated 7.9 million tonnes are expected to be excavated from the whole Ceneri tunnel system.

Almost all the spoil – 99.9 per cent – is removed via a network of conveyors supplied and installed by the Comestei joint venture of Agir Aggregat and Ferrari.

"The total length of the conveyors is 30km," said Carl Ulrich Wassermann, of Agir, adding that the system runs from the crusher at the drill and blast area to the final landfill, about 2km from the portal.

Approximately 300m of tunnel length at the Vezia and Vigana portals has been mucked separately, leaving the vast majority to be extracted from the Sigirino access tunnel.

Agir supplied a hanging conveyor in this access tunnel, to allow more room for traffic, while in the main tunnel tubes, ground-standing conveyors were chosen for reasons of speed and ease of installation.

The design capacity of the band systems is 1,000 tonnes per hour but when all four drill and blast areas were mucking at the same time, Wassermann said a maximum of 1,100 tonnes per hour was recorded on one of the conveyors.

He also reported that there have been no conveyor breakdowns as such, although there has been some downtime as a result of power failures. And some major repairs have been necessary due to excavators and trucks running into the

conveyors.

Agir performed the functions of crushing, sorting, washing, interim storage and final depositing of the spoil, including the management of the material that could not be reused – building roads, installing water pipes and fences, and planting, transforming it into embankments and landscaped areas.

It erected 10 silos, each with a capacity of 800 tonnes, plus another 10, each with a capacity of 1,400 tonnes. The silos have a diameter of 9.3m.

The aggregate production site is outside the access tunnel next to this silo array and Agir also handled the transport of these aggregate components back into the tunnel to the chamber housing the concrete production plant. This plant is required to produce 800m³ of ready-mix concrete a day and crews work around the clock in teams of two for three eight-hour shifts in order to accomplish this.

Almost 100 per cent of the cement, along with primary aggregates and concrete needed for the tunnel lining and bed are being supplied by Holcim. Around 0.4 million tonnes of aggregate for the Ceneri tunnel are from recycled spoil, with another 1.6 million tonnes of primary aggregates delivered by train from Holcim's Hüntwangen quarry. Around 390,000 tonnes of cement is being supplied from Holcim's plants at Siggenthal and Eclépens.

The twin bores of the Ceneri base tunnel are 8.5m diameter, are set 40m apart and are joined by cross passages every 325m. These cross passages – 46 in total – house infrastructure systems and also serve as self-rescue evacuation routes into the opposite tube.

Unlike the much longer Gotthard base tunnel, it is not deemed necessary to construct multi-function stations at intermediary points along its 15.4km length. Also in contrast to Gotthard, this tunnel does not have a ventilation centre. Instead, more than 50 jet fans mounted near the portals and in the middle of the tunnel will provide the necessary ventilation.

The main tunnelling works were split into three contracts – two smaller ones for the north and south portals and one larger contract for the main drives north and south from Sigirino.

The joint venture of Matro sud (Pizzarotti SA, Bellinzona CH; Pizzarotti SpA, Parma I; Implenia Schweiz, Wallisen CH; Cossi SpA, Sondrio I; Ennio Ferrari, Lodrino CH, LGV, Bellinzona CH; Rodio AG, Urdorf CH) is fulfilling the contract for the north portal, while the south portal is being handled by the CPV Consorzio portale Vezia joint venture (CSC SA, Lugano CH; Pizzarotti SA, Bellinzona CH). The Conzorzio Condotte Cossi joint venture (Condotte D'Acqua and Cossi) won the main CHF 987m (USD 1bn) contract in 2009 and has been digging the four headings, north and south, with Sandvik jumbos and Rowa suspended backup trains.

Maximum overburden is 800m and the southern drive proceeded well – despite hitting a problematic area of disturbed rock 1km into the drive, which necessitated major ground support.

"We expected we would have complications in this section of the tunnel," said Vicentini. "The face of the drive in the south-east pipe came down, breaking into the tunnel and bringing work to a stop for a couple of days while we explored the situation and developed an intervention measure.

"Luckily there were no injuries as the contractor anticipated the problem, pulled back its equipment and waited for the breakdown to happen."

The disturbed rock zone extended in to the south-west pipe and while there was no breakdown, there was some major movement of the walls. "We had to reprofile both the tunnels because we had too much convergence," said Vicentini. "And we had to wait a longer time before we were able to realise the concrete invert of the final lining."

A smaller disturbed zone also caused a slight delay in the excavation of the caverns. "Again, we had to reprofile the tunnel and reinforce a few metres with longer anchors," said Vicentini. "We also had to break the excavation stage down into more phases. We had hoped to be able to excavate the big phase of the cavern in two steps –an upper and a lower. In the end, especially in the west cavern, we had to break it down into four steps – three in the upper part and one in the lower part. This took a little time but the works continued in security and we recovered the delay after this."

SCHEDULE EXPECTATIONS

In fact, despite these hold-ups, breakthrough at the southern end of the western bore was achieved on 17 March this year, 13 months ahead of schedule and with a deviation of just 20mm horizontally and 10mm vertically from the planned alignment. A short while later, on 30 March, tunnellers broke through on the southbound eastern bore.

Breakthrough of the northern bores is planned for the beginning of 2016 although an area of faulted ground has caused delays.

"The geology that was encountered was expected but the disturbed section was bigger than foreseen," said Vicentini. "In addition to that, in many cases the orientation of schistosity and fracturation was particularly unlucky compared to the direction of excavation (parallelismus). This resulted in the application of shorter blast steps and heavy safety measures (meshes, anchors, shotcrete and steel ribs) and so progress in the drives was slowed down."

The original plan in the north section was to line the tunnel after excavation had finished but, to regain time, the contractor has installed the final concrete and foil lining in tandem with excavation.

Another measure, in a shorter section, was to open a third excavation face towards the north while, in the east pipe, the drive was about 400m behind.

