INTERNATIONAL EDITION
July 2015

Tunnels AND TUNNELLING

STABILISING SOHO

Compensation grouting works on Crossrail's Tottenham Court Road and Bond Street stations

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Australasia

Grouting

Jacking

HOLDING OUT FOR A HERO

AS I WRITE this comment the Greek banks have closed. Accounts, and non-internal payments for the majority of account holders have been frozen and queues of people are lining up on the high streets to withdraw no more than EUR 60 (USD 66.88) per day. Some hours from now it is due to repay EUR 1.6bn (USD 1.78bn) to the International Monetary Fund (IMF), but it has just requested a new two-year EUR 29.1bn aid deal from a bailout mechanism that is in place for Eurozone countries.

No decision on this has been made, and although Greece's public debt stands at EUR 323bn (USD 360bn), no advanced economy has ever missed a payment on an IMF loan, and the possibility of Greece leaving the Euro looms.

For the next issue of Tunnels and Tunnelling we have been preparing to publish a feature covering the development of Greek tunnelling projects before, during, and after the global financial crisis but for the moment the headlines are staying unwritten.

Greece's tunnelling market has been marked by extremes for the last few decades. Before 1990, there was relatively little tunnelling activity in the country; even Athens didn't have a true underground metro system (with the exception of a limited cut and cover section).

Between then and the crash of 2007 however, Greek tunnelling had it good. European Union funding, and a strong pipeline of planned works, and PPP-led ventures saw tunnels being constructed across all sectors (specifics in next month's feature). And due to the nature of Greek geology and topography, much of this work was quite deep and challenging to ventilate.

The Greeks are rightly proud of their innovations in this area.

However, severe delays struck projects following the crash. Fortunately major projects already under construction at the end of 2009 were not abandoned according to the Greek Tunnelling Society (GTS). Seeming to prove the saying that tunnelling projects are too big to fail. In the light of Greece's growing financial woes, hopefully that stays the case.

Speaking at the British Tunnelling Society's Design and Construction Course at Warwick University, CH2M managing director for tunnelling and earth engineering Martin Knights paid tribute to Mayor of London Boris Johnson as a "champion for British tunnelling".

During a presentation on innovative uses for underground space worldwide, Knights emphasised the importance of having a champion, no matter what you do. He also couldn't fail to mention the pipeline of underground work now looming for Britain. The best in living memory.

Austerity is a bitter medicine, especially when a country is trying to boost its economy and employment figures, and not just cut its deficit. Hopefully Greece gets its champion, and the funding to continue its innovative tunnelling work

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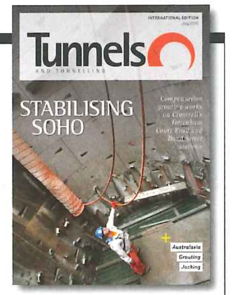
What do you think? Send your views to the editor and join the debate

Alex Conacher
Editor

Cover
Compensation grouting on Crossrail's Bond Street and Tottenham Court Road was logistically tight



Next issue
In the next issue of Tunnels and Tunnelling, we focus on the European tunnelling market for our regional focus, with articles from Greece and the UK also with a focus on health and safety concerns, as well as a report on shaft ventilation on the Lee Tunnel project

This month...

10 YEARS AGO
On 4 June the south drive TBM on the SMART project in Malaysia celebrated a successful breakthrough into the south junction box. After it's launch in September 2004, the 13.26m-diameter slurry Mixshield, operated by Gamuda-MMC JV, emerged from a 2km drive.
Tunnels and Tunnelling, July 2005, p.7

20 YEARS AGO
India's longest rail tunnel, the Karbude Tunnel, broke through on 31 May. Beginning in July 1991 and completed in a period of 45 months, the tunnel is part of the Konkan Railway on the western edge of the Indian subcontinent. With a cross section of 33m^2 it will carry a single broad gauge track. Contractors Gammon India and BT Patil & Sons installed three vertical shafts up to 107m deep so that work could be carried out from eight faces.
Tunnels and Tunnelling, July 1995, p.7

30 YEARS AGO
Road and rail facilities could be combined in the much-needed second Hong Kong harbour crossing. Nine of the originial 30 interested consortia have submitted proposals and it is known that the MTRC has been approached to discuss rail requirements for such a scheme.
Tunnels and Tunnelling, July 1985, p.9

Left: ***Work on Bond Street Station in London, UK. See page 36***

Contributors

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Max works as a freelance technical writer. In this issue he reports on compensation grouting at Crossrail's Bond Street and Tottenham Court Road stations for BAM Ritchies. See feature on page 36.

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SALLY SPENCER
Sally joins the Tunnels and Tunnelling this year as a contributing editor. In this issue, she reports on the WestConnex tunnel project in Sydney, Australia. See feature on page 15.

CROSS RIVER RAIL BUS COMPONENT DUMPED BY LOCAL GOVERNMENT

AUSTRALIA — A bus-rail combi-tunnel proposed for the next crossing under the Brisbane River has been rejected by the latest local government. That was the latest vision for getting the suspended Cross River Rail project going.

According to local media, Queensland Deputy Premier Jackie Trad killed off the bus component of the plan put forward by the previous government, although it did not rule out considering the alignment the Newman government had decided on.

Speaking at a Property Council of Australia breakfast, Trad said it was "definitely the case" a second river crossing for Brisbane was crucial. And the Labor government "would not be going back to the drawing board" on it.

"We will give some options to Building Queensland to consider," Trad said. "But what is not in dispute, is if we want to stop the chaos of public transport gridlock that is due in the coming years, then we need to build another river crossing for our city, for the south-east corner, and Labor will get on the job of doing it."

She added, "Buses were never part of the original scope of the second river crossing."

"So I think it is important that we go back to what is technically responsible. You need to go back to what this was intended for, as we know the Bus and Train Tunnel was the idea of the former Premier Campbell Newman.

"What we need is proper transport planners and technicians to advise the government, not a frustrated engineer who wanted to put buses and trains together in a tunnel, that essentially, most public transport experts said was more spin than substance."

Building Queensland, the independent statutory body currently being established by the Palaszczuk government, will have to review any proposal put forward.

Infrastructure Partnerships Australia chief executive Brendan Lyon said the question would always come back to the money, despite the well-recognised need for the project.

"The Cross River Rail is going from important to urgent given the growth in patronage on Brisbane's rail network and the fact that every train will be full to bursting point in just a few short years," Lyon said. He added that the Queensland government needed to explore a public private partnership to get the project operating.

"A new rail crossing of Brisbane's river needs to be a top order priority for Queensland, but finding the money to pay for it is going to be hard given the challenging budget and high levels of existing debt," Lyon said."While the state would be wise to use a PPP to finance the project, there will still need to be budget capacity to repay the cost over time."

In 2013 Infrastructure Australia rated the Cross River Rail project as "ready to proceed", with the then Queensland government seeking AUD 3.4bn for the AUD 4bn project. By mid-2013 no agreement could be reached between the governments in order to get the project off the ground and it was delayed.

Contractor selected for Tel Aviv Red Line

ISRAEL — Project authority NTA has selected a Chinese-Israeli joint venture to undertake civil works for the Red Line of the Tel Aviv light metro. The joint venture comprises the China Railway Tunnel Group subsidiary of China Railway Group (51 per cent) and the Solel Boneh Infrastructure subsidiary of Shikun & Binui Group (49 per cent). The design-build contract is valued at USD 810M.

The scope includes boring 11 km of 5.5m diameter twin tunnels linked by 16 cross passages, as well as six underground stations. The stations are to be designed by NTA. The 23km Red Line will link Petakh Tikva, to the northeast of Tel Aviv, with Bat Yam to the south; it is expected to open for traffic in 2021. Seven more lines are planned for the city, but delays have dogged infrastructure projects in Tel Aviv so far.

Bond Street awarded environmental award

GREAT BRITAIN — The Costain Skanska joint venture (CSJV) team working on the new Bond Street Station project (C412) has won a Green Line environmental award from Crossrail.

The Green Line is Crossrail's environmental award scheme, which rewards individuals and teams on its construction sites for tackling environmental issues and supporting environmental best practice. Chris Sexton, Crossrail's Technical Director, presented the award to the project team on recently.

In order to obtain the award, the team had to submit a comprehensive assessment of the project as well as an audit to demonstrate the commitment and regular involvement of the leadership team; visibly communicated environmental objectives; progress against targets monitored and regular feedback provided; and visible environmental engagement like site inspections.

The awards aim to improve environmental awareness and achieve positive environmental behaviour change across all of Crossrail's sites, with the ultimate aim of improving environmental performance.

"The biggest focus on C412 has been the promotion of behavioural change and increasing the amount of reported environmental observations, which really highlighted the commitment of the project team in promoting environmental awareness and behaviour change," said Melissa Wellings, the Environment Manager working on the project.

"The biggest focus on C412 has been the promotion of behavioural change and increasing the amount of reported environmental observations, which really highlighted the commitment of the project team in promoting environmental awareness and behaviour change," said Melissa Wellings, the Environment Manager working on the project. Following a behavioural awareness campaign, the project recorded a near four-fold increase in environmental observations between February and March 2015.

The award cannot be awarded based on short-term initiatives as the evidence has to demonstrate consistent 'buy-in' from everyone on the site over a period of time. There is also a follow up site visit from a Crossrail Environmental representative to ensure that improvements have been made.

"Regular monitoring of environmental observations takes place and there are monthly awareness campaigns on different environmental topics along with environmental toolbox talks," said Melissa.

Under the C412 contract, CSJV is responsible for the construction and fit-out of the Western Ticket Hall near Davies Street and Eastern Hall near Hanover Square.

GLOGGNITZ CONTRACT AWARDED

AUSTRIA — ÖBB-Infrastruktur AG has awarded Hochtief Infrastructure Austria, Implenia Austria and Thyssen Schachtbau the contract to build the Gloggnitz Tunnel, Hochtief announced last month. The contract value granted to the SBT 1.1 Tunnel Gloggnitz joint venture totalled some EUR 457M (USD 511M).

Hochtief's share is worth around EUR 183M (USD 204.6M), representing a 40 per cent stake in the JV. The future east portal of the Semmering Basis Tunnel (SBT) is situated on the edge of the city of Gloggnitz in southern Lower Austria. The SBT 1.1 Tunnel Gloggnitz contract section is around 7.4km in length and will be driven from two sides - both from Gloggnitz and via the intermediate access in Göstritz - using NATM. The JV will build two parallel, single-track tunnel tubes with 16 crosscuts at maximum intervals of 500m.

Owing to the challenging geology and to ensure optimal logistics, an around 1,000m access tunnel will firstly be driven into the mountain during the course of construction work, to secure smooth construction logistics. Furthermore, two shafts going to a depth of some 260m with the caverns required for construction operations will be created at the end of the tunnel. Completion of the Gloggnitz Tunnel is scheduled for 2024.

The 27.3km, twin-tube rail tunnel between Gloggnitz and Mürzzuschlag represents an effective investment in the rail infrastructure of both Austria and Europe. It is located on one of Europe's main traffic corridors, the Baltic-Adriatic Corridor.

Japanese TBM manufacturers sign consolidation basic agreement

JAPAN — IHI Corporation, JFE Engineering Corporation (JFEE), Japan Tunnel Systems Corporation (JTSC) (a consolidated subsidiary of IHI with 49 per cent of the shares held by JFEE), Mitsubishi Heavy Industries (MHI), and MHI subsidiary Mitsubishi Heavy Industries Mechatronics Systems all announced the conclusion of a basic agreement for the integration of their respective shield tunnelling machine businesses.

The five companies expect to conclude a binding formal contract this summer which will outline the conditions for the establishment and operation of the new company, and aim to realize the business integration by January 2016 subject to customary approval by the relevant authorities.

Under the agreement, JTSC and MHI-MS will split off their shield businesses which will be transferred to the new operating company. The new operating company will be positioned as an IHI consolidated subsidiary with JTSC and MHI having capital contribution ratios of 60 per cent and 40 per cent respectively.

The domestic market for the shield tunnelling machinery – large-scale equipment used to excavate tunnels for subways, roads, sewage lines and public utility conduits, and others – is expected to rapidly expand in the run up to the 2020 Olympic and Paralympic Games in Tokyo, driven primarily by large projects such as the Tokyo Outer Loop Road and the Linear Chuo Shinkansen (Bullet Train).

However, after the Olympics, there is expected to be a significant drop in domestic demand due in part to the conclusion of maintenance on Japan's highway network. However international demand for shield tunnelling machinery is expected to grow significantly due to the need for infrastructure maintenance and subway route expansion.

Such projects include the development of inland urban areas in China and India and further urbanisation in ASEAN nations, the Middle East, Turkey and other areas. In order to ensure the continued existence and expansion of the shield tunnelling machinery business in the medium and long term, there is a need for a business organization that can reliably capture growing domestic demand while also accelerating expansion overseas. The five companies reached today's basic agreement based on this common recognition.

VINCI-Bouygues JV bags USD 300M Cairo metro job

EGYPT — A joint venture led by VINCI Construction Grands Projets alongside Bouygues Travaux Publics, a subsidiary of Bouygues Construction, has won a USD 300M contract to build the extension of Line 3 of Cairo metro system.

Line 3 works will comprise the Phase 4 of the Cairo metro, which will continue on from Phase 2, and will connect between Haroun and El Nozha stations.

The project will involve construction of a 5.15km tunnel and five underground stations on the east-west line across the Egyptian capital.

Vinci Construction Grands Projets and Bouygues Travaux Publics will work with Egyptian partners, Orascom Construction and Arab Contractors to complete the project within a short design-build delivery deadline of 34 months.

The team will modify an earth pressure balance tunnel boring machine used on the previous phase, to operate as a slurry machine.

The new project will create around 3,200 jobs, mostly employing locals from the Egyptian region.

Fresh push for Vailoo-Singhpora tunnel in Kashmir

INDIA — The government of Jammu & Kashmir in northern India has begun preparation of a new detailed project report (DPR) for construction of the proposed 4.5km Vailoo-Singhpora tunnel. First proposed in 2010, five years on no progress on proposal to connect Anantnag with Kishtwar, provide alternative all-weather road to Kashmir.

"We will prepare a fresh Detailed Project Report for the tunnel and once the study is completed, we will take up its construction with the Union Government," said Minister for Roads and Buildings (R&B), Syed Altaf Bukhari according to local media.

Construction of the tunnel has been handed over to National Highway Authority of India, and as a result, the state government was been asked to prepare the fresh DPR. Earlier the military's Border Road Organization (BRO) was tasked with constructing the tunnel.

"The tunnel at Ahlan in Vialoo area of Kokernag would bypass treacherous stretch on road that remains buried under snow during winter and we can have traffic on the road round-the-year.

"Besides, it would also reduce distance between Daksum (Kokernag) in Anantnag and Chatroo in Kishtwar," said an spokesman for the R&B department. "The proposal for the tunnel, estimated at INR 4bn (USD 62M), was actually mooted in 2010 and the project was initially to be executed as a PPP, with J&K Bank as the funding agency.

"The entire project was targeted for completion in 18 months," he said. "However the project was later shelved for unknown reasons."

Delhi Metro damages historical building

INDIA — Delhi Metro's heritage line has damaged a 113 year old building. The underground tunnelling work for the Central Secretariat-Kashmere Gate line has led to the partial collapse of a heritage building in Kashmere Gate, within the complex that houses the Ambedkar University.

Part of the colonial-era structure, one of the most architecturally important buildings in the area, collapsed late last month after Metro's tunnelling work below the building had weakened the foundation, experts said. The complex has other historically important structures such as the Dara Shikoh Library.

Delhi Metro has pledged to reconstruct the collapsed portions of the building, built in 1902. An area resident said it came down in a huge cloud of dust one evening. No one was hurt.

Environmentally friendly revision to Fiordland Tunnel

NEW ZEALAND — A new plan has been put forward for a tunnel in Fiordland National Park to reduce the travel time between Queenstown and Milford Sound.

Milford Sound Link Rail has lodged a submission on the Queenstown Lakes District Council's Ten Year Plan, seeking support for a 13.5km rail tunnel.

The tunnel would link the Dart and Hollyford valleys, with electric railway wagons transporting buses and cars. The Conservation Minister has previously turned down two proposals for alternative routes between Queenstown and Milford - a monorail and another tunnel.

But the proponent of the latest plan, Colin Jenner, said it allayed concerns the minister had with the other proposals relating to environmental effects and tunnel safety.

Rather than using buses in the tunnel, as with earlier proposals, electric trains would be used that would pull in fresh air with them, he said.

Spoil from the tunnel would be spread on farmland in the Dart Valley, not left in the Hollyford Valley; the tunnel entrance was outside the national park, and a rail tunnel would be safer than a road one.

Breakthrough at Sanam Chai Station

THAILAND — Excavation completed last month on the MRTA Blue Line Contract One. A 6.44m-diameter Terratec EPBM broke through at Sanam Chai Station in Bangkok on 16 May, marking the end of tunnelling on 2,800m westbound alignment.

Contractor Italian-Thai Development passed through two unexcavated stations and one ventilation shaft along the route. The next, eastbound bore will require the crossing of two already excavated stations which the machine will need to be dragged through.

Geology consisted of complex stiff clay and Bangkok's aquifer sand with large gravels and sand stone at the deepest parts of the alignment. As well as high water pressure, the TBM passed under historical buildings in an old area of the city. Settlement control was key, said a Terratec spokesman. "The TBM was equipped with a 2-liquid type backfilling system and a special Clay Shock injection system through the shield. The combination of both was proven to be very effective and restricted the settlement to less than 10mm in those critical areas.

"The EPBM had to bore through as many as eight diaphragm walls, as well as several obstacles such building foundations. This was expected at the beginning of the project and Terratec selected a cutterhead design with conical shape to overcome those smoothly without disrupting the soil around.

"The TBM achieved the planned average rates of 18 meter per day or 82 metre per week during the boring cycles."

Now the TBM is being dismantled and moved to initiate the eastern bore by beginning of August.

Istanbul approves mooted mega project

TURKEY — Istanbul Metropolitan Municipality (IMM) has approved the USD 3.5bn three-level, sub-sea tunnel project that was recently announced by Prime Minister Ahmet Davutoglu.

The megaproject will have a three-storey, sub-sea tunnel running under Istanbul's Bosphorus Strait connecting the city's two sides with one railway and two highways and is expected to cut travel times to 14 minutes.

The project will be environmentally-friendly reducing fuel oil consumption by roughly 54 million litres in addition to decreasing carbon emissions by up to 175t per year.

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

editor@tunnelsonline.info

DENMARK APPROVES CONSTRUCTION ACT FOR ROAD AND RAILWAY TUNNEL PROJECT

DENMARK — The Danish Parliament recently approved the proposed Construction Act for the Fehmarn Belt fixed link road and railway tunnel. This new development will result in the construction of a tunnel to Germany and rebuilding of the connecting line from Ringsted to Rødbyhavn.

The Fehmarnbelt fixed link will see an 18km-long immersed tunnel between Rødbyhavn on Lolland and Puttgarden on the German island of Fehmarn.

On the other project, the upgrading work will result in the line expansion with two electrified rail tracks, allowing for speeds of up to 200kph.

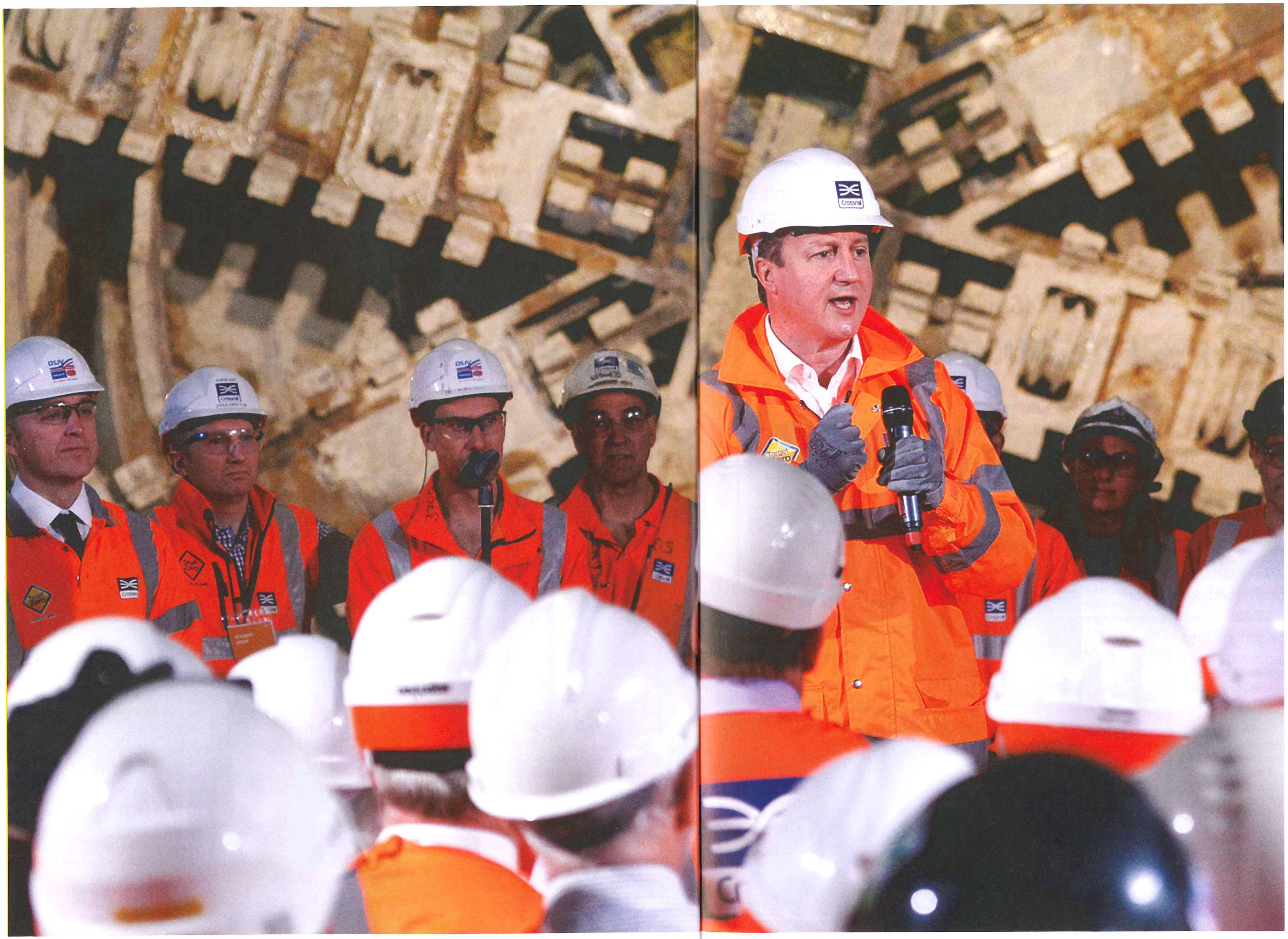
The Fehmarnbelt link is expected to minimise the travel time between Copenhagen and Hamburg by approximately 2.5 hours. Both the projects will be financed by users of the fixed link, Femern stated.

Constituting the final environmental approval of the project, the Construction Act, which will authorise the state-owned companies, Femern and Femern Landanlæg, to build and operate the fixed link and associated landworks in Denmark respectively.

However, construction on the project will start only when German plan approval is in place and after the review of the overall economics of the Fehmarnbelt project this autumn.

In Germany, even though the political decision for the project was taken in 2009, the process to give formal approval by the authorities in Schleswig-Holstein is still in progress.

Archaeological investigations will continue in parts of the production area as it is still awaiting environmental approval.



Left: UK prime Minister David Cameron visited Crossrail with Mayor of London Boris Johnson to mark "the end of tunnelling" on the project. Cameron said: "Crossrail is an incredible feat of engineering that will help to improve the lives of working people in London and beyond." Crossrail tunnelling began in the summer of 2012 and ended at Farringdon with the break through of tunnelling machine Victoria

SYDNEY GETS CONNECTED

Sydney's ambitious WestConnex project aims to get the traffic flowing freely – and two-thirds of it will be underground. **Sally Spencer** reports on the project, one of the NSW Government's key infrastructure projects which aims to ease congestion, create jobs and connect communities, said to be the largest integrated transport and urban revitalisation project in Australia

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

ANYONE WHO has urvived a long haul flight to Sydney only to endure another couple of hours stuck in a traffic jam on arrival should spare a thought for residents, commuters and hauliers who do daily battle with road congestion.

As a case in point, the M5 East, which links the central business district (CBD), Sydney airport and Port Botany to south-west Sydney, Canberra and Melbourne had a design capacity of 77,000 vehicles per day when it opened in 2001. That capacity was exceeded within just six months and daily volumes now top 100,000.

Sydney's road arteries are clogged, with congestion currently costing the NSW economy an estimated AUD 5.1bn (USD 4bn) a year, rising to a potential AUD 8.6bn (USD 6.7bn) by 2020.

The city's population is set to rise by 1.6 million over the next 20 years, with most of the population increase predicted to occur in Western Sydney, an area that has already grown to become the third largest economy in Australia.

Unless major infrastructure changes are implemented, NSW's capital city could grind to a halt.

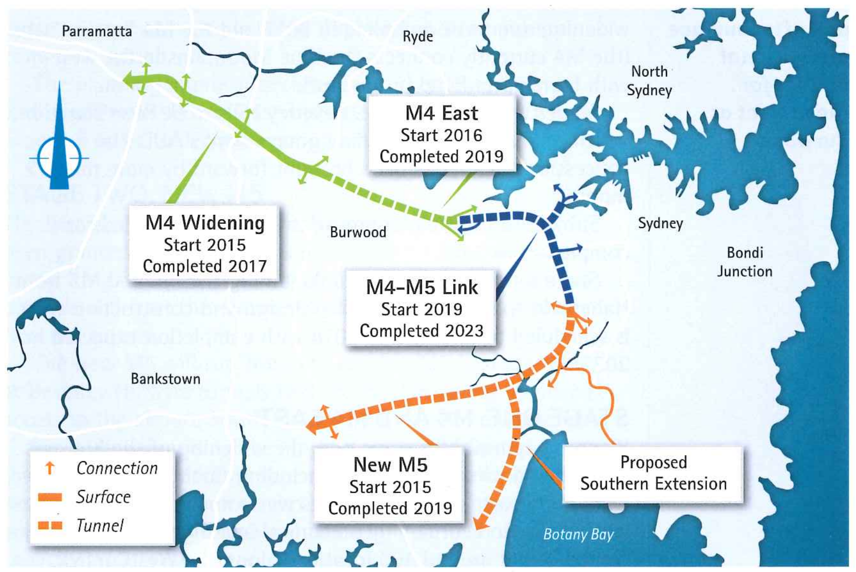
That's the compelling motive for the NSW government's investment of billions of dollars in the largest urban transport and infrastructure programme in its history, a programme that Duncan Gay, NSW's Minister for Roads & Freight, calls "a game changing project for Sydney and for the NSW economy".

The infrastructure improvements will include some rail links but as the city's road network accounts for 93 per cent of passenger journeys and 86 per cent of freight movement (freight and logistics are worth AUD 58bn to the NSW economy annually) the motorway system is being expanded.

In 2012 the government committed to building WestConnex, an integrated project to expand capacity and ease traffic flow on the existing M4 and M5 corridors and improve links to Sydney airport and the Port Botany area. Ultimately WestConnex will link the two motorways together, thus joining the east and west of the city for the first time.

The estimated AUD 11 to 11.5bn (USD 8.6 to 8.9bn) capital cost of the entire WestConnex programme will be funded in part by tolls but also by a AUD 1.8bn (USD 1.4bn) contribution from the NSW government and AUD 1.5bn (USD 1.2bn) from the Australian government.

Below: ***Distribution of motorway projects in the area***



Above: ***Before and after surface promotional images for the project at Burwood***

In addition, the Australian government is providing a concessional loan of up to AUD 2bn (USD 1.6bn).

The decade-long construction project, which is still at a very early planning and design phase, will total 33km of traffic signal-free motorway. And, in order to minimise the need for property acquisition and disruption to communities along the route in this densely urbanised area, two-thirds of it will be underground – WestConnex will include up to 22km of tunnels.

The development is being steered by the WestConnex Delivery Authority, which was established by the NSW government to deliver the programme of works for Roads & Maritime, and is being delivered through a series of projects in three stages:

Stage one is the M4 Parramatta to Haberfield section, which will be in two phases, with the M4 widening due to be complete in 2017 and the M4 East in 2019 (the M4 currently connects the Blue Mountains in the west with Parramatta Road in the east).

Stage two is the New M5 Beverley Hills to St Peter's section, which, thanks to the Australian government's AUD 2bn concessional loan, has been brought forward by more than 12 months.

Subject to planning approval, this is also scheduled for completion in 2019.

Stage three is the M4/M5 link, joining the M4 and M5 from Haberfield to St Peter's. Detailed design and construction work is scheduled to start in late 2018 with completion expected in 2023.

STAGE ONE: M4 AND M4 EAST

Planning approval for stage one, the widening of the M4, was granted and preparatory work, including final geotechnical work and investigation of utilities was completed before site work began in February (geotechnical investigations are being carried out at around 100 locations along the WestConnex corridor in order to inform the design and construct tender process and the Environmental Impact Statement). The design and construction of this 7.5km section of WestConnex has been contracted to the Rizzani De Eccher Leighton joint venture.

Work on the M4 East section will include two three-lane tunnels in each direction under the Parramatta Road corridor to Parramatta Road and City West Link, Haberfield. The tunnels will be about 5km in length, with additional length required for the ramps in each direction.

Moving the motorway underground will enable "urban revitalisation and regeneration" of the area at surface level, said the WestConnex Delivery Authority, which anticipates the development of different housing types, plus business and retail investment along Parramatta Road.

It also expects the tunnels "will provide a general improvement to local air quality on surface roads where traffic numbers are reduced".

Design development is ongoing and is aimed at optimising the function and cost of the M4 East project and also mitigating, or preventing potential environmental impacts.

Ongoing design options include optimising the alignment of the tunnels to avoid specific geotechnical constraints such as palaeovalleys and to provide appropriate gradients for heavy vehicles; and selecting appropriate sites for tunnel portals, ventilation stacks and possible air intakes along the alignment.

The most recent road tunnels constructed in Sydney – including the M5 East tunnel, the Cross City Tunnel and the Lane Cove tunnel have all been designed to avoid portal emissions and tunnel air is primarily discharged from ventilation stacks.

Once operational, the tunnel ventilation system is expected to be the main consumer of energy within Stage one of the project.

The WestConnex Delivery Authority says an "iterative design process" would investigate means to reduce energy consumption as much as possible but extrapolating data from existing tunnels has led to the conclusion that the M4 East tunnels have the potential to consume anywhere between 11,200 and 54,000MWh per year, depending on ventilation system efficiencies.

These figures equate to the energy consumption of 1,800-8,500 households.

Thiess Samsung John Holland JV (Thiess, Samsung C&T Corporation and John Holland) have been appointed as contractor and designer for the M4 East. An Environmental Impact Statement (EIS) is being displayed and community comment invited.

The planning approval decision is expected late this year and major work should start mid-2016. Tunnelling activity is expected to be undertaken on a 24-hour basis.

STAGE TWO: NEW M5

The first part of stage two, the New M5, has also recently been granted planning approval and will see improvements to the King George's Road Interchange. Construction on this upgrade will start this summer and will clear the way for the New M5 tunnel.

The New M5 will run from the existing M5 East corridor at Beverley Hills via tunnels to St Peter's, providing improved access to the airport, south Sydney and Port Botany precincts.

New twin tunnels will be "higher, wider and flatter" than the existing M5 East tunnels (the steep gradient in the westbound tunnels slows travel speeds and worsens congestion and greenhouse gas emissions) and will more than double capacity.

Once the New M5 main tunnels are open it will be possible to undertake a programme of refurbishment and equipment upgrades on the existing M5 East tunnels.

The government is working with the private sector to develop the best design and the precise location of where the tunnels will emerge and where the exhaust stacks will be won't be available until late this year when the WestConnex Delivery Authority lodges its EIS.

However, the location of the western portals will be somewhere between King George's Road and Bexley Road, while the eastern portals at St Peter's will be in the vicinity of land generally bounded by the Prince's Highway, Campbell Road, Burrows Road and Canal Road.

Tunnel stubs will be constructed to allow for the future connection to Stage three of the WestConnex programme.

The current thinking is that the 9km tunnels will have a vehicle clearance of 5.3m, an improvement on the 4.6m in the existing M5 East tunnels, and gradients will generally be limited to 4 per cent, compared with up to 8 per cent.

Tunnel depth will vary depending on geological constraints and operational design requirements (such as road gradient). Construction of the tunnels will be carried out around the clock, seven days a week and road headers and/or TBMs may be used for the deeper parts of the alignment, while cut and cover construction methods may be employed at shallower sections, such as the tunnel portals.

Other excavation activities are likely to include the creation of cross passages and caverns or shafts for other support infrastructure.

On and off ramps at each end of the project will include sections of tunnel to provide direct connections from the main motorway tunnels to the M5 East motorway and the proposed St Peter's interchange.

Spoil from tunnel excavations is expected to be largely uncontaminated and its removal will be managed in accordance with WestConnex Delivery Authority's management strategy, which is in development.

The EIS will provide further details on the estimated volume of spoil and the preference is for it to be re-used in other construction projects wherever possible – these could include development sites that need engineered fill, or other land rehabilitation projects.

The Alexandria Landfill site has been earmarked to support the tunnel and road construction activities required for

Above: ***Before and after surface promotional images for the project at Flemington***

the St Peter's Interchange.

The tunnel carriageways will be built to accommodate three-lane operation and will boast more efficient and modern tunnel ventilation systems, which will ensure "visibly clean air quality".

The NSW government has appointed an Advisory Committee on Tunnel Air Quality to review current national and international best practice. A detailed air quality study will be included in the New M5 EIS and will assess air quality impacts from the construction and operation phases of the project.

The ventilation system will be designed and operated to meet stringent in-tunnel, local and regional air quality criteria imposed by the Department of Planning and Environment. As well as ensuring the air quality within the tunnel is maintained, it will ensure the tunnel has a negligible impact on local and regional air quality.

The locations of the ventilation facilities will be subject to further design development but they are likely to be located close to the tunnel exit portals.

This is deemed to be the most cost effective and energy

Geology in the New M5 project corridor

The western areas of the project are relatively flat and low-lying, with gentle undulating hills ranging from 30-40m. The topography of the project corridor near the confluence of Wolli Creek and the Cooks River is relatively flat and low-lying (5-10m) and gradually declines towards Botany Bay.

The geology along the project corridor relates to the Sydney Basin Stratigraphy, with Ashfield shale (part of the Wianamatta Group) overlying Hawkesbury sandstone. The Mittagong Formation separates the Ashield shale from the underlying Hawkesbury sandstone over much of the Sydney Basin.

Ashfield shale corresponds to ridgelines within the project corridor and is present largely in the west and to the north of Sydney airport.