A further delay has been caused not by the construction works but by a dispute over the railway system tenders. AlpTransit said that while it believed that the original opening date of December 2019 was still feasible, the risk of failing to meet this target was sufficient that it felt it had to push the opening of the Ceneri base tunnel back to December 2020

BEND AND BREAK-THROUGH

A short drive in Oregon could revolutionise how small bores are advanced through congested ground. *Jon Young* looks at how removing the driver from SBUs could cuts costs and make impossible projects routine

Jon Young
Based in London, Jon is the associate publisher of *Tunnels and Tunnelling*

IN THE CITY OF BEND, Oregan, a machine that is set to revolutionize precision boring has made it's debut. The 300ft drive beneath a railroad has demonstrated the abilities of a remote controlled small boring unit (SBU) to stay on target. The SBU was driven through abrasive rock for some 100m and never wandered more than 17mm of course. If taken up by the industry, this machine, which cuts 36" (0.9m) bores in solid rock, would slash equipment costs by two thirds for projects where maintaining the line is critical, such as busy urban environments.

In the past, the way you avoided microtunnelling on a critical line is to bore a bigger hole and make up deviation inside the casing when you lay your pipe. However, this has a number of setbacks. First, and perhaps my crucially, if you only have space for a 36" (0.9m) pipe, you can't bore a 48" (1.2m). Second, is price, a 48" (1.2m) casing is considerably more expensive than a 36" (0.9m) casing, the contractor is excavating less material and using less grout material in the annulus. But the machine has to be able to guarantee the grade.

ROUND THE BEND

In Bend, Oregon, USA, local contractor Stadeli Boring & Tunneling had a unique set of circumstances for a new gravity sewer interceptor. "We had a contract with general contractor Taylor NW to furnish and install 323ft (98m) of 36" (0.9mm) steel casing under railroad tracks. Line and grade were very crucial, and the tolerances were very close. We had to be right on," says Larry Stadeli, president and owner of Stadeli Boring & Tunneling.

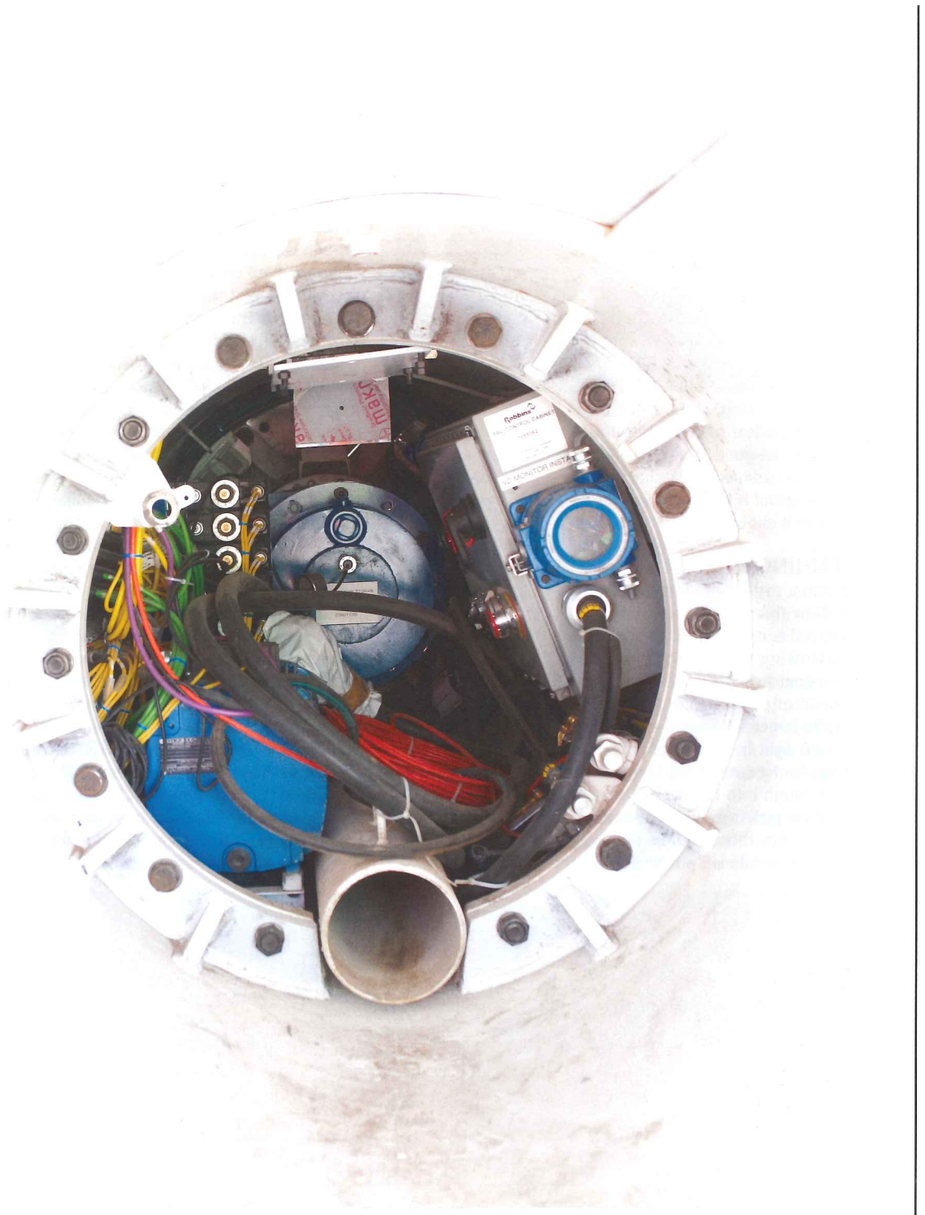
"We met with Robbins in Ohio and told them what our needs were. They felt like their 36-inch (900 mm) prototype machine, would be a good fit. They listened to what we were wanting and needing to have done," said Stadeli.

At Robbins, Kenny Clever, SBU Sales Manager, and a group of engineers were honing the prototype machine that fit the bill. Known as the SBU-RC, for Remote Controlled Small Boring Unit, the machine was equipped with a smart guidance system by TACS.