The Ashfield shale is estimated to be around 60-70m in thickness and consists of siltstone and laminate sub-group units.

The Mittagong Formation comprises fine-grained sandstone and siltstone. The thickness of the formation is variable but is generally less than 10m.

Hawkesbury sandstone is present towards the Cooks River within the project corridor, in areas of steeper topography. Hawkesbury sandstone is a medium to coarse-grained quartz sandstone deposited in beds of 1-3m thick.

Hawkesbury sandstone and Ashfield shale are overlain by unconsolidated Quaternary sediments in areas adjacent to the Cooks River and Alexandra Canal.

Sections of the project corridor in the vicinity of Tempe and St Peter's are understood to be near to the location of historical brick pits, quarries and disposal facilities, which are underlain by Pleistocene-aged Botany sands, comprising Aeolian sand and dune deposit with lenses of peat and clay.

efficient location given the reduced requirement for pushing tunnel air in the opposite direction to traffic flow.

Having said that, management of in-tunnel air quality may necessitate the construction of ventilation facilities at intermediate locations along the main alignment tunnels.

WestConnex Delivery Authority is installing air quality monitoring stations to establish additional baseline data.

The choice of portal location, together with the tunnel alignment to St Peter's and the detailed design, will be proposed by the contractors tendering for the project.

A shortlist for the design and construction of the New M5 was announced in November 2014 and tenders were invited shortly after.

The five consortia bidding for the contract are: Lend Lease Acciona joint venture; Leighton Dragados Samsung joint venture; Salini Impregilo; Strabag: and TunneLink (consisting of Ferrovial Agroman, Ghella and McConnell Dowell Constructors).

The preferred bidders were due to be announced in summer as Tunnels and Tunnelling went to press.

Below: ***Artist's concept of the finished tunnel***

STAGE THREE: M4/M5 LINK

Stage three, the M4/M5 link, will deliver a motorway tunnel with three lanes in each direction, joining the M4 and M5 corridors (Stages one and two).

The indicative route has already been realigned as the WestConnex Delivery Authority has factored in a possible northern extension of WestConnex towards ANZAC Bridge.

This would tie in with Infrastructure NSW's proposal to build a new Sydney harbour tunnel – the Western Harbour tunnel – which would run from Balmain to Lane Cove and link with the M2.

The harbour tunnel project is a good decade away but the chairman of Infrastructure NSW, Graham Bradley, is keen to see the plans progress and for the link with WestConnex to be established.

"It's a 10-year plus project away but it could well be an adjunct to WestConnex that will have an impact on how it might affect the interconnection here with the city," he said.

The M4/M5 tunnel, which has lengthened by 1km to 8km as a result of the realignment, will now follow the route of the existing City West Link Road before turning south to St Peter's.

"This new alignment will continue to support the reduction of traffic on Parramatta Road, enabling urban renewal, and in addition will support the NSW government's proposed future Western Harbour tunnel and will help provide a much needed western bypass of the CBD (central business district)," said Duncan Gay.

Again, said Gay, "the government is committed to delivering wider, higher and flatter road tunnels for Sydney, designed to world's best practice, avoiding mistakes of the past".

"Overheight tunnel incidents can cause considerable damage to Sydney's tunnel infrastructure, such as lights, fans and sprinkler systems and have a massive impact on traffic flows, inconveniencing thousands of motorists," said a WestConnex Delivery Authority spokesperson.

"Learning from the past, tunnel clearance will be 5.3m rather than 4.6m."

As with the New M5 tunnels, the M4/M5 link tunnels will also be built at a low gradient.

"By 2031 the M4/M5 link is expected to carry 120,000 trips each day, about 40 per cent of daily WestConnex trips," said the spokesperson. "Unless Stage three is built these trips will be borne by surface roads in the inner west and across the Sydney road network"

NEXT GEN POTASH

At a joint meeting of the *British Tunnelling Society* and *Min South*, **John Elliott** - Managing Director, *Alan Auld Engineering* and **Alun Price Jones** - Technical Director, *Cementation Mining* presented the Picadilly potash mine in Canada. The presentation looked at some deep mine shafts and explored the next generation of potash mines currently being sunk in Canada. The design and construction of the shafts for the Piccadilly project were also described in detail

MINING IS one of Canada's most important sectors and plays a vital part in the country's economic prosperity. Canada is blessed with a wide variety of resources, and while the industry has had some serious ups and downs over the past five years, particularly on the exploration side, growth is expected once more.

New Picadilly Mine in the background, Penobsquis Mine in foreground

"Canada has an extremely active mining industry, many many deep mines which are located in different provinces but there are a number of major mining fields," says John Elliott, managing director, Alan Auld Company, which made its as a specialist designer of deep mine shafts. "The country has pretty much everything; gold, copper, diamonds. The shafts for these mines are typically between 500m and 2km deep. There are quite a few new projects ongoing - some of these are under construction, some are in planning. There is also a lot of ongoing upgrade and maintenance work."

POTASH

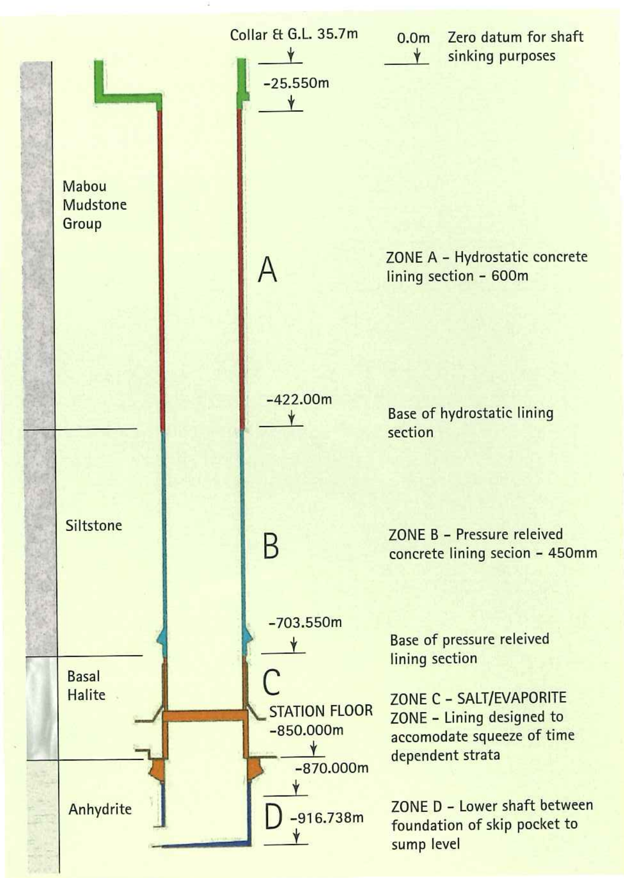
Potash is mainly found in Saskatchewan; it was first discovered in the province during the early 1940s while drilling for oil. Around this area gold, copper and nickel can also be found. Whereas some of the base metals are over in the east of Canada and diamonds are in the far north.

What is potash? The mineral's name refers to several forms of potassium salt, the most important being potassium chloride or KCL. The mineral is found in thick massive seams and is pink and crystalline. It is found within evaporative sequences including thick beds of halite and other related minerals, such as carnallite.

Right: ***Shaft station excavation works***

Below, right: ***Shaft station excavation in halite***

Below: ***Simplified cross section of production shaft on the Picadilly project showing geology and shaft lining zones***



"Potash is mined by continuous mining methods using cutting machines, which excavate long rooms in more than one pass," says Elliott. "Most mines are located around 1km or more beneath the ground. Once you get below this depth ground control begins to become a problem due to high ground loads and relatively weak strata."

In terms of the world potash production, Canada is a major player - nearly half of the world's potash production comes from the country. "A load of it comes from Russia [34.7 per cent] and Belarus [7.9 per cent] as well. But if you go on Google look at 'Russian sink hole' you'll see the Russians are a little less careful; they have a lot of problems with collapses. There isn't this problem in Canada as it's generally deeper. However, there are a few new mines in Russia and Belarus that are now of a similar depth," says Elliott.

Potash offers huge potential. BHP Billiton, the world's biggest miner, has shown its ambitions in this area. In 2010 BHP Billiton offered PotashCorp of Saskatchewan (PCS) CAD 39bn takeover offer, signalling the seriousness of its ambition. While this attempt failed, it was a boost that the potash market needed. Since then, BHP has continued with its Jansen project in Western Canada, the cost of which has been put at CAD 14bn and which would be the world's largest potash mine whenever it opens.

The existing potash mines in Saskatchewan are Vanscoy, Cory, Patience Lake, Alan, Colosay, Langian, Belle Plain, Esterhazy, and Rocanville. "There are currently some new mines going down," adds Elliot. "Picadilly is now ramping it up to full production. BHP is are building Jansen and we're currently designing the shafts on that one. There's a new ventilation shaft going down at Rocanville while K3 is a new mine that will replace K1 and K2. There's a lot of activity."

When PCS purchased the Penobsquis mine, mill and port facility as part of a larger USD 112M transaction from Rio Algom, it was another example of potash making a comeback. The future of potash looked promising, but even more promising was what lay about 1km beyond the Penobsquis mine.

PICADILLY

The Picadilly mine is a new mine in New Brunswick, situated adjacent to the old Penobsquis mine. The overall scope for Picadilly was to ramp up for production over three years to produce two million tonnes per annum with a mill plant and brine pipes. The project was an engineer, procure and construct project with 30 active subcontracts at any one time. Cementation Canada Inc was approached to carry out the design and construction of the shafts for the new Picadilly mine and engaged the Alan Auld Company as the shaft liner designer.

"PCS are the largest producer in Canada and own and operate the Penobsquis mine," says Elliot. "They currently are underway with a production expansion programme and are gearing up to produce a lot more potash, as are the other players. As part of this programme PCS planned to construct a new mine in Sussex, New Brunswick, which is next door to Penobosquis. The Picadilly mine be the first new potash mine in over 30 years. The mines are less than 1km together - when I first saw it I couldn't understand why you'd want to sink the mines so close, it seemed bizarre to me."

Water is the nemesis for most potash mines. Flooding can eventually lose the mine after years of operation - as what happened to the abandoned PCS's Cassidy Lake mine about 50km from Sussex.

"If you look at the geology around Picadilly, you'll see it's a salt dome, but it's actually more of an anticline. It's a salt dome that has caused the rocks above it to form an anticline. Penobsquis has a problem and the problem is water - they were shipping 120 water tanks a day of brine and putting it in the Bay Fundy so the mine is slowly drowning. They can keep it open but one day it will probably become too much, so the new mine is on the opposite side to the anticline and isolated from water problems associated with the Penobsquis mine."

The project has two shafts - a production shaft and a service shaft - some 900m deep with a diameter of 5.5m. The shafts are concrete lined with a single station entry in each shaft rather than multiple access points.

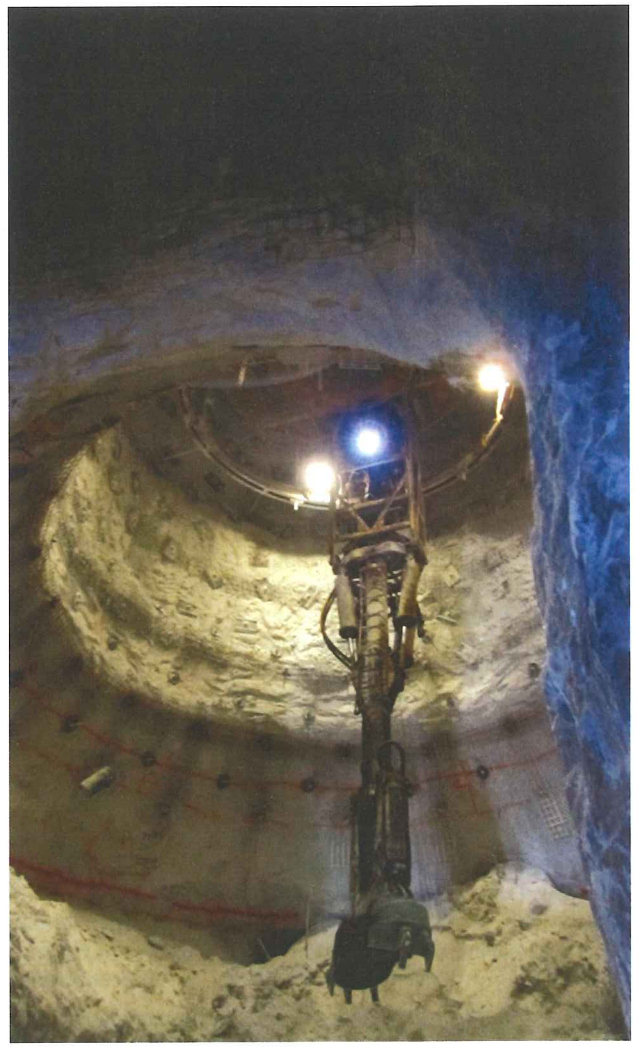
The predominant geology is the Mabou mudstone - similar to Mercia mudstone - into siltstones lower down but with less water problems before entering the basal halite and anhydrite. "Mabou mudstone is good when it's dry but not very nice when it's wet," says Elliot. "Below 420m the geology changes and there are more siltstones, it's very tight - there are still fractures but they are filled with jitson and you don't get water problems. While we could have designed the lining for deeper than that, the deeper you go the more problematic it becomes and the more expensive it becomes."

The shaft lining was self-levelling 60Mpa concrete with particular attention paid to matcher joints between each 6m height pour. Heavy duty PVC grout and stainless steel grout injection points were used with the lower shaft lining through the halite and potash being carried on a pylon structure.

The salt creeps over time so historically a steel tower would be placed to provide support but created difficulties as the salt squeezed. Though polyurethane was originally to be used a liner for Picadilly, the risks involved with fire were believed too great and cellular concrete was adopted instead.

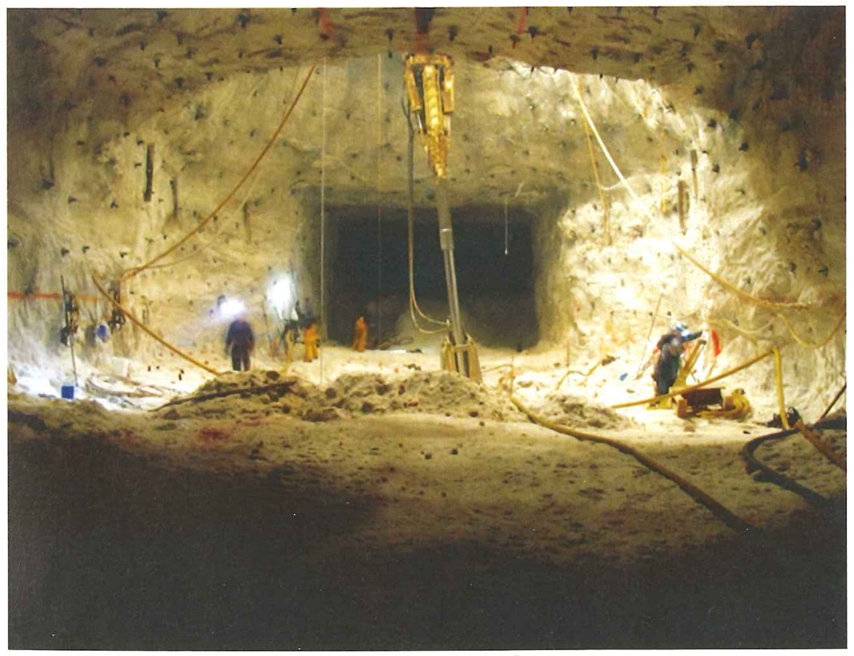
Analysis was undertaken on creep predictions as the mine is to have a 40-year life before the loads on the lining will begin to cause damage.

At station level the openings are larger hence the need for a pylon structure. The pylons sit on a horseshoe shaped mass concrete structure on a compressible fill. The ground is unlined in the anhydrite.



SINKING THE SHAFTS

The shaft collar for the service shaft had a shallow overburden of 3 - 4m and was open cut with excavators whilst the production shaft had a deep overburden of 9m with artesian water and a secant pile support. There was pre-excavation grouting down to 40m depth. Once the collar was placed, the shaft was excavated by hand until there was sufficient depth to install a Galloway frame over the shaft.



The Galloway installation is a secure structure equivalent to a five storey building. "It is clear of any columns so we can work freely and have easy access," says Alun Price Jones, technical director, Cementation Mining. "The Galloway installation is a busy place, there's not a lot of elbow room. Once the Galloway installation was erected we picked it up with a crane and lowered it into the shaft."

Next, the construction of the headframes for the production shaft took place. The headframes at Picadilly went up quickly, over two and a half weeks. The headframes were constructed using slipform methods and are 100m high. Once in position, crews installed hoisting equipment to sink the shafts.

The muck was brought to the headframe then into a chute and muckbin before removal.

The Galloway was supported on three ropes and act as guides for the muck bucket to prevent swinging.

"You cannot lower an unguided conveyance down a deep shaft, it will just swing out of control and hit someone," says Price Jones. "So, the Galloway is suspended on ropes and you can run the bucket out at very high speeds, it goes where it's meant to, and when it gets to the Galloway it goes through the bucket well."

The sinking hoist was a Hepburn 9ft (2.7m) diameter single line drum hoist able to support the self-weight of the rope and controlled from a hoistroom with cameras within the shaft and at stations. Each rope has a load cell and the proven system of bell signals used to communicate. The bottom deck of the Galloway was the concreting deck with the mucking deck below that.

The excavation cycle was generally as follows: The advance grouting was undertaken which could take up to two weeks; the bench was then drilled; the rock was blasted; the rock was mucked out and ground support placed; the bench was then cleaned and the benching cycle repeated on the other half of the bench; the curb ring (formwork) was lowered and poured with matcher joint grouting; and the mains were lowered, and contact grouting of the back wall undertaken every five sets.

Care was taken not to over pressurise the grout to avoid fracturing the ground. Grout hole deviation plans were produced.

The drill jumbo was stored in the headframe with a gantry for maintenance purposes. "Once you drill the bench, you blast, and the next stage is to muck that out," says Price Jones. "This style of shaft advance is called benching because we take half the shaft to begin with and then the other half later on. It has its advantages because if you've got very wet conditions you can let the water pummel into the deeper parts and when you need to clean up the bench ready to drill next time it's easier to get below the loose material."

The vertical shaft mucker(VSM) was a long telescopic arm with a grab. Two could sometimes be used together but for Picadilly only one was required. With only one bucket well, the buckets would be switched with a filled bucket being transported to the surface, emptied then returned to the shaft bottom and replaced.

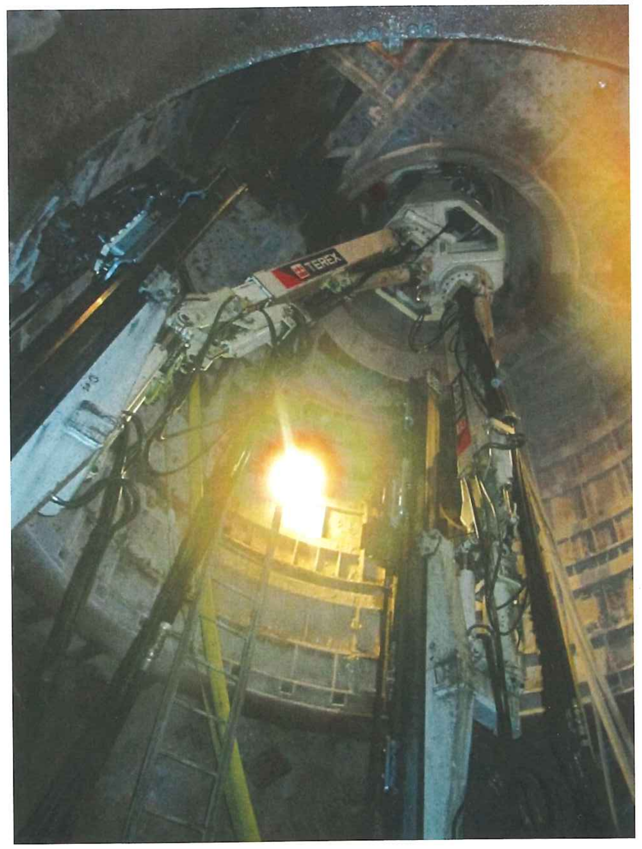
Price Jones says: "In this shaft, it's only 5.5m diameter so one is all that is needed. We have only one bucket well so we send one empty bucket down and unhook it while the BSM fills it and the hook goes back to surface and brings down an empty bucket.

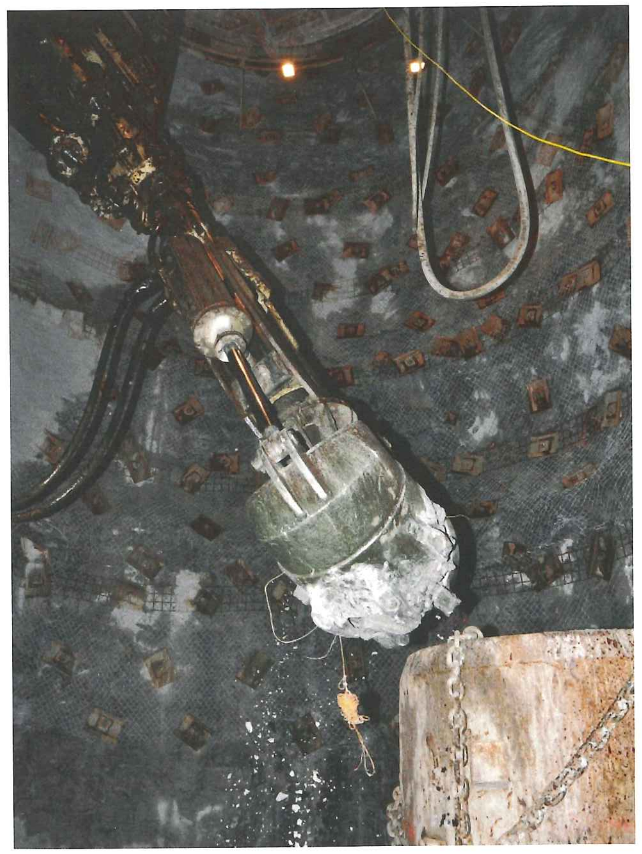
The ground support was initially short rock bolts and weld mesh. Sometimes in the Mabou mudstone the bolts would be ineffective if the rock was too soft so a permanent oversize formwork would be required with a concrete lining.

When the curb ring was set, accelerated concrete was used with the ring supported on Dywidag rods. When sinking through the salt layers a spray on material called Rock Web was used to prevent the salt hydrating and disintegrating. Full safety gear with face masks was required for application.

Below, left: ***Drilling portion of the shaft excavation cycle***

Below, right: ***Mucking portion of the shaft excavation cycle***





At the oversize locations the shaft diameter became about a metre greater in diameter than the Galloway itself. A larger ring suspended off the Galloway was taken 100m through the halite and stabilised by rods. The halites were relatively stable to excavate through. As the proposed station was approached the benches were constructed by enlarging out.

A drawbridge from the bench was then needed from the Galloway to the shaft station. The pillars were eventually constructed at the entrance at the shaft station. The foam concrete liner could be placed top down as the self-weight of the liner would not support the weight of the lining itself. On the way back up the shaft, the formwork was placed to provide a sacrificial liner to provide a temporary lining before the permanent lining was in place.

Grouting behind the liner was then undertaken by casting stainless steel tubes in the concrete to deliver grout to the matcher joint and rock/concrete boundary. For finer fissures, microfine cement grouts would be used or chemical(urethane) grouts for short term water stoppage.

FINISHING THE JOB

"So we've done the shafts and part of our contract was to get these mining equipment in," says Price Jones. "There was a lot of engineered lifts using the hoists. The equipment had to be broken down into chunks and lowered down and assembled in workshops we had excavated underground ready to receive them."

The mining machines used were the Sandvik MF420 and the MB670 Borer Miners weighing over 200t. The M420 is currently the world's heaviest and the most powerful, it can cut a mining width of 6.5m by 3.6m high.

The Sandvik MF420 Borer Miner is a variable height and width, boring-type machine that cuts and transports material to auxiliary haulage equipment in one continuous operation. The machine drives entries, excavates mine rooms and extracts pillars as rapidly as haulage equipment can remove material to the main passageway. Depending on the haulage system being used, the Sandvik MF420 can cut and convey approximately 15 metric tons of potash ore per minute.

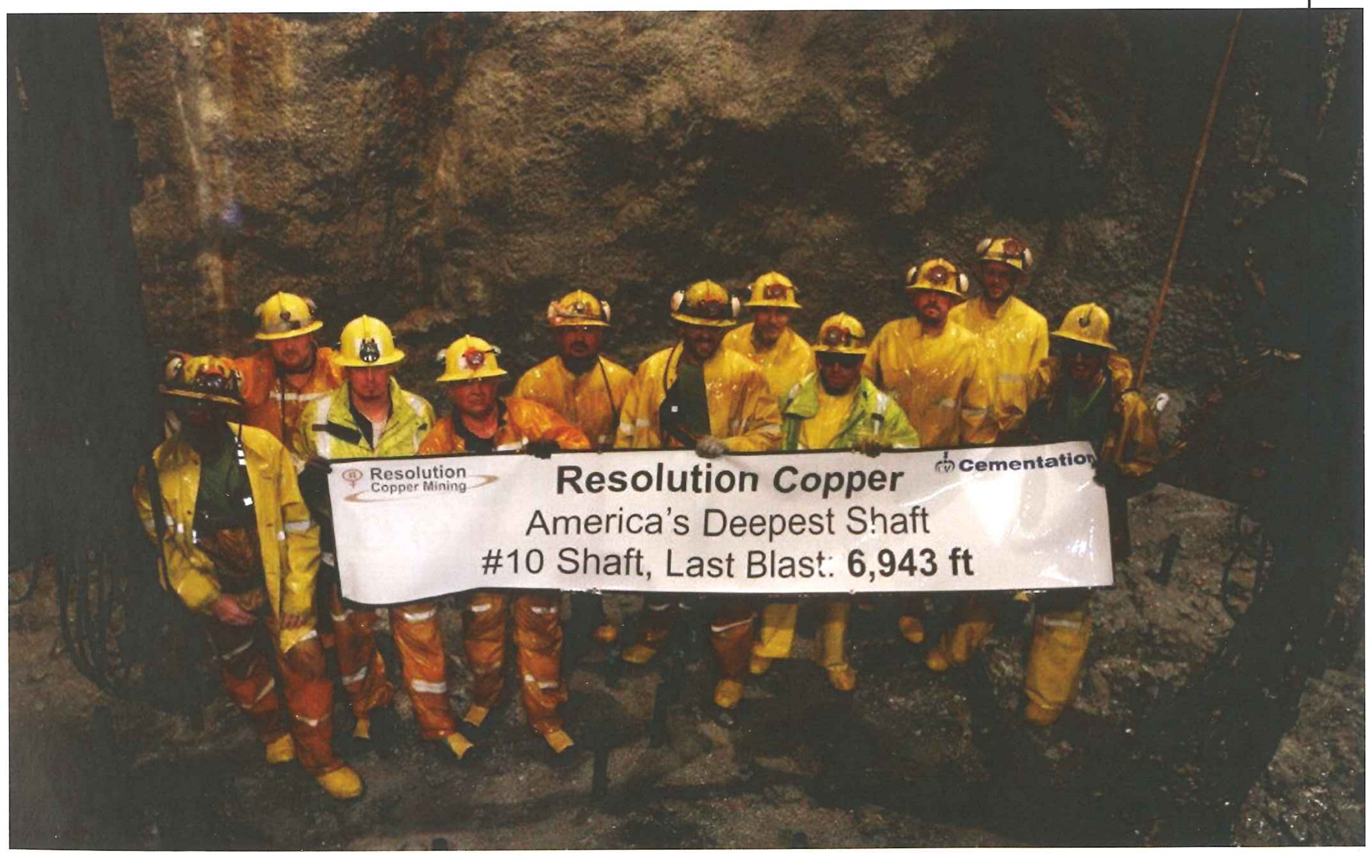
The MB670 (four machines) are not quite as big but still a decent size. It has a ranging drum and it can cut a bigger hole than the M420.

"We had to do all the engineer lifts and we worked closely with the manufacture to get it down the shaft," says Price Jones.

The project boasts zero lost time for injuries on the project. Price Jones explains that this was achieved by constant training of the staff combined with regular audits and positive safety culture. "Shaft safety is a big deal to us. We had zero lost time on this project because of injuries, nobody failed to come to work because they were injured. In order to keep up this level of safety it involves constant attention."

The best shaft sinking advance was 3.98m per day with the bottom of the service shaft being reached by March of 2012 and a further year to fit out to a permanent state. The production shaft lagged the first by about three months and reached the bottom by July 2012. The fitout was complete by the end of 2013. The new mine is now complete and in production

Below: ***Last blast at Resolution Copper, 17 November 2014***



CENTRAL AMERICA'S FIRST METRO

Santiago Erans
Santiago was head of the Panama Metro Line One project for contractor FCC

Central America's first metro is a boon for tiny Panama's traffic-beleaguered highways, but despite a positive start future work neglects tunnelling. **Santiago Erans** of FCC speaks to *Tunnels and Tunnelling* in the aftermath of a successful completion of Line One, and the award of Line Two

THE ISTHMUS of Panama is, for its size, one of the most influential geological structures in the world. It was formed by underwater volcanoes, a tectonically-induced rising of the seabed, and then gradual sedimentation and siltation of the result to create a more complete land bridge.

Recent scientific discoveries made during engineering works to expand the Panama Canal have pushed the date of its formation (in a tenuous state) back from a few million years, to around 10M years or even more. The visualisation of the state of this bridge between North and South America drives a lot of what scientists believe they understand about the Earth's current glacial cycles. The glaciation of the Arctic, and the creation of the Gulf Stream are thought to be caused by this slender link. It also allowed mass migration (the "Great American Interchange") of plant and animal life between the Americas.

In modern Panama, the eponymous capital city sits on the only practicable crossing at the narrowest part of the country, and efficient movement of people through public transport is vitally important to keep the main highways as clear as possible. The country's economy has been relatively undamaged by the global financial crisis, with up to eight per cent annual growth, and public finances were available to be levelled at the problem of residents relying on buses and cars, a problem that "would cause the collapse of vehicle traffic by 2015" according to the Panama Ministry of Economics (see Tunnels and Tunnelling December 2011, p.17).

BURYING YOUR PROBLEMS

The solution to the traffic jams of Panama City was metro. And

***Right:** Early site works for line one*

Box Metro timeline

- October 2009 – Pöyry, Cal y Mayor and Geoconsult selected to provide consultancy services and conceptual design on Line One
- January 2010 – Panama Government invites pre-qualification tenders seeking interest in design and build of Line One
- August 2010 – Bids for design & build submitted by Linea Uno Consortium (Odebrecht&FCC)
- October 2010 – Linea Uno Consortium selected to build the metro
- December 2010 – Work commences on metro
- August 2011 – FCC takes delivery of two TBM's built by German company Herrenknecht AG, shipped to arrive separately in Panama in September and October
- September 2013 – Construction 92% complete allowing first test-run of rolling stock
- February 2014 – Completion of construction
- April 2014 – Inauguration of metro

Box he Material in, material out

- Concrete in the delivery of the work exceeded 420,000 m3
- More than 47,000 tonnes of steel were used
- 476,938 m3 of ground was excavated just in the underground stations and trenches
- The structures of the underground stations have 92,650 m2 of concrete walls
- Almost 27,000 linear meters of piles (of diameters ranging from 1.2m to 2.5m) were created

Table 1. Tunnel overview

Name	Value
Total length	7.3 Km
Length of first drive	4.2 Km
Length of second drive	3.1 Km
Quantity of rings	4,075 u
Quantity of segments	28,525 u
Excavated diameter	9.77m
Internal diameter	8.7m
Maximum gradient	3.5 per cent

Source: FCC

the City awarded the USD 1.45bn contract (which rose to USD 2bn with addendums) to construct Panama Metro Line One in 2010 to an Odebrecht-FCC consortium. The scope of the underground works was 7km of tunnels and seven underground stations, with the remainder of the 13.7km line to be constructed on viaducts with five elevated stations. Although it is a dream, and was a pet project of former Panamanian president Ricardo Martinelli to set the ball rolling to have an entire underground transport system for the city by 2035.

CRITICAL TUNNELLING THROUGH DIFFICULT GEOLOGY

According to Santiago Erans, Panama Metro Line One leader for FCC, The critical element for the success of the project was the tunnelled stretch of the works. Some 7.3km (a 4.2km and a 3.1km drive) of tunnel were excavated using two 9.77m by Herrenknecht EPBMs through difficult geotechnical conditions.

Rock up to 100MPa was encountered in places, and the highly fractured nature of the ground meant that the TBMs "needed their tools changing into hyperbaric form" according to Erans.

In general, excavation took place in problematic areas with mixed geology, fractures and shallow ground with a changing level of rocky substratum. A general overview of geology was provided by the client during the tender process, allowing an analysis of the information to give an idea of the hydrological and geotechnical situation along the drive, a complementary study was undertaken.

Erans continues, "The complementary study expanded the stratigraphic, tectonic and hydrogeological knowledge of the terrain as well as the geotechnical characterisation of the terrain, allowing geotechnical parameters to be determined for tunnel design, stations and shafts.

"Passive seismic refraction (micro tremor) and electric tomography determined the rock and soil contact boundaries. In addition, based on the speed of the waves, the modules of dynamic deformability of rock and soil and their behaviour faced with seismic actions and the excavation possibilities could be determined. All of this allowed us to accurately define lithological distribution and complete a geotechnical and hydrological characterisation of the terrain, especially relative to its deformability, abrasiveness of the rocks and the aquifer definition and parameters of hydraulic loads."

In total 58 explorations were undertaken (34 in tunnels and 24 in stations) that covered 1856m (approximately 392m in soil and 1464m in rock). In addition 165 permeability tests were carried out and 234 pressure tests. Three shafts were set up in the station areas (with a total of 75m of perforation) for pumping tests. In terms of geophysical works, 2300m of passive seismic tests were carried out, split into 27 types, and a tomographic electric test of 400m.

With regards laboratory testing, mechanical and deformation classification and state tests were carried out which included uniaxial compression, uniaxial compression with extensiometric bands, triaxials for rock and soil and traction resistance.

For the pump tests a diameter perforation test was carried out allowing a tube of 200mm minimum ventilation diameter to be positioned. Each pump shaft had at least four piezometrics.

Lining

Universal precast concrete segmental rings lined the tunnel and were grouted with a two component grout to achieve uniform contact and minimise movements and achieve uniform pressure, and to help reduce permeability. Segments were 1.6m-long and 350mm thick, and were in a 6 + key arrangement.