Clever explains, "The TACS guidance system has been in the microtunnelling industry a long time, this is how they have steered microtunnelling machines for years, it is very, very effective. It was an easy conversion for us to put it in the SBU as the technology was already there, we didn't have to do anything.

"You mount it up in the front of the machine, it feeds you back information giving projections on where you are headed if you continue on the same course. It doesn't just tell you where you are, it is giving you forecasting information, so you are able to make heading corrections proactively, before you go off grade."

The machine itself works a lot like its larger cousin, the motorised SBU. Starting at 48" diameters the larger machine



has able room for all the gadgets and luxuries an SBU needs, such as muck removal systems, and a spot for the drive. On the 36" machine, there is no such room. The shield is jam packed with the essentials for the bore, so any spare part, including the driver, had to go.

"The machine itself works on the same principle as the larger motorised, man operated SBUs. We have up front an electric driven motor, which drives through a gear reduction box and a bearing housing in the forward shield. So the cutterhead is turned by an electric motor, powered by a VFT [variable-frequency transformer] on the surface.

There is a jacking station in the pit to provide the thrust.

Above: The compact SBU-RC operates much like the Motorized SBU (SBU-M), with an in-shield drive motor for torque (view shows the inside of the SBU-RC and drive motor)

There is no space in the shield for an invert auger to handle the muck removal. That all had to come out. We are instead using a vacuum system to pull the muck out.

The forward shield articulates in two degrees and in any direction. There are four small hydraulic cylinders up front, operated electronically. You steer it just like a 1.5m motorised SBU, the same principle. Everything is exactly the same, only now the package is so small we

can't fit a man in there to control it. So we have made it remote controlled with electric over hydraulics."

With the driver in a control cabin on the surface there is no visual reference as to what is going on below the surface. So the Robbins designers added in closed circuit TVs to monitor the machine. "So we have two things going on," says Clever, "we have the TACs guidance system that we are watching from the control cabin, and we have the closed circuit TV to watch everything that is going on inside the machine. With that closed circuit TV we are watching the primary target, the laser coming down to hit that target; we are making sure that nothing is leaking, and that we are not getting an inflow of water into the machine. It is just good to see up in that machine to rest assured with what you see with the visual is showing everything is working as it should."

MAINTAINING SUCTION

There is also a camera mounted up front to show that the pipe used for muck removal is not getting clogged. Having a working vacuum muck removal system was crucial to the development of this machine. Clever says, "In the larger SBUs we use a small invert auger, right in the bottom of the casing. As the cutterhead brings the spoil through into the back of the cutterhead we pick it up with the invert auger and convey it back to the pit. Now, because that area is so small and confined we can't get an auger up in there effectively so now we are running a small tube up right behind the cutterhead, and we are running pvc connections all the way back to the launch pit, hooking it to a high suction vac truck. We are just sucking it right out of the cutterhead."

To carry chunks of volcanic basalt the size of golf balls the 300ft (91m) back to the launch pit requires the biggest vac truck available, with 6,000cu.ft (170cu.m) per minute of suction. Clever says, "We have designed, and in fact modified on the first bore, the cutterhead so that if the material passes through the cutterhead, it passes through the suction. So we have closed down that cutterhead not to allow bigger pieces to go by it because our first problem right out of the gate was that the muck was passing through in larger pieces than we could vacuum out. The machine has a mixed ground cutterhead on it so we've closed that up with grill bars. It is now typically coming back about the size of your thumb. But before adding the grill bars we were getting pieces about the size of a softball when in clumpy ground, now those pieces are held out of the cutterhead until they have been ground up.

While the machine is aimed at short drives in congested ground, Clever thinks the vacuum solution will continue to be effective over greater distances. "In Canada they have already done some long vacuum excavations for hydro projects," he says, "When you get further out you can Y pipe these machines together. Say I get out there 150m away and I start to lose suction and can't excavate the face, I set another vac truck right next to the one I'm using, run two vac lines right down to the cutter head and Y pipe them into one, and now I have double the suction. You can get a lot of air moving with these trucks and you can piggy back them."

MAINTAINING LINE AND GRADE

The Bend, Oregon project represents the target project for this machine according to Clever. "It was a gravity sewer, so they had already established the invert of the pipe on both sides of the railroad, and the exit pit was just barely big enough that they could land, because a manhole already had to go there."

Below: Breakthrough was two weeks early, on 5 May 2015.

This means there were restrictions on both the vertical and the horizontal tolerances.

"Most of the projects that this machine was designed for are 100m or less. The problem on these projects is line and grade. We are installing projects in areas where the ground is already so cluttered with other utilities that line and grade is critical. You can't deviate from your line or you will be into the sewer line that exists, or the water line that exists or gas main. This wasn't intended to be out in the countryside boring under a road way, it is an innercity project where they dig down, it is solid rock and they need to avoid deviating from side to side or up and down. Or where they need to cross an interstate and enter an existing manhole," says Clever.

"In the past, in soft ground you would use a pilot tube system. It works very well in soft ground. You shoot that across, establish the line and grade and pull the product line across after it. In solid rock, that is just not possible. Guys have tried for years with directional drilling, with small diameter tricone bits, and still it is nearly impossible when you are looking at tolerances of 20-30mm. It is ridiculously difficult to hold a directional drill with those type of tolerances. Then the Axis system came out from Vermeer, this is very effective for getting a good pilot hole across and then you have to ream it open to the desired diameter, which is typically 30-36" (0.7-0.9m). So what we have done is eliminated the need for a pilot hole because now we can steer it all the way across. This machine is not designed to have the ability to steer, it only has steering capabilities to maintain the line and grade we have already established. It is not designed to go around curves or go up and down. It is made to go straight and we want to keep it going straight. But the machine has a tendency to migrate towards a softer part of the rock formation, or the torque in the cutterhead might make it want to go to the right and climb upwards out of the hole.

"The ability to steer a cutterhead of that diameter really is a game changer. We can bore one pass and get across a 900mm diameter pipe, and maintain line and grade. We were never more than 17mm off line the whole way across. Half an inch was the most we were off in 300ft (91m). That is unheard of in solid rock.

Not only did the drive at Bend maintain a steady line, it also made good pace. "It is much quicker than a two-pass method. Once we were launched and got going we were achieving 30-40ft (9.1-12.2m) per day, a lot of the days were eight-hour shifts. One of the days we managed 50ft (15.2m). We went slow at the beginning intentionally just because we wanted to make sure we were hitting our line and grade. We were in some pretty abrasive ground and wanted to make sure we didn't break anything. The when we got to a point where we felt comfortable we started picking up pace a little bit and setting two pieces of pipe a day. We were hoping for a 20ft (6.1m) per day production rate, when we were setting two pipes instead of one pipe we thought we didn't need to do any better than that. The production rate was amazing. The pipe was installed two weeks ahead of deadline. This is solid rock, 10-15,000psi (69-103MPa) rock, this is not dirt work," says Clever.

Contractor Larry Stadeli adds, "We were able to cut off a couple of weeks of our schedule time. Taylor NW was very pleased about it. When you look down the pipe now after it's finished, it looks like a rifle barrel. There is no sag, it's all in one straight line."

ESTABLISHING DEMAND

The past ten years have seen a change in demand for technology like this. "A decade ago there weren't as many critical line of bore rock jobs. We have a 48 inch motorised SBU, so if someone had a project where line and grade were critical, the norm was to upgrade it to 48" (1.2m) so you can get a man in there and steer it across. For years that was the acceptable method," says Clever.

Above: Crew members from Stadeli and Robbins were able to hole through on line and grade after achieving up to 50 ft (15 m) of advance per day

"But more and more over the past 10 years, that has not been acceptable. There has not been enough room to put a 48" (1.2m) pipe in there, because now you are talking about 6" (152mm) on both sides in clearance and there is not that much room for deviation. As these tunnel passes become smaller in target zone, we haven't had the room to upsize the bore; we really need a smaller diameter."

In the past, if that were the case, microtunnelling was the option. But microtunnelling in solid rock is really not that productive. Advance rates are often poor. The contractor needs to have a slurry cleaning system on site, giving the project a huge footprint on the surface; it is not the ideal situation for a small bore dig.

The other reason microtunnelling is unpopular for these projects is cost. "The [SBU-RC] machine and the control cabin, less the vac truck and jacking station, is going to come in at about USD 650,000 to purchase. A microtunnelling system would be about three times that."

However, the future of this technology is going to be demand driven. The size of the market for these machines is unknown, it has just been launched, and the industry is only just learning that this solution exists.

"There has been a huge amount of interest from engineers and contractos alike. We really need to educate the engineers, and this will be a game changer as now they will be able to design project around equipment like this. They will know these tighter parameters can be achieved and can factor that into design," says Clever

UNEXPLODED ORDNANCE

UXO (unexploded ordnance) can arise from both hostile and defensive military activity and is often related to World War I and II. **Simon Cooke**, *6-Alpha Associates*, explains to the March 2015 meeting of the *British Tunnelling Society* how UXO can pose a risk to tunnelling activities and how risk can be managed and mitigated to ALARP (as low as reasonably practical), in accordance with the law and using best practice

ON MAY 8 1945 Winston Churchill broadcast to the UK that World War II had come to an end, marking an Allied victory in Europe following six years of war. It has been 70 years since the end of WWII yet Unexploded Ordnance (UXO) can still be a serious problem to construction projects throughout the UK. It is estimated that 10 per cent of bombs dropped on London alone failed to detonate and could therefore pose a threat if unearthed.

There has been an increased emphasis on brownfield development, which includes many inner city areas that were targeted during WWII, and therefore it is unlikely that the risk of encountering UXO during the construction phase of projects will diminish in the near future.

Furthermore, there is currently little publicly available guidance to specifically assist construction professionals. Indeed, up until 2007 construction professionals depended solely on UXO disposal contractors and there was no technical guidance. There was also no direct legislation regarding the potential UXO risks encountered by the construction industry.

Construction Industry Research and Information Association (CIRIA), through its research project, "A clients' guide for assessing risk on UXO sites", has produced the first UK good practice guidance to help developers and clients deal with UXO. The guide enables these professionals to understand the different approaches and how to appoint specialist contractors, and the second half of this feature will look at the risk and how to mitigate it in more detail.

"There is definitely limited knowledge of UXO by many developers, even ground workers might never encounter unexploded ordinance unless they are working in areas that are heavily contaminated such as London or Coventry," says Simon Cooke, managing director, 6-Alpha Associates. "They might only come across it once or twice in their lifetime. In the past, there has been inappropriate advice for dealing with UXO. Typically, there was a lot of scaremongering going on."

*Below: **Modern military engineers preparing unexploded ordnance (and IEDs) for disposal***

THE THREAT

Let's look at what unexploded ordnance is. According to the United Nations, "unexploded ordinance (UXO) are explosive munitions, which have not yet been set off. UXO may already have been fired, dropped, or launched, but it has failed to detonate as intended."

High explosives effectively have the capacity to transfer energy very quickly. They pose a risk of detonation. If a bomb was discovered, unearthed, and did explode it would work very much as intended during WWII; a significant blast wave will be generated together with concurrent fragmentation of the bomb case, with shrapnel flying omnidirectionally at supersonic speeds (more than 768mph).

During WWII many defensive establishments, cities and towns throughout the UK were subjected to comprehensive bombing campaigns, which resulted in extensive damage to city centres, railway infrastructure,

docks, associated industrial areas and military installations. Across London an average of 84 bombs fell on civilian targets and failed to explode every day from 21 September 1940 to 5 July 1941. Most of the unexploded bombs found were either 50kg or 250kg. However, UXO can range in size from Small Arms Ammunition to large UXBs weighing more than 2,000kg.