Below: *Route map for the metro project*

Table 2. Underground stations for Line One

Station	Length	Excavation (m3)	Width (m)	Depth (m)
5 de Mayo	115.00	46.680,00	19.20	22.50
Loteria	100.00	40.281,60	19.20	20.98
Santo Tomas	115.00	48.664,32	19.20	22.04
Iglesia del Carmen	115.00	48.645,32	21.15	20.00
Visa Argentina	115.00	53.776,88	21.50	21.75
Fernandez de Cordoba	115.00	42.444,86	17.60	20.88
Ingenio	115.00	31.682,59	14.50	19.00

Source: FCC

CRITICAL PATH CHALLENGES

Erans said the team knew it would be difficult to deliver the whole project in 38 months, and points out that this included all design, enabling works, auxiliary line and M&E installation, and rolling stock supply. "Right from the start we analysed in detail the activities which formed part of the project's critical path and we studied the possibility of reducing, within what was possible, the length of some parts of the process, guaranteeing the delivery of the tasks without the possibility of delays."

There were several key decisions. "Firstly, from the detailed analysis we did we concluded that the TBM purchasing process needed to start on day one. This included a specialised team overseeing the whole process at each stage. This team had to focus on the TBM fabrication in Germany. It was also critical to properly select the team responsible for affected utilities. Several companies were contracted to detect and organise the re-locating of utilities affected by the project.

"Then the construction process for the elevated stations was changed, making it independent from the lines. This way the lines could continue to be worked on without the stations having been finished, and in addition certain parts of the design were changed, so that instead in situ construction, they were built with prefabricated elements. The goal throughout these changes was to reduce the construction time.

Erans adds that during the project, the team had to take measures to bring the project back on schedule when unforeseen complications slowed them down. "For example, we increased the number of hydromill trench cutters from three to four to accelerate the excavation of the concrete walls on the underground stations; we also increased

Below: *Aerial view of Panama City showing elevated portion of line*

Interested parties

- Consultancy and design services – Consortium of Pöyry, Cal y Mayor and Geoconsult
- Construction – Consortium of Odebrecht (55%), and FCC (Fomento de Construcciones y Contratas FCC) (45%)
- Engineering & electromechanical support – Electromecanical group of companies led by Alstom (subcontracted by the Line One Consortium) - responsible for engineering, integration and commissioning of the electromechanical works for the project, installation of traction substations and its Urbalis communications-based train control (CBTC) system. Supplied a fleet of 20 three-car Alstom Metropolis trains built in Barcelona
- Project management & technical assistance - Consortium of TMB, Ayesa, Metro de Barcelona and Inelectra
- TBM supply - Herrenknecht supplied two tunnel boring machines (TBM) for the Line 1 construction
- Bearings supply - Mageba group supplied 1,600 LASTO-BLOCK Type B bearings

the amount of formwork on elevated stations, and finally we increased the number of machines used in the piling of the underground station accesses and the trenches (the transition sections between tunnel and surface)."

On particular challenges working in Central America, Erans says: "Sourcing staff and equipment for a project of this scale in Panama was a challenge. Local engineering expertise in Panama was lacking due to no previous experience on projects of this type or scale. Careful management and planning allowed the consortium to source their workforce for the project (90 per cent Panamanians) and complete the design, shipping and assembly of the two TBMs and vital materials in just 14 months."

FUTURE

The metro is required to transport 15,000 people an hour now it is in operation. When all four lines and a tram system are completed in 2035, as per the 'Red Master Panama Metro Plan', it is expected to transport 40,000 people an hour.

Erans concluded, "The opening to the public in April 2014 marked a significant moment in Panama's economic and urban development and represented a shift in attitudes towards public transport investment in Central America. The Panama metro is the first system of its kind in the region."

Continuing the government's USD 15bn programme to upgrade Panama's infrastructure, the same consortium of Norberto Odebrecht and FCC was awarded the contract for Panama Metro Line Two on 14 May 2015.

However, this section for the east of the city is not underground. The bid of USD 1.858bn against a reference price of USD 1.819bn covers engineering design services, construction of the civil works, and installation of auxiliary works on the line, supply and installation of the railway line including rolling stock. The works will include 16 stations and 21km of elevated track and connecting stations

CULVERT JACKING

Pipe supplier *Hobas* gives this brief account of a simple flood relief project near the village of Cikowice in southern Poland. The company argues that a jacked pipe solution requires less maintenance than alternatives

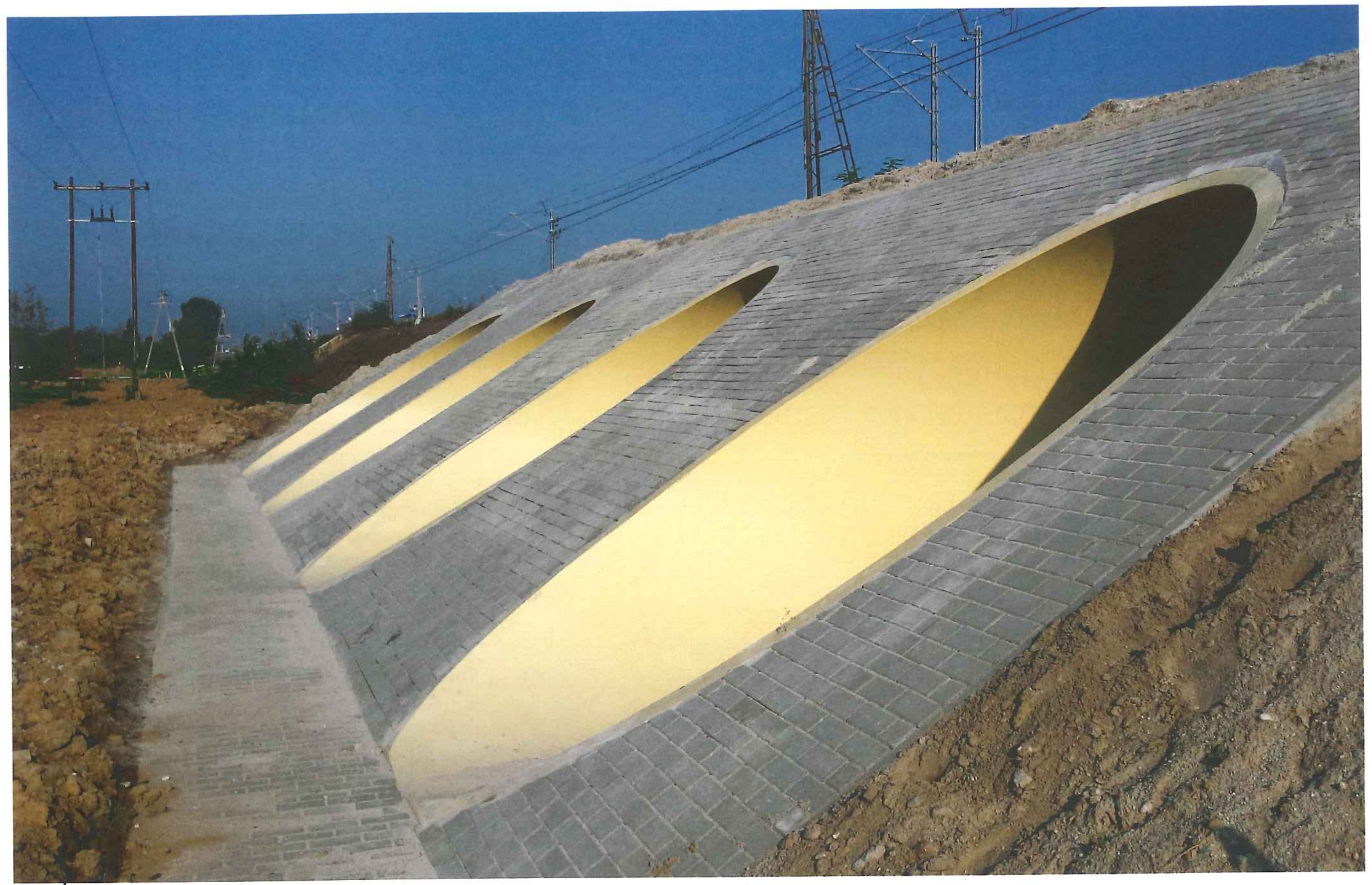
When a pipeline route crosses a railway embankment, jacking is usually the optimal installation method as it does not require disruptions in rail traffic. In the village of Cikowice in southern Poland, four culverts with a diameter of 3,000mm and a length of 34m each have been jacked under a railway line for the sake of flood control.

In 2010, the Raba River overflowed its banks and flooded Cikowice and its neighbouring villages. Unfortunately, Cikowice is bordered by a railway embankment to the north, which acted as a dam, causing an additional accumulation of water. The water level on the village side was almost a metre higher than that on the opposite side, an area consisting largely of meadows. In order to prevent such incidents in the future and enable the outflow of excessive water, a flood prevention project was initiated in 2014.

Project summary

Year of construction: 2014
Construction time: two months
Total length of pipeline: 136m (four parallel lines of 34m)
Diameter: 3,000mm
Pressure class: PN 1
Stiffness class: SN 40000, SN 64000
Application: Culvert beneath railway for flood protection
Client: PKP (Polskie Linie Kolejowe) S.A. (Polish rail infrastructure company)
Installation method: trenchless installation / pipe jacking
Contractor / Subcontactors: Intercor / PROI, PROI2
Advantages: smooth inner and outer wall surface, high structural strength

Jacking the pipes below the operational railway



It was realised in the context of the modernisation of the railway line E30/C-E 30 and involved the construction of four large culverts beneath the railway embankment. If the water level rose again, the culverts should allow for the water to pass freely to the other side.

PIPE SOLUTION

Hobas Poland supplied the pipes to form the culvert, which had an external diameter of 3,000mm. A smooth inner surface ensures that flood water which flows through them (and usually contains various impurities) does not lead to siltation over the lifetime of the installation.

Pipes also make it much easy to resume jacking works after an installation interruption due to heavy rain: the water causes the sandy soil to become slightly compacted and adhesive, and the thrust force required to restart works after the interruption is usually quite high. Thanks to the smooth outer surface, the necessary forces would be comparably lower and a restart quite easy.

Before the start of the jacking works, the rail tracks were equipped with special beams that transferred the load from the trains evenly to the rails in case of any ground movements.

The structure of the pipes, on the other hand, was strong enough that even in the course of their installation the vibration induced by passing trains was not felt inside.

Above: The culvert is now in operation

The jacking machinery was secured against sliding on the sandy and slippery soil and positioned in a way to install the pipes with a slight slope, so that the water would eventually flow in the right direction. Once a culvert had been jacked through the embankment, its ends were specially prepared: one side was bevelled from the top, while on the uninhabited side of the embankment the culverts were equipped with special flaps, which prevent the backflow of water to the village.

SUCCESSFUL COMPLETION

The construction of the culverts in Cikowice took around two months and the project is now in operation protecting the site from weather events

STATION TO STATION

Compensation grouting for the construction of Crossrail's Bond Street and Tottenham Court Road stations is due to finish in May, marking the end of a logistically-complex and technically challenging three-and-a-half year project to protect buildings above and around the route. **Max Soudain**, a technical writer for the joint venture, and former engineering geologist reports

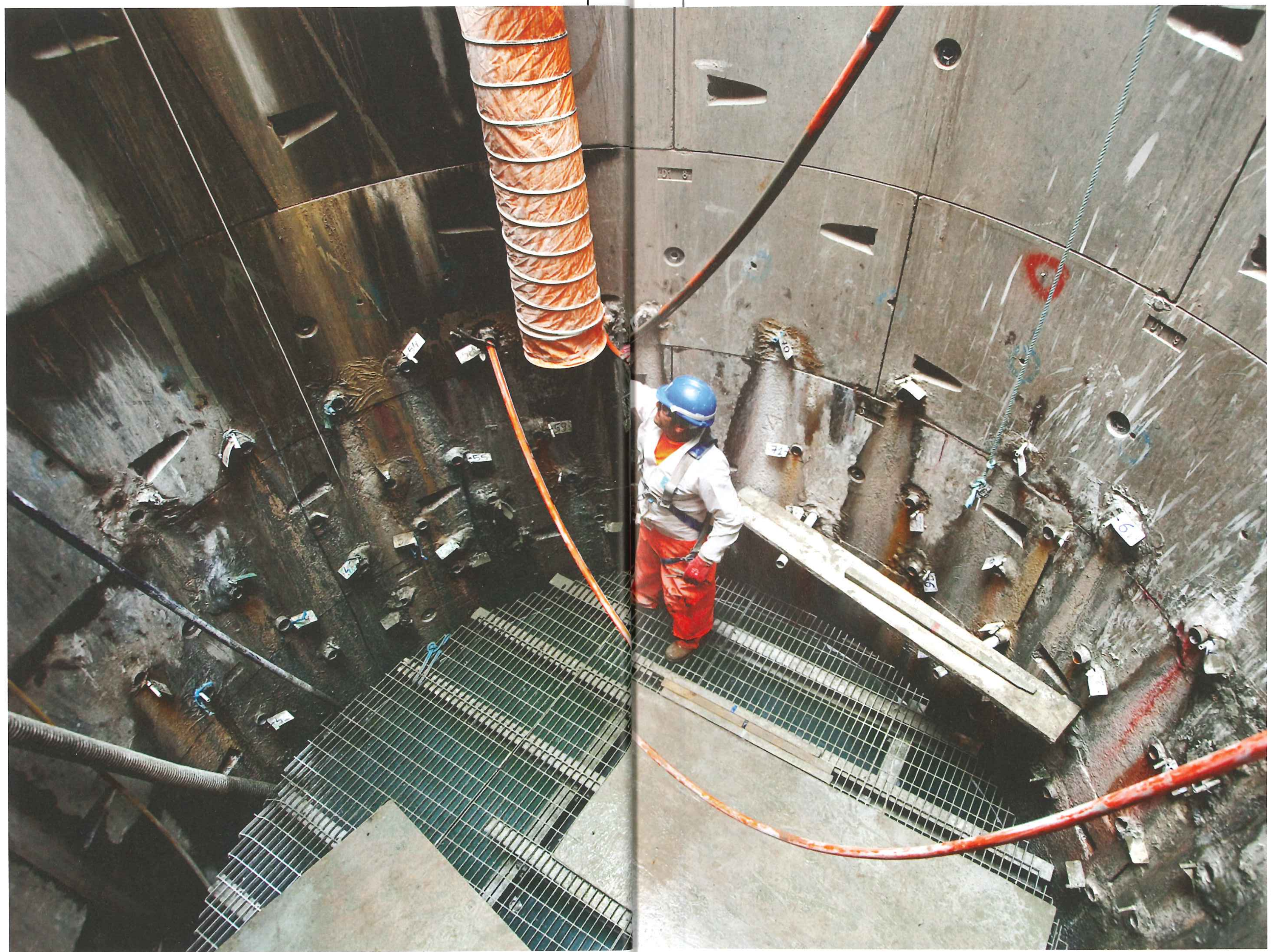
VIEWERS OF the first episode of the BBC's 2014 documentary on Crossrail, The Fifteen Billion Pound Railway, may recall the sight of GBP 1M of vintage Rolls Royces, Aston Martins and other classic cars being squeezed past (and in fact over) a grout shaft to reach the auction rooms of Bonhams in New Bond Street.

For the team using the shaft tucked behind the Bonhams' building, access is a daily challenge, however.

All plant, equipment and materials needed to carry out compensation grouting works for this section of Crossrail have to be brought in through a narrow arch to the shaft site, and stacked above, in a vertical compound built on scaffolding platforms.

This is just one of 13 shafts being used by KBR (a joint venture of geotechnical contractors Keller and BAM Ritchies) to protect buildings above and around the new Bond Street and Tottenham Court Road stations on this 2km stretch of the route. Almost every shaft is down a narrow alley, hidden behind a façade or up against a building, in one of the most prestigious postcodes in London.

"Logistics have certainly been a significant challenge," confirms KBR Contract Manager David Bradley. "We have some very close neighbours and highly sensitive buildings, so we have had to take a collaborative approach, managing stakeholder relationships very carefully, and keeping a close eye on the details."



Below: TAM pipes were drilled out at a depth of about 13m

CONTRACT

KBR was awarded the GBP 40M settlement mitigation contract in January 2011 by main contractor BFK, itself a joint venture of BAM Nuttall, Ferrovial and Kier. KBR covers two of BFK's Crossrail packages: C300, the Western Running Tunnels, and C410, Bond Street and Tottenham Court Road Stations.

KBR's remit is to protect buildings from damage through ground movements caused by the excavation of the station boxes and the tunnels and to enable safe construction of the underground structures.

The running tunnels are built using Herrenknecht TBMs. The larger diameter platform tunnels were formed by the TBM tunnel, which was then enlarged using conventional excavators and sprayed concrete lining (SCL). SCL is also being used for the cross passages and links to the nearby London Underground stations.

Most of KBR's work involves compensation grouting (although it has also carried out some permeation grouting – see box).

To achieve complete coverage, grout injections are carried out using an array of tube-a-manchette (TAM) pipes radiating out from the approximately 15m deep, 4.5m diameter shafts dotted around the area. TAMs, drilled at a depth of around 13m, are between 5m and 92m long.

Along with the five shafts at Bond Street, there are seven at Tottenham Court Road and one at the Fisher Street ventilation shaft near Holborn Station, just to the west of this section.

"The shaft locations were decided before we finalised the treatment design," Bradley says. "This meant that some of the areas requiring treatment were some distance from the shafts and a few of the TAMs are longer than usual."

The job in numbers

Contract value: GBP 40M (USD 63M)
Number of grout shafts: 13
Total length of tubes-a-manchette: 50km
Maximum TAM length: 90m
Treatment area: 63,500m²
Total volume of grout injected: 3.5M litres.

GETTING STARTED

Drilling of the 50km of TAMs started in November 2011. By February 2012, KBR had begun pretreating the ground to raise ground levels by 5mm and to compensate for settlement caused by installing the TAMs. Drilling continued until April 2013, with pretreatment complete that June.