"A WWII 250kg bomb only contains about 25kg of high explosives," says Cooke. "Builders would find them and dig them out on a Tuesday afternoon, put them to one side and leave it until Friday afternoon because they didn't want any down time. We would then be called out, which could be highly dangerous especially if it's left baking out in the sun. Interestingly the smallest bomb dropped in London in WWII was 50kg – and over 50 per cent of bombs dropped were one of these. There were 17,000t of bombs dropped on London alone in WWII. 50 percent of these contained about some 25kg of high explosives. If a JCB at its maximum digging capacity had a 6m reach and initiated that bomb, it would kill. That's the smallest of the bomb – then it's the 250kg, around about of which 50 per cent is high explosives. Then it's the 500kg, the 1,000kg and larger varieties – so highly dangerous and not to be trifled with."

Cooke also adds that the German bombs in WWII often incorporated booby trap mechanisms in fuzes, for example the German ZUS40 anti-removal bomb fuze. "Bombs were often booby-trapped with an integral anti-withdrawal mechanism designed to kill anyone who tried to render the bomb safe," says Cooke. "However, the Germans would drop bombs and 10 percent would not go off, which was by accident and not by design. Either the electric impact fuse has hit the ground and broke or sometimes they had insufficient charge in them (they were charged in the aircraft). If the bomb was booby trapped the delayed mechanism would last from zero to 72 hours on a countdown timer. So, if a bomb hit the ground it would bury itself into the ground at a certain depth depending on a number of factors. For example, the kinetic energy associated with the bomb, the angle of the incident and the speed at which it hit the ground - which could be 500-600mph. The maximum depth is some 20m but the average is about 6m. If depends on the soil too; in London it's typically about 6m.

*Above: **Disposal of a bomb dropped during World War II in Germany***

*Below: **Pile of recovered unexploded ordnance***

"The rule of thumb is the bomb will travel laterally no more than three times its depth. So if you have a bomb that's 6m deep it would not travel more than 18m. It will not travel 50 or 60m but you might be told that to get some survey work out of you. Commonly a bomb will be be missing its tail and it's rare to find one attached , I've only come across that once."

Furthermore, unexpected ordanance may be subject to the 'J-Curve', which is used to describe the characteristic curve followed by an aerial delivered bomb dropped from height after it penetrates into the ground. As the bomb is slowed by its passage through the ground its trajectory curves around to a final heading that points back towards the ground surface. Some UXO are found with their nose section pointing upwards. "With some very high energy bombs, they come out, they fly in the air and go in the ground again. So you have an entry hole, an exit hole and another entry hole. It's not that common but it has happened and it has been recorded," says Cooke.

Finally, sources of contamination include WWI and WWII, in the UK this is especially prevalent in London, Coventry, Manchester and Birmingham; military training sites; and weapons/explosives manufacturing plants. Whereas the generic threat comes from German air-delivered bombs; British Anti Aircraft Artillery; Allied Land Service Ammunition; Allied Small Arms Ammunition (the British have contaminated their own areas with training, especially in the South East of England); and training/practice munitions.

DESIGNED TO KILL

It is vital to understand the risk if unexploded ordinance initiates. "Military weapons are designed to destroy equipment or kill people," says Cooke. "If you have

unexploded ordnance personnel is the key thing you need to think about. If a bomb goes off on the surface shrapnel can be thrown out 1,000m and kill you. So it has significant destructive capacity."

In addition to the risk to personnel, UXO can cause destruction to underground utilities, property, tunnelling equipment as well as damaging corporate reputation.

"Some years ago there was a housing developer that built on a former RAF site. The company took no risk mitigation measures whatsoever; so people were laying gardens at the back of their "executive homes: when unexpected ordinance was discovered in the ground. Phase two didn't sell quite as well as phase 1, especially when 250 people were evacuated from their homes" notes Cooke.

Discovering UXO can have the following consequences for a tunnelling project: programme delay; standing time; project redesign; it can affect the reputation; and cause increased costs.

Cooke explains that the risk of unexplained ordnance needs to be considered early: "Think about UXO early and it's cheaper and cost-effective to mitigate. If you think about it when you encounter it, it's a nightmare, especially in the offshore environment. Which poses the question when it comes to risk management, what should you do?"

Indeed, Cooke adds that "the possibility of UXO being encountered on a site falls within the category of a potentially significant risk and is therefore a matter that should be addressed as early as possible in the life-cycle of a project".

All employers have a responsibility under the Health and Safety at Work Act 1974 and the Management of Health and Safety at Work Regulations 1999 to ensure, so far as is reasonably practicable, the health and safety of their employees and that of other persons who are affected by their work activities. Construction professionals have further specific duties under the Construction (Design and Management) Regulations 2007 (CDM). Under CDM, the client has the legal responsibility for the way that a construction project is managed and run and they are accountable for the health and safety of those working on or affected by the project.

"Clients have a legal duty under CDM 2007 to provide designers and contractors with project specific H&S information needed to identify hazards and risks associated with design and construction work," says Cooke. "The possibility of UXO being encountered on a site falls within the category of a potentially significant risk and is therefore, a matter that should be addressed as early as possible in the life-cycle of a project. :

CIRIA's research project has been approved by the Health & Safety Executive (HSE). The forward, by Dr Donald Lamont, HM principal specialist inspector (construction engineering), HSE, states the following:

"One unintended outcome from construction activity is that UXO is occasionally discovered. When it is, it usually generates considerable media interest and causes major disruption to the public. Fortunately experience shows that the risk of casualties has been very low.

"However, as it is a high consequence but low probability event, appropriate allowance should be made at the design stage for assessing the risk of encountering UXO on-site and for assessing the risk of encountering UXO on site and for mitigating that risk if significant."