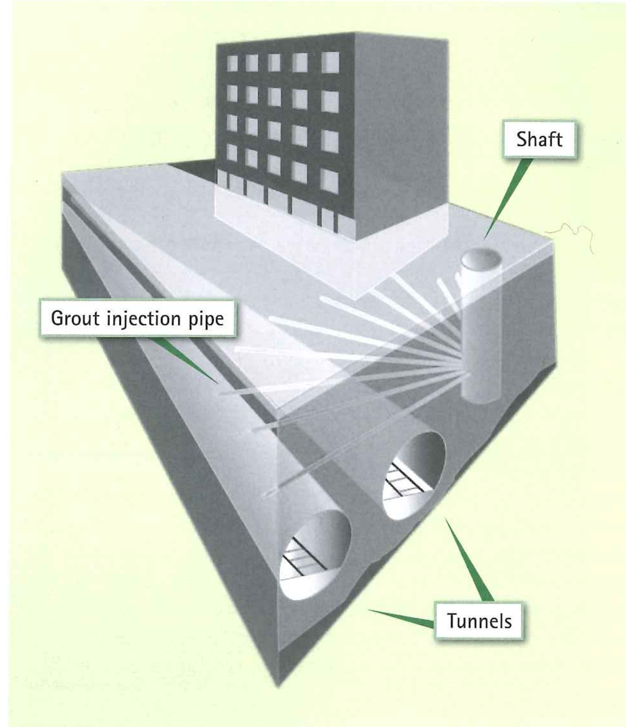
"Most of our work involves 'concurrent' grouting over the tunnels as they are excavated, with typically one grout pass carried out for every 2m tunnel advance," Bradley says.

"The aim is to inject grout to lift the ground in front of the tunnel face, let it settle slightly as the excavation passes and then inject to lift it back up again. Pretreatment is crucial as it 'activates' the ground, making it immediately responsive to subsequent grout injections."

While the overall volume loss of the tunnelling, and therefore the settlement, is minimised by using TBMs in the running tunnels and the platform tunnels, there is still a need for compensation grouting, Bradley adds.

"It is best to control all the movements within the station footprint [with grouting] because it minimises the number of cycles of lifting and settlement of the buildings above, reducing the risk of damage.

*Above: **Shafts had to be fit within the dense confines of London's Soho and Mayfair neighbourhoods***



*Left: **Graphic showing representative grouting setup***

*Below: **Crossrail grouting and exclusion zone***

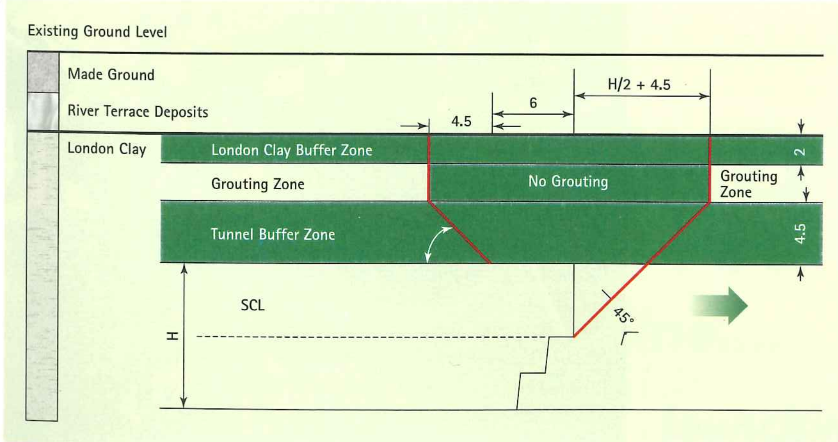
GROUTING DOMAIN

Grouting is concentrated in a 2m thick layer of London Clay, about 2m beneath its boundary with the River Terrace Gravels and 4.5m above the tunnel crown. Grout injections are carried out in advance of, rather than directly above, the tunnel face to prevent instability and, in the case of the SCL tunnels, to stop additional stress being placed on the fresh concrete, Bradley says.

Grouting operations are 24/7 and to date, KBR has carried out more than 1,300 passes. Before each shift, a review meeting is held to check the planned grout injections for that shift and to examine ground and building movements, which are being monitored continually through a network of sensors and surveying equipment.

Monitoring is being carried out by a joint venture of Getec and ITMSoil.

Grout designs are sent to the grouting modules on site, specifying volumes, pressures and injection points. The TAMs have rubber sleeved ports every 0.5m to allow grout to flow into the surrounding ground, with injections performed via a packer which is pushed to a predetermined distance along the TAM by hand and inflated.



The packer seals off the rest of the TAM and grout can then be injected precisely where it is needed.

About 40 to 100 litres of the 2N to 3N cement bentonite grout is used for each injection, pumped at between 25 and 40bar. Larger volumes, of up to 150 litres, have been pumped where a steep settlement profile is expected (typically located directly above the tunnel) or where the ground is less responsive. Engineers are on hand throughout grouting to ensure the ground reacts as predicted and can adjust injection schedules if need be.

"We have injected about 3.5M litres of grout over the three years of the project, which sounds a lot but it should be remembered this is for 2km of tunnels. In fact, this is a precision project. With a wide range of buildings, foundation types and underground structures, it is about injecting the correct volume of grout, in the correct place, at the correct time," Bradley says.

"The key is not to use high volumes of grout in every injection but to use multiple passes and lower volumes to move buildings slowly and evenly. What we are trying to avoid is differential movement, which causes the most damage."

This is particularly important when dealing with a number of sensitive structures along the route, including the House of St Barnabas in Soho Square. This beautiful Grade 1 listed house has ornate cornicing and plasterwork, which could be damaged by excessive and rapid movements.

As well as historic structures, KBR had to cope with ground movements caused by new buildings.

Part of the reason for the very restricted position of the shaft next to Bonhams was the fact that the auction house built a new GBP 30M extension to its headquarters (with a basement), just 500mm away from the shaft wall – during grouting works.

"It was certainly a challenge to keep settlement within limits during this time," Bradley says. "Bonhams' work involved demolition, basement excavation and then construction, which obviously involved unloading and reloading of the ground. There has also been additional grouting to ensure the new building is not exposed to detrimental movements."

This grouting, or 'jacking', mitigates medium to long term settlement and is carried out for up to 12 weeks after the tunnel has passed, based upon on-going monitoring of ground and building movement.

CONSIDERATATION GROUTING

While grouting is carried out at any time of day or night, all work is undertaken with due consideration to the neighbours.

"We are working closely with the local community to notify residents and businesses when grouting work is happening. With up to 90 operatives and engineers on site at any one time, things can get noisy," Bradley says.

"We make every effort to minimise disturbance. If it is feasible, we will do it. Plant and vehicles are not operated at night, deliveries are restricted to the day and all equipment is super-silenced and housed in soundproofed timber sheds or containers.

"Mayfair and Soho have some of the most valuable properties and exclusive businesses in the world – the last thing they want is construction sites right outside their front door.

"Fortunately, everyone is aware of Crossrail's long term benefits and understands that we need to work together to get the job done."

Any inconvenience experienced by the local community, due to grouting works at any rate, will soon be over, with tunnels at Tottenham Court Road finished and approximately 90 per cent complete at Bond Street as Tunnels and Tunnelling goes to press.

Grouting at Bond Street was finished in this year, with KBR continuing to monitor movements up until July. By then, the shafts are due to have been backfilled and covered over, leaving little evidence of the past three years' activities.

FINAL THOUGHTS

For the KBR team, there will be an immense sense of satisfaction on leaving site. "While the project has been technically challenging, and logistically highly complex; good planning, monitoring and having the right procedures in place meant we were prepared for any eventuality," Bradley says.

"We have done a fantastic job here. We have not delayed tunnelling at any point and have controlled the settlement of some very sensitive buildings. That is something we are very proud of and the client is extremely pleased about"

Permeation grouting

While compensation grouting was underway, KBR was called in by BFK to help construction of a ventilation tunnel which was due to pass close to the London Clay/River Terrace Gravel interface.

"BFK was concerned that if the boundary was breached, it could cause water and material to enter the excavation, which would endanger the tunnellers and the tunnel construction. With work due to start in a matter of weeks, we had to react quickly," says KBR contract manager David Bradley.

"After ruling out a number of options, we decided that permeation grouting of the gravels to create an impermeable barrier above the tunnel was the most appropriate solution."

To ensure the solution was viable, KBR developed a 3D BIM model of the shaft, the tunnel section and the grout injection boreholes. The theoretical grout spreads were then added, to demonstrate the ground would be fully treated.

"The grout shaft was partly backfilled to bring the base high enough to allow injection boreholes to be drilled at a shallow angle from above the water table," Bradley explains. "We had to be very precise when drilling to ensure the bores were in the correct place – there was no room for error." Drilling and grouting took 10 weeks.

"The target permeabilities were challenging but permeability testing after we had finished showed treatment was successful. To be absolutely sure, the tunnelling team drove a controlled bore up through the tunnel crown and into the treated area. The water return was absolutely minimal and gave extra confidence that tunnelling could safely continue," Bradley says.

Right: Aerial view of one of the 13 shafts required for grouting this 2km section of Crossrail

GROUTING A CROSSING

Jet grouting ensured a successful crossing for an EPBM beneath an existing sewer tunnel with minimal clearance for the new Southeast Collector in Ontario. **Jordan Schreiner, Matthew Geary** and **Daniel Cressman** of *Hatch Mott MacDonald* presented this paper at TAC Vancouver

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Jordan is an EIT at Hatch Mott MacDonald based in Toronto, Canada.

Matthew Geary
Matthew is a principal tunnel engineer at Hatch Mott MacDonald based in Toronto

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Formerly with Hatch Mott MacDonald, Daniel is a project engineer based in Toronto

THE SOUTHEAST Collector (SeC) is a 15km-long, 3.0m-diameter sewage tunnel that twins the existing 2.6m diameter York-Durham Sewage System (YDSS) north of Toronto. The project includes construction of 19 shafts with depths of 4 to 48m, and seven facilities to support the sewer when operational. The tunnelling was performed by four EPBMs and the tunnels were lined with steel fibre reinforced precast concrete tunnel lining (PCTL). The TBMs tunnelled through full and mixed-face excavations of plastic till, non-plastic till, silt and sand with depth of cover ranging from 4 to 45m. EPB pressure of up to 3.0 bar was required to counteract ground and water pressure from the overlying water table and aquifers.

The YDSS was completed in 1979 and was constructed using rib and lag temporary support with an unreinforced cast-in-place concrete final lining. The sewer flows under gravity conditions and collects flows from all of the major urban areas in York Region. The current capacity of the sewer, 420 ML/d, has been reached and is putting a strain on the municipality's ability for population and employment growth (The Regional Municipality of York 2009). The integrity of the YDSS is of particular concern because it is the main connection between the upstream systems and the Duffin Creek Wastewater Treatment Plant. In addition, construction of the SeC will allow the YDSS to be taken offline to clean, inspect and undertake any necessary maintenance within the tunnel.

To meet an aggressive schedule, the owner procured four EPBMs in advance of construction to excavate four tunnel drives concurrently. The sewer alignment design included several crossings under roadways, intersections, railways, tributaries, gas mains and various city and municipal utilities. The east end of the tunnel alignment crossed under the existing YDSS in two distinct locations, one of which posed a unique challenge with significant risk to the project. The first crossing was west of Liverpool Road in the City of Pickering. At this crossing location, the clearance between the TBM and the YDSS was 1.3m and the cover was in a mixed face condition primarily comprised of flowing fine sand and silt, including clayey silt. Due to the ground conditions, the associated potential for settlement, and the close proximity of the YDSS, this crossing was identified as a high risk event for the project. Interruption of sewer operation was not an option and any failure of the existing sewer as a result of the TBM crossing would have significant environmental and societal impacts. The second crossing was not considered an area of risk due to significant cover and favourable ground conditions. The TBM crossing of the existing critical utility near Liverpool Road will be herein referred to as the YDSS crossing.

Due to the age of the existing sewer and the close proximity of tunnelling operations, specialised measures were taken to ensure the integrity of the existing sewer during the crossing. This paper aims to show why jet grouting was selected to provide support to the critical utility at this TBM crossing and evaluate both the effectiveness of this technique and the potential for its use in similar situations.

RISK ASSESSMENT

Settlement and potential damage

During the design phase of the project, boreholes were conducted at approximately every 100m spacing to develop the project stratigraphic profile. An additional borehole was placed directly beside the YDSS at the crossing location to obtain a representative sample of the ground. The additional borehole confirmed that the geological conditions at this location (the SeC tunnel obvert) consisted of cohesionless, unstable, fine sand to silt under approximately 7.0m of water pressure. Borehole records for the sand and silt layer estimate a water content of 8-28 per cent. Under these conditions, sand and silt have very short stand up time and would flow when left unsupported.

Given the geological conditions identified above, the potential for ground loss and settlement while tunnelling beneath the existing YDSS was identified as a major risk. Settlement prediction and an assessment of potential utility damage were conducted to quantify the settlement-induced risk on the existing sewer. The settlement prediction method utilised a theoretical volume loss potential to calculate the maximum theoretical settlement at a given location. The theoretical volume loss potential was defined as 1.5 for a percentage of face loss in cohesionless fine sands and silts. This value was determined based on historical tunnelling performance on the Sheppard Subway and the Channel Tunnel Rail Link. This number was thought to be conservative and easily achievable if good tunnelling practice is used to maintain face pressures and consistency in the excavated soil. Equation 1, below, was used to calculate maximum theoretical settlement (Rankin, W.J. 1988):

$$[1]\ W_{\max} = \frac{0.0125 V_l \cdot r^2}{Z_o \times K}$$

- wmax – maximum settlement, tunnel crown, trough centre
- Vl – volume loss potential, 1.5 for fine sand and silts
- r – tunnel radius
- Zo – tunnel depth
- K – constant defined as 0.4 (Peck 1969)

Using Equation 1, the maximum theoretical settlement at the crown of the tunnel was calculated as 21.7mm. This value was then used to calculate the maximum resultant horizontal strain, joint slip and joint rotation on the existing YDSS (Attewell et al. 1986) through Equations 2, 3 and 4, respectively:

$$[2]\ \varepsilon_y = \frac{n}{Z_o - Z} \cdot w \cdot \left(\frac{y^2}{i_y^2} - 1\right)$$

$$[3]\ Jointslip = \varepsilon H \cdot Lj$$

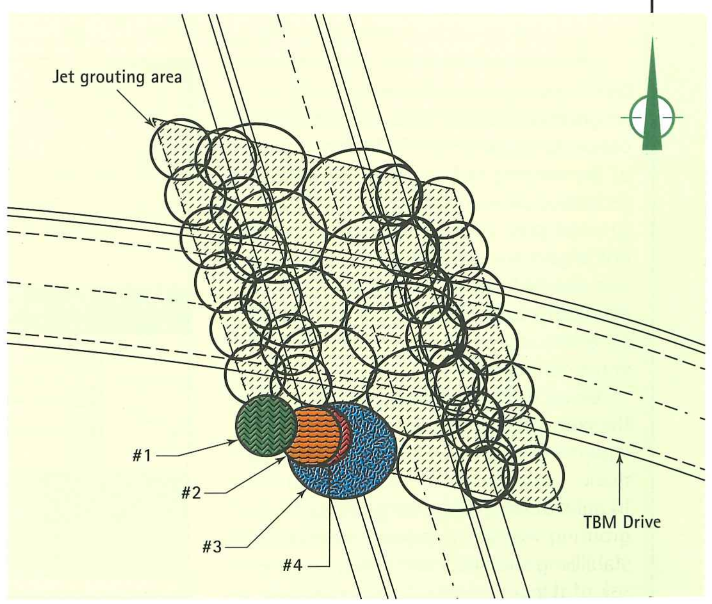
$$[4]\ Jointrotationj = \frac{(W_{i+1} - W_i)}{Lj}$$

- Ɛy, Ɛh – horizontal strain
- n – 1
- Z – depth of utility crossing
- y – distance along parallel utility
- iy – trough width parameter, (K)*(Zo-Z)
- Lj – length of joint
- w, wi+1 – vertical settlement and at next joint
- Lj – length of the joint

The results for horizontal strain, joint slip and joint rotation were compared with allowable damage criteria developed by Lake et al. (1992) to evaluate the potential for damage to the existing YDSS. Upon comparison with the established criteria, it was determined that the maximum predicted joint rotation exceeded the maximum allowable joint rotation for maintaining the integrity of the pipe. Based on the results of the settlement prediction and utility damage assessment conducted, it was concluded that there was potential for damage to the existing YDSS if vertical settlement was not reduced through mitigation measures.

There were two significant settlement incidents that occurred during tunnelling operations prior to the YDSS crossing near Liverpool Road. One event of approximately 158mm occurred in the roadway about 145m from the YDSS crossing and damaged local utilities. Flowing sands and high moisture content were also noted in the boreholes at this location, similar to the geological conditions in the borehole conducted at the YDSS crossing. A second settlement incident of approximately 300mm occurred 30m from the crossing location and began when the TBM stopped for repairs. It is also important to note that the 500m of tunnelling prior to the YDSS crossing had resulted in an average of 20.5mm of settlement on the surface (the two aforementioned settlement incidents were excluded from this calculation), and that the geological conditions in this section of tunnel are similar to those found at the YDSS crossing. The previous tunnelling-induced settlements on Liverpool Road made clear the high risk nature of the YDSS crossing and confirmed the necessity for ground support and mitigation measures to be identified in the design phase.