In the past the lack of guidance and understanding about UXO has resulted in project delays and occasionally forced developers to pay for unnecessary and expensive mitigation measures. However, in CIRIA C681, Unexploded Ordnance (UXO): a guide for the construction industry, there is explanation and guidance given including good practice guide for the management of UXO risks; good practice methodology using tiered assessments; how to prepare transparent UXO risk assessments; UXO mitigation options; and the role and appointment of UXO consultants and contractors.

CIRIA has designed a robust four-stage risk management process to help construction professionals to deal with UXO hazards.

1. Preliminary Risk Assessment (In order to identify whether more detailed assessment might be required. The assessment is based on data obtained from a desktop review of historical information.)
2. Detailed Risk Assessment (Detailed risk assessment enables an estimate to be made of the likelihood

Questions from the floor

Q: Some years ago, I was working on a tender that involved driving a tunnel in soft ground conditions under a harbour somewhere in the North West of England. The harbour was used for storage in the Second World War. The contractor's attention was drawn to the likelihood of unexploded ordinance in the soft harbour muds and they should mitigate the effects. I didn't know how to address this so I sought advice and I was given all sorts of information but without any specific guidance. Then I recalled a story some years previous in Tunnels & Tunnelling about a TBM in Berlin that managed to chew its way in to unexploded from WW2, it went off and two tunnel workers were killed. So, what's your advice, what do we do?

A: Firstly, if it was a number of years ago I would argue that the client, the developer, the principle designer and contractor would all try and avoid the liability. That used to happen. Since the 2007 Act came out, it is not acceptable to put out to tender a project saying that it could have unexploded ordinance, for the contractor to deal with it and wash your hands of it. They will not get away with it. If a developer or a designer puts that out in a contract now and the contractor doesn't deal with it appropriately or deals with that risk negligently, the directors of the organisations be prosecuted. So, I'm not saying it doesn't happen any more, but they would be putting themselves at terrible risk if this happened today. Everyone has a stake in this and must take reasonable measures to manage and mitigate that risk.

So, if there is an unexploded ordinance risk what you need is a preliminary assessment. The preliminary assessment is important if there is suspicion that unexploded ordinance is there. If the answer is yes, you need a detailed risk assessment and the risk assessment will confirm what kind of unexploded ordinance is present. You'll then continue to follow the four-stage risk management process to reduce the risk.

Q: Working for London Underground for many years, one of the more interesting jobs I've had is looking at possible bombs going off near the tunnels. With Government department and others I'm quite surprised at how much information they have with regards to coordinates of where the bombs were. However, these maps are quite difficult to get hold of.

A: You've hit the nail on the head; these maps are difficult to get hold of. We, and others, have spent a lot of time getting hold of these maps and we've geo referenced them and loaded into a UK database every bit of information we have and we use that database to produce risk assessments. You can get hold of the information yourself - it's just time consuming and the data isn't digitised. There's a lot of information scattered all over the place, there are probably half a dozen companies that have this information. My advice to you would be don't do it yourself, it has taken us a decade to get the information we have. If you do it, it could be inaccurate and you'd be liable for it. Just buy it.

Q: Is there a difference between the ratio of unexploded bombs to exploded bombs between bombs hitting the river and those hitting the land?

A: The only ratio between exploded and unexploded bombs that we have is that 10 per cent didn't go off. If you have a bomb that falls on very soft material or rivers or lakes, then there might be a higher percentage of unexploded ordnance. Often in those areas there is a higher risk as there is no sign of entry (for example, with water there is clearly no sign of entry and with marsh (or soft) land it falls back in on itself). So if you have an area with hard and soft ground, there is likely to be more unexploded ordnance present in the softer ground.

Rapporteur: Rhian Owen, Tunnels and Tunnelling

of encountering a UXO hazard present on a site, giving due consideration to the development type and construction methods to be employed)
3. Risk Mitigation (to eliminate risk or reduce it to an acceptable level)
4. On-site UXO Survey & Clearance (to ensure that the selected plan is implemented correctly and efficiently during the construction phase of the development works and that the works are verified as having been completed to the required level)

Companies need to consider whether a project falls into the as low as reasonably practicable (ALARP) category. "Any risk mitigation should be both necessary and sufficient," says Cooke. "The risk - harm, delay, blight - needs to be considered against sacrifice - money, time, and effort. You don't need to spend millions of pounds if there is no risk. The law allows acceptable residual risk. You don't have to get all risks to zero, because otherwise we wouldn't build anything."

For sites where there is a possibility of encountering UXO, there should be an emergency procedure in place that provides clear guidance on what to do should an item of UXO be encountered, and/or initiated as part of the site works, with accompanying emergency management team roles and responsibilities.

6 ALPHA'S EMERGENCY MANAGEMENT GUIDELINES INCLUDE THE FOLLOWING STEP (PRINCIPAL CONTRACTOR'S RESPONSIBILITY)

- Cease work
- Confirm
- Clear (get personnel at risk behind hard cover)
- Cordon (the area to prevent accident access)
- Control
- Communicate

UXO has continued to cause many problems for construction projects in the UK and elsewhere. These problems have led to expensive delays, during the site investigation and especially groundwork phases of construction, and could have been avoided if an appropriate risk management procedure had been implemented.

"Knowledge dispels fear," concludes Cooke. "Give yourself knowledge: you're not going to die if you do come across unexploded ordinance, as it probably won't go off. It's not my aim to terrify people, quite to opposite. However, if you do come across unexploded ordinance or think that it might be present, then call in the professionals"

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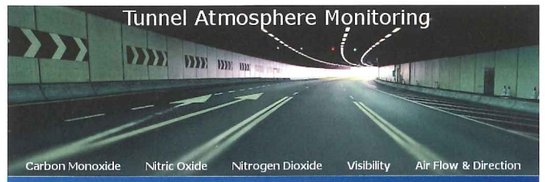

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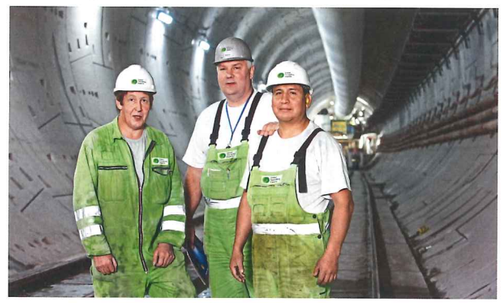