Above: Figure 1, jet grouting column layout for the TBM crossing



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DESIGN APPROACH

There were several design options available for mitigating the risk of damage to the existing pipe during the YDSS crossing. These options were selected based on constructability and past experience and were considered against the following primary design constraints:

- The existing YDSS must maintain a live flow at all times
- Schedule is the priority
- The integrity of the existing pipe must be preserved

The design options that were under consideration are listed below, along with the final evaluation of each method.

- Moving the tunnel alignment: the easement obtained for the SeC tunnel identified that the crossing must be completed to avoid private properties
- Open excavation to hang the existing pipe: this method yielded a high amount of risk during the excavation and hanging operations and would require a major amendment to the EA
- Secant piling to isolate ground movement: a more aggressive option in close proximity to the YDSS; however, the lack of support for the bottom of the pipe and the presence of overhead wires above the crossing limited equipment selection
- Ground improvement by ground freezing: issues with controlling expansion of the freeze body around the YDSS pipe raised concerns
- Ground improvement by jet grouting: suitable option for stabilizing the YDSS prior to the TBM arrival
- Ground improvement from TBM (drill and grout): not conducive to schedule

After assessment of the proposed techniques, ground improvement by jet grouting was selected as a suitable option to facilitate the TBM crossing of the existing YDSS. The jet grouting technique allowed ground improvement to occur prior to the TBM arrival and did not impact the schedule. Jet grouting was also well-suited for the geological conditions in the area and would provide adequate support encompassing the entire YDSS pipe.

Given the limited overhead space of the construction compound, the smaller equipment required for jet grouting also made it more practical than other options. In light of the project constraints, jet grouting was an appropriate method for stabilising the YDSS and mitigating the risk of damage during tunnel crossing.

Table 1. Jet grouting preliminary design parameters[1]

Design Parameter	Specified Value	Unit
Grout System	Double Fluid	-
Column Diameter	1.3-2.3	m
Water-Cement Ratio	0.8 until 1.2	-
Air Pressure	4-15	bar
Air Flow	2-10	m^3 per min
Grout Pressure	200 until 400	bar
Grout Flow	150 until 350	L per min

[1]Parameters not defined for each soil layer
Source: Authors

Jet grouting was chosen during the design phase and was included in the contract documents. After the contract was awarded, it was the responsibility of the contractor to develop the column layout and test the jet grout block while adhering to the following constraints:

- Dimensions of the jet grout block – minimum 7.2m x 8.0m
- Utilise a double or triple fluid jet grouting method
- Minimum compressive strength of grout is 2 MPa
- Average in-situ permeability of 1.0x10-5 cm/sec
- Column overlap is to be a minimum of 1/8 of the column diameter or 150mm
- The jet grout block is to be completed prior to the TBM arrival

Following the constraints above and considering the geotechnical information, the optimal jetting parameters were determined by the contractor (Table 1).

The contractor was also required to perform jet grouting test columns prior to, and independent of, the proposed jet grout blocks on the project to demonstrate acceptable in situ results. The tests aimed to confirm the diameter and effectiveness of the jet grout columns in all soil types expected on the project, including the silt and sand layers at the YDSS crossing. Although the design parameters had been established, the contractor, aware of engineering limitations and potential variability in ground conditions, anticipated the need to adjust the parameters based on field results.

Below: ***Figure 2, profile of jet grouting column layout for the YDSS-TBM crossing***

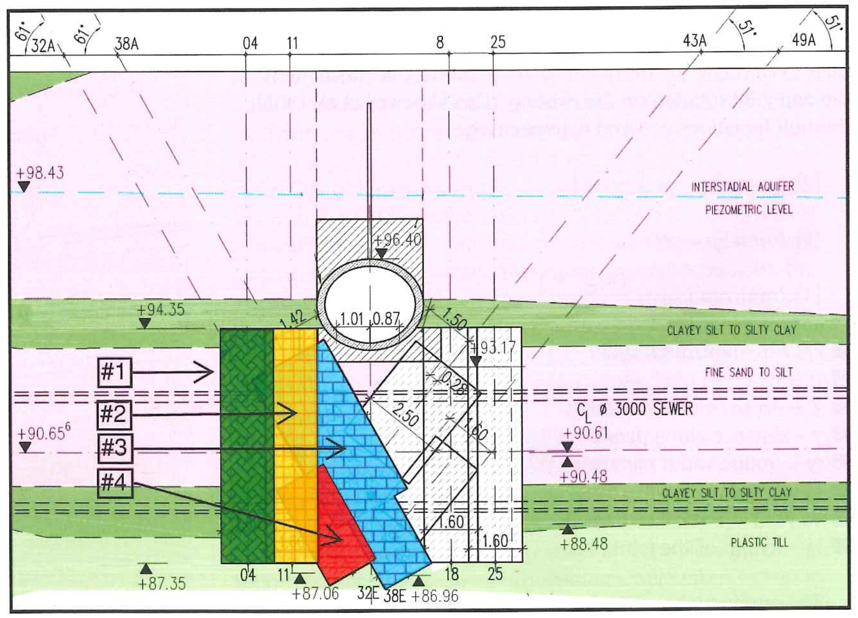


Table 2. Comparison of test column jetting parameters[1]

Geology	Clayey Silt to Silty Clay				Sand to Silt			
Column	TC1	TC2	TC3	TC4	TC1	TC2	TC3	TC4
Diameter (m)	1.8	2.3	2.0	2.4	2.7	2.3	3.1	3.6
Station1 (s)	15	15	15	15	8	15	10	15
Rotation (rpm)	3	8	3	9	8	8	3	8
Flow, Air (l/s)	70	60	60	60	80	60	60	60
Pressure, Air (bar)	6	4	6	6	6	4	6	6
Flow, Grout (l/min)	320	320	320	320	320	320	320	320
Pressure, Air (bar)	400	400	420	400	400	400	420	400

[1]Station: lifting time of the jetting nozzle for a defined step size
Source: Authors

JET GROUTING THE CRITICAL UTILITY

To satisfy contractual obligations, the contractor elected to conduct the jet grouting soil-cement test columns within the Shaft 2 construction compound. Shaft 2 is located approximately 500m south of the YDSS crossing. This location was advantageous to the contractor because it enabled the testing of jet grouting behaviour in the most common stratigraphic layers found on the project. The ground conditions of the YDSS crossing were similar to the hydrogeological and geotechnical conditions of the sand and silt layer found within Shaft 2. This layer was located at a depth of approximately 3.5m and continued to a depth of 6m with an estimated water content of 12-25 per cent.

The test column layout consisted of four independent and three overlapping columns. The three overlapping columns were core-drilled to demonstrate homogenous grouting and verticality while the independent columns underwent temperature monitoring using thermocouples for comparison with Finite Element Models (FEMs).

The contractor closely followed the design parameters while constructing each jet grout column. Upon review of the quality assurance tests for the in situ columns in the sand and silt layer, the temperature distributions consistently followed the FEMs and the core-drilling demonstrated an acceptable vertical homogenous structure. The comparisons of test column jetting parameters are shown in Table 2 for both the clayey silt and sand to silt layers.

On average, the double-fluid jet grouting construction in the sand and silt layer had a water-cement ratio of 1, grout pump pressure of 400 bar, grout flow of 315 L/min, air pressure of 6 bar, air flow of 4 m3/min, permeability well below 1.0x10-5 cm/sec and a diameter of 3.0m. The preliminary design parameters in Table 1 were not defined for each type of soil layer. If the diameters of all of the columns in Table 2 are taken into account, then the average diameter is adjusted to 2.3m, which was within the upper limit of the design range. It is important to note that during construction the contractor lowered the air pressure and flow to the lower limits of the design range. The air acts as a barrier between the grout jet steam and any groundwater that may be present, allowing for deeper penetration by the jetting process (Chauqui et al. 2012). It was found, during jet grouting, that air parameters did not have to be maintained at such high values in order to achieve the desired diameter of the columns.

After completing the test columns, the contractor began installation of secant piles for the Shaft 2 structure. Upon completion of shoring, the contractor proceeded to install the jet grout columns for the Shaft 2 TBM entrance jet grout block. The contractor continued to use the same design parameters as in the test field; however, jetting and grouting the columns had since become a challenge. Frac-outs and up to 75mm heaves in the road and surrounding features had begun to occur in the immediate jet grouting vicinity. It is suspected that the incidents of ground movement increased due to the historically disturbed soils close to the road and the fact that the entrance block jet grout columns were being installed on the outer circumference of the secant piles. It is also thought that the heaves were mitigated during the test column installation by the hardness of the frozen ground at the time. The test field had been constructed during the winter with a mean temperature of -1.3C in February while the Shaft 2 TBM entrance block was constructed in June and July with mean temperatures of 20.2C and 23.5C, respectively.

The YDSS jet grouting was in close proximity to the existing pipe and was approximately 20m from a watercourse. This was an immediate concern as the heaving experienced in the test field and, more notably, at the Shaft 2 TBM entrance jet grout block indicated that similar heaving and frac-outs could occur at the YDSS crossing. These incidences could potentially damage the existing critical utility and frac-outs near the watercourse could cause serious environmental impacts. To decrease the risk of heaving and prevent damages, the contractor adjusted the operating parameters of the jet grouting process at Shaft 2. While still conforming to the design parameters outlined in Table 1, the contractor removed the air component of the double-fluid system and continued with a single-fluid jet grouting process. This modification was acceptable since the desired diameters could still be achieved with a single-fluid system by adjusting the jetting parameters (Shen, Wang, Yang, Ho 2013). Eliminating the air from the system greatly improved the heaving issues, thus, this optimised design was also implemented at the YDSS crossing to decrease the risk of ground movements and frac-outs.

Constructing the jet grout block

The contractor was responsible for determining the number and layout of the jet grout columns required to satisfy

Table 3. Design allowable ground movement limits and typical response plan[1]

Zone	Movement	Typical Contractor Action
Acceptable	+/- 0-7 mm	No action required, continue monitoring program as planned
Review	+/- 7-11 mm	Continue operation and investigate cause of ground movement while taking measures to restore ground movement to acceptable zone, increase level of monitoring program if required
Alert	+/- 11+ mm	Stop operation and immediately investigate integrity of nearby structures and utilities, take all necessary measures to ensure public safety, increase monitoring program (CCTV, survey, etc.)

[1]Limits are defined for both jet grouting and tunnelling
Source: Authors

the minimum surface area design of 7.2 x 8.0m. The contractor proposed an array of 52 variably-sized columns at different installation angles. As a precaution, three test holes were drilled prior to the permanent jet grout block to reconfirm the geological conditions at the site. As no issues were noted as a result of the test holes, column construction began.

The column layout and sequence of construction are shown in Figure 1 and Figure 2, and are comprised of:

- Two rows of 1.6m diameter vertical columns along each side of the existing YDSS
- One row of 1.6-2.5m diameter columns on the west side of the pipe inclined to extend directly below the existing pipe
- One row of 2.5m diameter columns on the east side of the pipe inclined to tie into the columns on the west side
- A final row of 1.6m diameter columns on both sides of the pipe and inclined to complete the full block foundation directly below the YDSS.

Each row of 1.6m diameter columns had a minimum overlap of 0.26m and each row of 2.5m diameter columns had a minimum overlap of 0.5m. This layout produced an interconnected jet grout block that covered all but a minimal area immediately below the existing concrete cradle, as shown in Figure 2. To provide sufficient support for the critical utility, all of the 1.6m diameter vertical columns and the inclined columns on the west side of the pipe were embedded 0.5m, at the minimum, into the plastic till layer, creating a jet grout block with an approximate height of 7.0m.

The single-fluid jet grouting for the YDSS jet grout block utilised jetting parameters from the test columns (see Table 2). The removal of air from the system decreased penetration depth during jetting; however, this was not a concern as the test columns were slightly larger in diameter than what was required. The clayey silt layer required columns to be constructed with 1.6m diameters. This was achieved using the parameters for TC1 and was classified as Parameter Case I. Parameters for TC1 were also used to construct the 2.5m diameter columns in the sand to silt layer and was classified as Parameter Case III. In lieu of a comparable test column, rotation speed was increased and station time was decreased to achieve the 1.6m diameter columns in the sand and silt layer. This modified condition was classified as Parameter Case II. As an example, for column 3, as identified in Figure 1 and Figure 2, Parameter Case I was used to construct the first 3m and Parameter Case III was used to construct the remaining column length.

The construction sequence shown in Figures 1 and 2 continued until all of the columns on the west side of the existing pipe were completed. The jet grouting operation then continued construction on the east side of the pipe, following the same sequence. This order of column construction was implemented to minimise heaving of the existing pipe. Jet grouting in this sequence reduced the stress from upward lift that the jet grout columns would have introduced if the larger inclined columns were built from the top-down. As a result of the design optimisation, the jet grout block was successfully completed using a single-fluid jet operation without frac-out incidents or ground movements of concern.

Monitoring program

Prior to the start of jet grouting at the YDSS crossing there were a number of procedures put in place to monitor potential movement of the ground around the critical utility and of the pipe itself. A CCTV monitoring plan within the existing pipe was implemented using an operable robot to provide real-time feedback. The robot was used to observe flow levels, movement, damage or infiltration into the pipe. A screenshot of the CCTV monitoring is shown below in Figure 3.

Noise and Vibration Monitors (NVMs) were installed at the beginning of the project to provide automatic alerts for excessive vibration or noise within the NVMs' range. The closest NVM was located 40m from the YDSS-TBM crossing. In addition to the project-wide NVMs, there were several Vibration Monitors (VMs) placed in close proximity to the jet grouting operation to provide automatic alerts as well. Settlement Monitoring Points (SMPs) were also installed along the design tunnel alignment and around the surface of the proposed jet grout block and were used to measure changes in ground elevation. Ground movement limits defined by the design are shown in Table 3, and were calculated based on the allowable

***Right:* Figure 3, a screenshot from the CCTV monitoring of the YDSS during jet grouting operations**

Table 4. Settlement as a result of tunnelling[1]

Location	After Tunnelling Mining		After Tunnelling Grouting	
	Max	Average	Max	Average
YDSS (inside of block)	1	0	2	1
SEC (inside of block)	0	0	5	3
SEC (outside of block)	8	4	12	8

[1]*Measured settlement error tolerance: +/- 1mm*
Source: Authors

pipe deflection of the YDSS. The SMPs were monitored continually throughout the work day by surveyors for the entire duration of jet grouting to minimise lag time in the event of an incident. In addition, as a final precautionary measure, the surrounding area was constantly monitored by personnel for frac-outs or any other obvious surface movements during operation.

The jet grouting monitoring was both stringent and comprehensive to ensure the integrity of the existing YDSS pipe. Throughout the jet grouting operation, no concerns were raised by CCTV monitoring and the VMs measured a pre-construction reading of 0.21mm/s and a maximum reading of 0.6mm/s during jet grouting from approximately 30m northwest of the jet grout block. This reading was within the acceptable limits for vibration and therefore was not a concern. There were three SMPs installed above and in direct contact with the existing pipe, which were measured throughout the day during jet grouting operations. Temporary heave fluctuations were measured from an average of 10mm up to a maximum of 14mm. These peak fluctuations were both temporary and expected as an outcome of jet grouting and were considered acceptable pipe movement. It is noteworthy that subjecting the pipes to jet grout heave movements was a more desirable risk than incurring settlement below the pipe, as unnatural heave disturbances have the potential to settle over time and return to the previous state but recovery from settlement is improbable. As described in Table 3, jet grouting operations were not stopped upon exceedance of review level ground movement. Since pipe movements were expected, the main purpose at the review level was to investigate the cause of settlement increase. However, when ground movement exceeded the alert level of 11mm, jet grouting operators would stop construction and the sewer would be thoroughly scrutinised using the CCTV robot. During this time the surveyors increased the frequency of monitoring until the heave subsided and the CCTV operators reported no issues. On all cases of alert during this operation, the measured fluctuations were considered tolerable and no discrepancies were noted in the sewer. As a final achievement, there were no frac-outs or visible surface movements noted during general surface inspection by monitoring personnel. Success of the jet grouting and the minimal ground and pipe movement is directly attributed to extensive risk assessment and design optimisation that preceded construction of the permanent jet grout block.

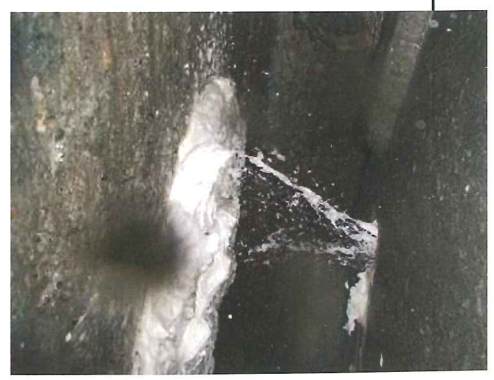
CROSSING THE CRITICAL UTILITY

Tunnelling operations for the YDSS crossing were planned as continuous and uninterrupted production from a cutterhead distance of 10m downstream (east) to 20m upstream (west) of the critical utility, herein known as the Critical Zone. This schedule was intended to not only reduce the risk of settlement due to stopping the TBM but also to avoid interferences in workflow patterns of the crew, i.e., workflow disruption. While tunnelling-related downtime due to unexpected stoppages for repairs and troubleshooting are unavoidable, all expected stoppages required for TBM production within the Critical Zone were eliminated to facilitate the scheduled mining program. High voltage cable extensions, resetting of the surveying laser and maintenance procedures are examples of some of the tasks completed prior to the TBM entering the Critical Zone.