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3-4 February 2016
Atlanta, USA
For 21 years, the Underground Construction Technology International Conference & Exhibition (UCT), has been the meeting place for business-professionals involved in maintaining the underground utility pipe infrastructure.
www.uctonline.com

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

NASTT's No Dig Show
20-24 March 2016
Dallas, USA
The overall No-Dig Show program is focused on one objective: helping you maximise your investment in trenchless technologies, services and applications. If you sell trenchless products and services you'll want to be sure to exhibit.
www.nodigshow.com

InterTunnel
5-7 April 2016
Turin, Italy
InterTunnel is Italy's only exhibition dedicated exclusively to the construction, maintenance and operation of rail and road tunnels and it provides an ideal venue for suppliers targeting this market.
www.intertunnel.com

Bauma Munich
11-17 April 2016
Munich, Germany
The 31st meeting of the world's largest trade fair for construction machinery, building material machines, mining machines, construction vehicles and construction equipment returns to its traditional home: the Neue Messe Munchen exhibition centre in eastern Munich. Bauma is a global driving force behind innovations, an engine for success and a marketplace. It is the only trade fair in the world that brings together the industry for construction machinery in its entirety.
www.bauma.de/en

Infrarail
12-14 April 2016
London, UK
The UK's definitive railway infrastrcture exhibit. Infrarail 2016 takes place against a background of high levels of investment in Britain's main line and urban rail infrastructure. Network Rail has embarked on its GBP 38 billion CP5 spending round, including completion of Thameslink, Northern Hub projects, major electrification schemes and modernisation of signalling.
www.infrarail.com

International Symposium on Submerged Floating Tunnels and Underwater Structures
20-22 April 2016
Chongqing, China
This event, organised by the National Engineering Laboratory for Highway Tunnel Construction Technology, the China Institute of Mechanics, the Chinese Academy of Sciences, and the University of Naples will cover all topics from conceptual design up to operational emergency rescue.
www.cmct.cn

World Tunnel Congress and NAT
22-28 April 2016
San Francisco, California
The 2016 World Tunnel Congress (WTC) and the 39th General Assembly of the International Tunnelling and Underground Space Association (ITA) will be held in conjunction with the UCA's North American Tunnelling conference. Bringing the events together in the US is unprecendented.
www.wtc2016.us

Underground Construction Prague and EETC
23-25 May 2016
Prague, Czech Republic
Delegates are cordially invited to the thirteenth Underground Construction (UC) Prague Conference. Past conferences confirmed that the Prague conference thanks to its scientific and social programmes found a firm position among European tunnelling events.
www.ucprague.com

Swiss Tunnel Congress 2016
15-17 June 2016
Lucerne, Switzerland
The annual Swiss Tunnel Congress (STS) is organised by the Swiss Tunnelling Society and is the premier event for tunnelling in Switzerland. Approximately 800 delegates attend from around 15 nations to take in the high quality presentations and enjoy the technical excursions to construction sites within Switzerland, as well as the surrounding countries. The STS is broadening the spectrum of topics this year.
www.swisstunnel.ch/en

GeoChina International Conference
25-27 July 2016
Shandong, China
This conference will provide a showcase for recent developments and advancements in design, construction, and safety Inspections of transportation Infrastructures and offer a forum to discuss and debate future directions for the 21st century. Conference topics will cover a broad array of technical issues.
www.geochina2016.geoconf.org

No Dig Live UK
20-22 September 2016
Peterborough, UK
Following the success of No Dig Live UK held in September 2014, the 13th biennial trenchless technology exhibition, outdoor demonstrations and seminars will return to Peterborough. Visitors to thie show were offered a wide ranging programme of educational opportunities.
www.nodiglive.co.uk

Innotrans
20-23 September 2016
Berlin, Germany
InnoTrans is the leading international trade fair for transport technology and takes places every two years in Berlin. Sub-divided into the five segments Railway Technology, Railway Infrastructure, Public Transport, Interiors and Tunnel Construction.
www.innotrans.com

Expo Tunnel
19-21 October 2016
Bologna, Italy
ExpoTunnel is an exhibition dedicated to the world of tunnelling, drilling, mining, underground construction and research. It is an opportunity to meet in a global framework of supply and demand of high technology and its field applications, with the chance to learn new methods, access state-of-the-art techniques and face the world market.
www.expotunnel.it

Bauma China
22-25 November 2016
Shanghai, China
Bauma China is Asia's largest and most important event for the construction industry. It attracts international buyers—a fact that guarantees a high return on your investment as well as sustainable success. The show is a platform for product presentations and a grand industry party for communication.
www.bauma-china.com

Bauma Conexpo India
12-15 December 2016
Delhi, India
The International Trade Fair for Construction Machinery, Building Material Machines, Mining Machines and Construction Vehicles—provides the construction industry in India with a professional platform for networking, investment and the exchange of ideas and information. The show launched in 2011 and did an impressive job of putting this quality standard to the test.
www.bc-india.com

2017

World Tunnel Congress
9-16 June 2017
Bergen, Norway
The theme of the 2017 WTC is 'surface problems - underground solutions'. The Norwegian tunnelling industry produces tens of kilometres of drill and blast tunnel every year and is keen to share its expertise with attendees.
www.wtc2017.no

AFTES International Congress
13-15 November 2017
Paris, France
The main French engineering event is themed 'the value is underground' for its 2017 show and will be held in the French capital at 'Le Palais des Congrès de Paris'.
www.aftes.asso.fr

The British Tunnelling Society

The BTS has a membership of almost 800 individual and 68 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. Regular BTS monthly meetings are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month. In recent years, the BTS Young Members (BTSYM) group has also begun hosting events.

BTS Christmas debate
10 December 2015
The traditional end of year debate will this year argue the proposition "This house believes further development of SCL for complex urban tunnels is the best way forward for our industry". After hearing the arguments for and against, some more serious than others, a vote from the floor decides the issue.
Speakers: Ross Dimmock of TAM, and Keith Bowers of London Underground

Sochi Tunnel, Russia
21 January 2016
The January meeting will describe the Sochi Tunnel, built for the 2014 Winter Olympics on the Black Sea coast of Russia, describing the design approach, laboratory and field testing to validate the design parameters and the construction works which took place from February 2011 to January 2014.
Speakers: Carla Zenti of Bekaert Maccaferri Underground Solutions, and Giovanna Cassani, technical director for Rocksoil

The history of the Davy Lamp (joint BTS-MinSouth event)
18 February 2016
The presentation will be about the History of The Davy Lamp and will be given by a mine rescue professional who was involved with the Chile Mine Rescue It should prove to be of great interest to both mining and tunnelling professionals.
Speaker: Brian Robinson of Mine Rescue

Mission Control: monitoring temporary works in tunnels
17 March 2016
The presentation will describe the application of 'cloud based data' to real time review of temporary works performance against design within tunnels, illustrated by a number of example projects in the UK and Hong Kong.
Speaker: Angus Maxwell of Maxwell Geosystems Ltd, Anmol Bedi of BAM Nutall

Harding Prize Presentations
21 April 2016
The annual competition is named in honour of Sir Harold Harding, founder chairman of the BTS and is open to engineers aged 33 or under. Entrants must submit an original paper relating to any aspect of tunnelling which they consider of interest to the industry. The winning paper is selected by members of the BTS Committee.
Speakers: Harding Prize Finalists

AGM followed by presentation on Singapore's Thomson Line
19 May 2016
Singapore's 30km all-underground Thomson LIne (TSL) involves the operation of 30 TBMs to complete the twin running tunnels and the construction of 22 underground stations including 6 interchange stations. This involves a number of challenges in complex urban areas and partially reclaimed land.
Speakers: Andreas Raedle, Leo Suhaendi and Rob Harding (Arup)

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

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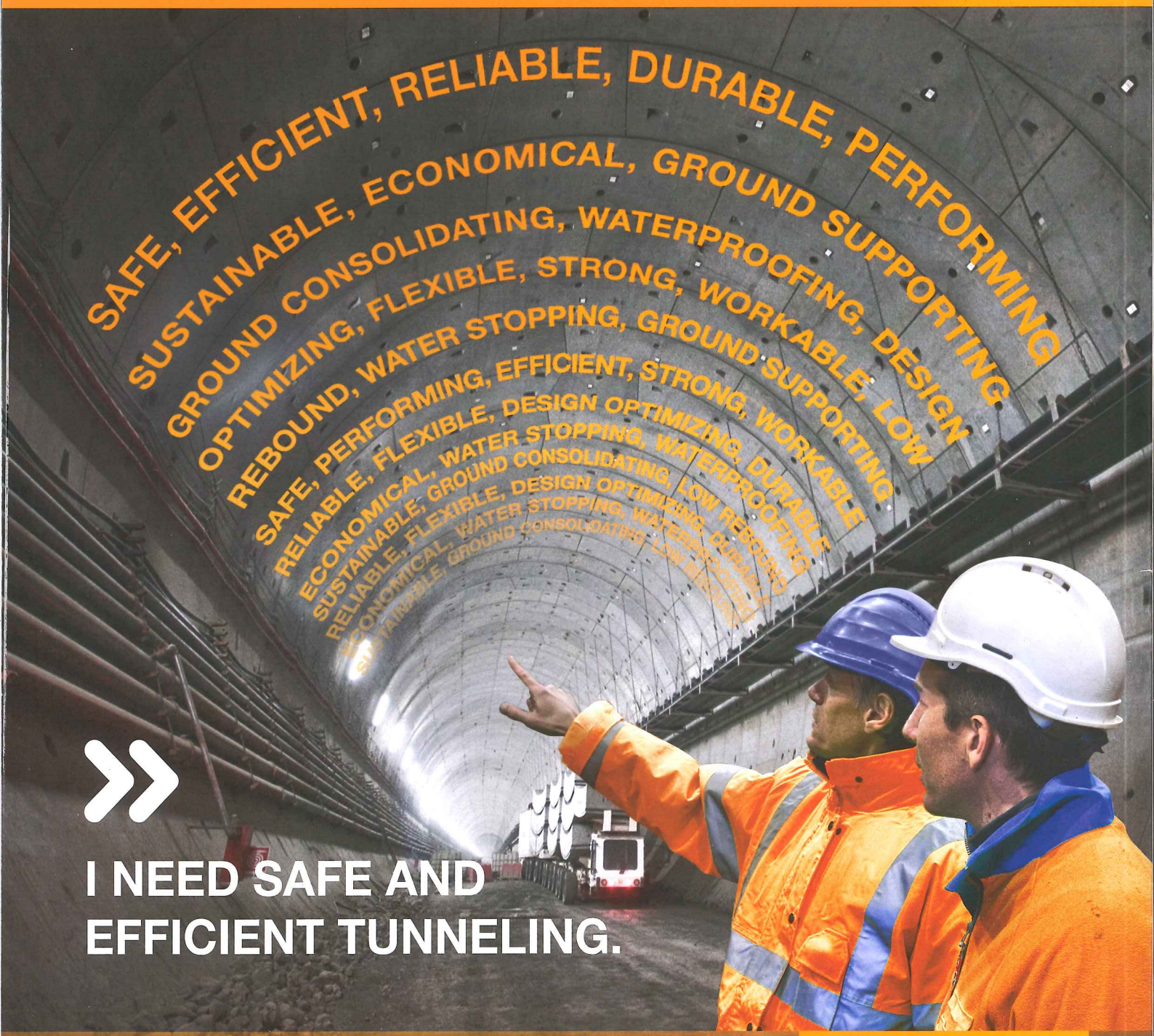

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