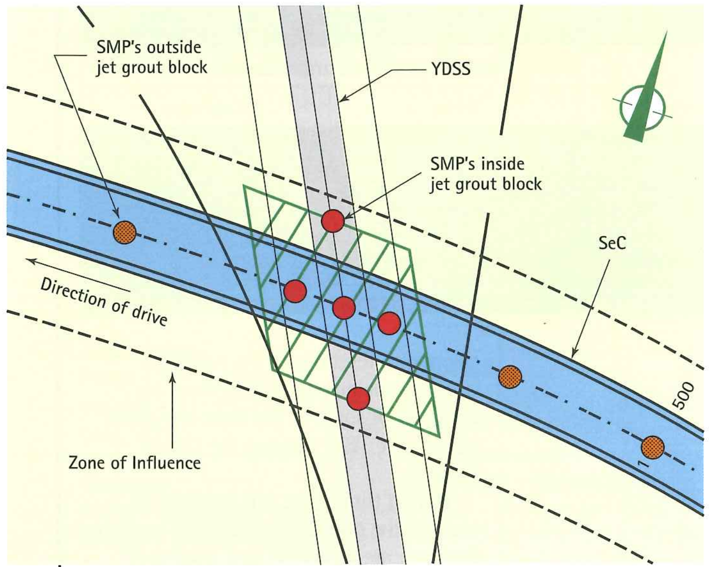
During tunnelling, it is essential to monitor the operating parameters to ensure that they are consistent and compliant with the contract specifications. Preparing for approaching changes in geology as outlined in the GBR and adjusting parameters based on the encountered ground conditions encountered are essential aspects of efficient tunnelling. While tunnelling up to and under the critical utility, the EPB pressures, Ground Conditioning System (GCS) parameters, tail seals grease volume, screw rotation, annulus grout pressures and annulus grout and muck volumes were monitored and adjusted carefully to control the inflow of material into the TBM. To control inflow into the cutterhead and excavation chamber, the GCS was adjusted as required and the EPB pressures were continuously maintained within the contract specified window of 1.92 +/- 0.3 bar.

Ground conditioning

As mentioned previously, there were two significant settlement incidents as the TBM progressed towards the YDSS crossing location. The second one was caused by an attempt to enter the cutterhead to initiate repairs on damaged GCS lines. A fully operational GCS was necessary for efficient and controlled mining and was critical for crossing the YDSS; however, the geological conditions in this area were comprised of flowing fine sands



***Right:** Figure 4, testing GCS lines after repair in the headwall*



Above: Figure 5, SMP layout of crossing during tunnelling

and silt and did not permit safe access into the cutterhead to complete the necessary repairs. Consequently, in order to repair the GCS lines the TBM needed to mine into a maintenance secant pile headwall approximately 25 m from the YDSS crossing. Upon completion of repairs (Figure 4), the TBM continued its advance towards the YDSS crossing.

Monitoring program

CCTV monitoring was also implemented while tunnelling under the YDSS. While no issues were noted by the CCTV monitoring program during the tunnelling operations within the Critical Zone, if the review or alert limits, as defined in Table 3, had been exceeded, the corresponding required action would have been initiated.

As mentioned previously surveying of the design tunnel alignment on the surface showed that an average of 20.5mm of settlement had occurred in the 500m prior to the crossing. In addition, there were two settlement incidents that measured up to 158 and 300mm, respectively. As a result, surface movement monitoring was critical during the crossing. The SMPs were installed with approximately 10m spacing along the tunnel alignment. In addition to these survey points there were supplementary SMPs installed on the existing YDSS sewer alignment and in the crossing area. Figure 5 shows the SMP layout at the critical utility crossing. The SMPs were measured twice a day before the TBM reached the Critical Zone and four times a day when the TBM was within the Critical Zone. The SMP located directly on the YDSS pipe at the TBM crossing was measured every 30 minutes.

The settlement readings during the TBM progression in the Critical Zone are shown in Table 4. There was little to no movement noted for the existing YDSS and minimal settlement of the area stabilised by the jet grout block both during and after the TBM had passed. The settlement due to tunnelling outside of the jet grouting block was, on average, 75 per cent greater than the area within the jet grouting block. These results clearly demonstrate that the support provided by jet grout ground improvement was sufficient to mitigate the risk of ground loss and settlement-induced pipe damage at this critical utility crossing. Additional safety measures were mobilised to the YDSS crossing site as precautions in the event of a failure of the pipe. One of these measures was to install a dewatering system and monitoring wells around the YDSS-TBM crossing. The dewatering system would be utilised to reduce water pressure in the immediate area as well as to mitigate the environmental impact of contamination seepage in the event of pipe failure.

Other precautionary measures included the delivery of a large extended-boom excavator, a holding tank, pumps and hoses and other miscellaneous equipment to facilitate the exposure of the critical utility and to maintain flow around potential blockages.

CONCLUSION

Tunnelling beneath the critical utility under live flow proved challenging. To mitigate risk and avoid damage to the existing pipe, specific procedures and precautionary measures were implemented during both design and construction. Furthermore, to avoid scheduling delays and minimise the environmental and societal impact, it was beneficial to select measures that could be implemented prior to the TBM arrival at the crossing.

Ground improvement by jet grouting around the YDSS was an effective solution for ensuring the integrity of the existing sewer during the crossing. Although heave occurred during the jet grouting process, it was reasonably controlled, within an acceptable limit and was preferred over the potential risks, such as settlement, of other solutions. Settlement of the existing sewer was kept within acceptable design limits during tunnelling. Settlement at the crossing was also markedly reduced compared to settlement just outside of the jet grout block. The difference was even greater between the final jet grout block settlement readings and the settlement readings in the 500m of tunnelling prior to the crossing. The consistent and favourable measurements from the jet grouting block strongly support the use of this technique as ground improvement to facilitate tunnelling beneath critical utilities

References

Attewell, P.B., Yeates, J., Selby, A.R. 1986. Soil Movements Induced by Tunneling and their Effects on Pipelines and Structures, Chapman and Hall, New York, NY, US.

Chuaqui, M., Hu, F., Gurpersaud, N. and Lees, D. 2012. A Case Study: Two-fluid jet grouting for Tunneling Application – Soil stabilization and permeability reduction. Proceedings of the 4th International Conference on Grouting and Deep Mixing, Deep Foundations Institute, New Orleans

Hatch Mott MacDonald and Aecom 2011. Southeast Collector Trunk Sewer Geotechnical Baseline Report, The Regional Municipality of York, York Region, ON, CA.

Lake L.M., Rankin W.J. and Hawley J. 1992. Prediction and Effects of Ground Movements Caused by Tunneling in Soft Ground Beneath Urban Areas, CIRIA Funders Report/CP/5.

Peck, R.B. 1969. Deep exc. and tunnelling in soft ground. Proceedings of the 7th Intl. Conf. on Soil Mech. and Foundation Eng., Mexico City, State of the Art Vol. 3, 225-290.

Rankin W.J. 1988. Ground Movements Resulting From Urban Tunnelling: Predictions and Effects. Engineering Geology of Underground Movements. Proceedings of the 23rd Annual Conference of the Engineering Group of the Geological Society, Nottingham Uni.

Shen, S.L., Wang, Z.F., Yang, J. and Ho, C.E. 2013. Generalized Approach for Prediction of Jet Grout Column Diameter, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 139, No. 12.

The Regional Municipality of York 2009. Water and Wastewater Master Plan Update.

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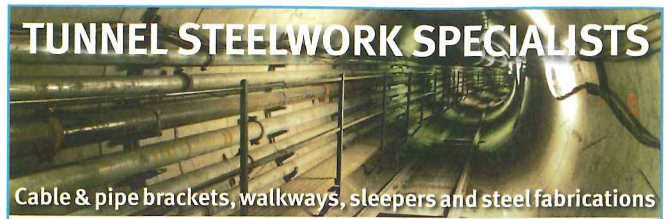

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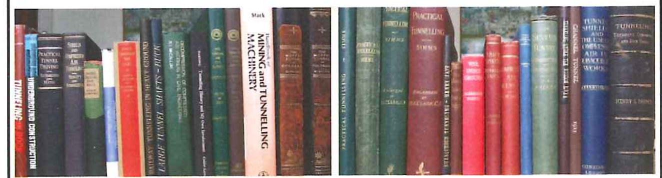

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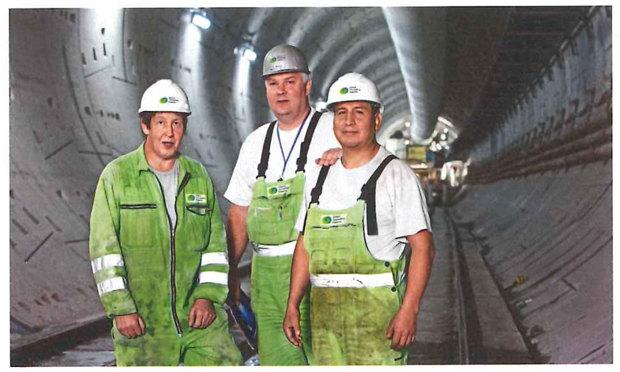

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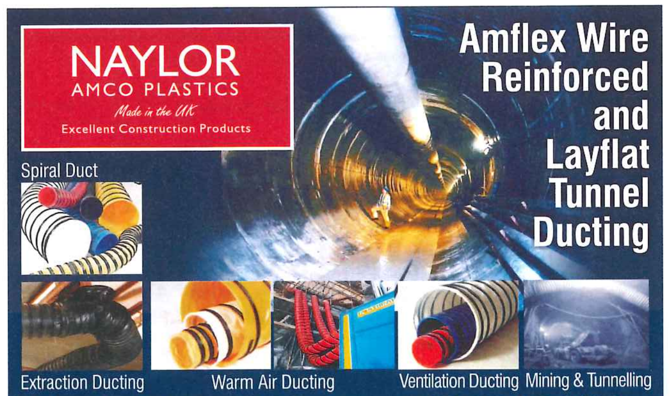

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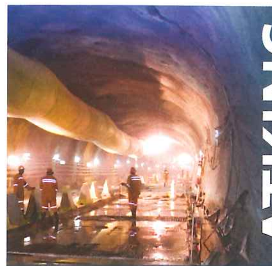

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This is not the full list of British Tunnelling Society Corporate Members. To see a full list of all members visit: **www.britishtunnelling.org.uk**

If you wish to become a British Tunnelling Society Corporate Member please email: **bts@britishtunnelling.org.uk**

BRITISH TUNNELLING SOCIETY

What's on

2015

Tunnel Expo Turkey
27-29 August 2015
Istanbul, Turkey
Turkey is fast growing in the tunneling sector. This event namely Tunnel Expo Turkey focuses on the fast growth.
www.10times.com/tunnel-expo-turkey

Crossrail's tunnelling story exhibit - final day
31 August 2015
London, UK
The final day of the six-month exhibit on Crossrail at the London Transport Museum in Covent Garden falls at the end of August. The exhibit is open seven days a week for the majority of the day, so don't miss out.
www.ltmuseum.co.uk

Underground Design and Construction Conference 2015
11-12 September 2015
Hong Kong
The Hong Kong branch of the Institute of Materials, Minerals and Mining expects to have over 500 delegates and numerous exhibitors, building on the 2009 event. Keynote speakers include N. Barton, M. Herrenknecht, C. F. Lee and L. Home.
www.udcc2015.com

Bauma Conexpo Africa 2015
15-18 September 2015
Johannesburg, South Africa
The premiere of bauma Africa in September 2013 attracted 754 exhibitors from 38 countries and 14,700 visitors from over 100 countries. Covering a total of 60,000sq.m of exhibition space, this is the biggest event for the sector in Africa.
www.bcafrica.com

Health and Safety - what's next?
23 September 2015
London, UK
Get up-to-date insight from the industry's best. The BSC's annual conference will tackle key issues from across the health and safety landscape. It will give you the opportunity to gain insight into innovation and best practice in health and safety management, while networking with your peers.
www.britsafe.org

Roads. Bridges. Tunnels International Exhibition
23-25 September 2015
St. Petersburg, Russia
Roads. Bridges. Tunnels (the International Specialised Exhibition) takes place in St. Petersburg, Russia from 23 September to 25 September.
www.tofairs.com

ICUEE 2015
29 September-1 October 2015
Louisville, Kentucky
The largest demonstration show in North America for the construction and utilities industries. This biennial show attracts persons involved in the electric, cable, sewer/water, gas, construction and public works sectors. Hands-on, practical desmonstrations of construction and utility equipment are also planned to be held alongside the event.
www.icuee.com

Workshop on Innovations and Challenges in Tunnelling
5-6 October 2015
Kingston, Ontario
Save the date for the TAC 2015 Workshop, AGM and annual awards dinner, to be held at Queen's University's Grant Hall in Kingston. Further details of the workshop including program and registration will be available in Summer.
www.tunnelcanada.ca

8th Annual Health and Safety Excellence Conference
7-9 October 2015
Amsterdam, Netherlands
This conference will help companies to develop their safety culture and achieve optimized technical safety through increased engagement. Cross-industry experts will deliver practical case studies on how they have successfully implemented an optimized safety culture
www.marcusevans-conferences-paneuropean.com

Eurock 2015 & 64th Geomechanics Colloquium
7-10 October 2015
Salzburg, Austria
The ISRM Regional Symposium EUROCK 2015 Future Development of Rock Mechanics, is to be held in conjunction with the 64th annual Geomechanics Colloquium also in Salzburg.
www.eurock2015.com

25th World Road Congress
2-6 November 2015
Seoul, South Korea
The World Road Congress has been held every four years for more than 100 years. Since the first meeting in Paris in 1908, it has toured the member countries of the non-government organization, Permanent International Association of Road Congresses (PIARC).
www.aipcrseoul2015.org

Controlling exposures and health risks in construction
10 November 2015
Birmingham, UK
The Breathe Freely campaign has been launched recently with a view to raising awareness of the occupational health issues related to respirable materials in the construction industry.
www.breathefreely.org.uk

ITA Tunnel Awards
19 November 2015
Hagerbach, Switzerland
The International Tunnelling Association has launched its own independent awards to recognise industry achievements. The first presentation will be held alongside a conference and banquet at the Hagerbach Test Gallery.
www.awards.ita_aites.org

Third Arabian Tunnelling Conference and Exhibition
23-25 November 2015
Dubai, UAE
This conference is the industry's opportunity to share the knowledge, projects and application experiences, and provide you the opportunity to hear what others have to say. Case studies, which show real-world applications and the implementation of new technologies.
www.atcita.com

Stuva Conference
1-3 December 2015
Dortmund, Germany
Held every two years, this conference sees 1,500 participants and visitors from about 20 countries. It is numbered among the world's leading get-togethers for underground construction experts. In 2015 the chosen venue for this premier event is Dortmund.
www.stuva-conference.com

Building simulation
7-9 December 2015
Hyderabad, India
This conference is the 14th International Conference of the International Building Performance Simulation Association.
www.bs2015.in

2016

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 the field of tunnel safety and security. Each day will be opened by invited Keynote Speakers.
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 maximize your investment in trenchless technologies, services and applications. Owners, utilities and municipalities can immediately benefit.
www.nodigshow.com

Bauma 2016
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.
www.bauma.de/en

World Tunnel Congress and North American Tunnelling conference 2016
June 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 Tunneling conference. Bringing the three events together in the US is unprecendented.
www.smenet.org
www.wtc2016.us

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 issues
www.geochina2016.geoconf.org

British Tunnelling Society

The BTS has a membership of almost 700 individual and 60 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. 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) have also begun hosting events.

Glasgow Shieldhall Tunnel and tunnelling Seminar
7 July 2015
The Scotland Region in conjunction with the British Tunnelling Society is delighted to announce an afternoon seminar on Scottish Water's prestigious GBP 100M (USD 157.47M) project, the Shieldhall Tunnel, a 3-mile (5km) underground waste water tunnel which will run through the south of Glasgow, topics include: Shieldhall from the client's perspective, Shieldhall from the contractor's perspective, Shieldhall from the supplier's perspective, as well as a summary of the BTS and UK tunnelling activities, a summary of BTSYM initiatives and a roundup of international tunnelling points of interest. Admission and car parking to this event is free.
Please confirm attendance to: james.halfpenny@cemex.com
Please also note that this event is in the Marriott Hotel on Argyle Street in Glasgow, Scotland

Innovation and technology in segmental lining design
17 September 2015
A presentation by a tunnel engineer who has extensively published on topics related to segmental lining solutions. This talk will cover the future of segmental tunnel linings. The speakers stated: "Over the last 40 years TBM tunnelling and segmental lining technology has seen significant changes in the technologies adopted and how it operates. This presentation aims to stimulate industry-wide discussion by sharing our views on where we are and where we collectively believe our industry is heading."
Speakers: Mike King, director at CH2M; Anthony Harding, global technology director for tunnels at CH2M; Malcolm Chappell, director at Ozengi Associates

Waterview Connection project in Auckland, New Zealand
15 October 2015
The Waterview Connection project is New Zealand's largest and most complex road construction project. It is due to be completed by 2017, and includes one of the country's most challenging tunnels to-date: some 2.4km of 14.1m-diameter twin bores.
Speaker: Chris Ashton,
Waterview Connection project tunnel manager

BTS Underground Health and Safety Course
24-25 November 2015
The Health & Safety Course is organised and run by the British Tunnelling Society (BTS), an Associated Society of the Institution of Civil Engineers. The purpose of the course is to provide a comprehensive introduction to Health & Safety in tunnelling. It has been decided to repeat the two day format of the last five years to allow more time on specific subjects and include more discussion and debate.
Fees: BTS Members: GBP 100; Non-Members: GBP 150

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

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See the society website for further information:
www.britishtunnelling.org.uk

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