INTERNATIONAL EDITION
June 2015

Tunnels AND TUNNELLING

KING KONG

Hong Kong's longest and deepest subsea drive: the Tuen Mun to Chek Lap Kok Link

+ Constructability | Asia | Underground Utilites

GIVE A VOICE TO FUTURE TECH

IN A PREVIOUS comment I wrote about ITA president Soren Eskesen's progress with bringing tunnelling to the attention of the UN bodies studying ways to mitigate the effects of flooding and other natural disasters caused by climate change. He has had some success in this, but talking about innovations and actually putting them in place are sometimes a world apart.

WTC is usually pretty good for coming across new and interesting ideas. This year the Dragon project made an effort to promote itself. The team running the project tries to encourage the purposeful use of spoil, and have had interest from major jobs such as Crossrail, but not early enough to be implemented. In previous years the Rehau system of moving water through pipes in a precast lining and taking advantage of heat differentials to generate energy has been on show.

These ideas are often a bit of a sideshow at events. But there is something the ITA could do to help.

Every year the Muir Wood lecture is held after the opening ceremony, and is understood to be a chance for a speaker to give the audience a new perspective on an old issue. The ITA statement on the Muir Wood Lecture reads: "After his death in 2009, ITA decided to create a Sir Alan Muir Wood Lecture. Each year at WTC a chosen lecturer gives [their] view on tunnelling."

And although there was nothing wrong with the lecture this year, other topics could suit the mission statement better, and benefit more from the exposure.

ITACUS exists to look at the use of underground space in innovative ways to solve the problems of the future. When their leadership attended an ITAYM event at WTC this year it was a good match.

New generations will be the engineers implementing these ideas, and will be the people experiencing the effects of climate change (and the other various problems of a rapidly increasing population) more and more.

ITACUS leader Han Admiraal also paid tribute to the ITAYM in the General Assembly at the end of WTC, saying the ITA should be proud of its enthusiastic band of rebels, and that it was heartening to meet them. A nice change from what he sees as the gradual pulling away from Underground Space concerns even in terminology. It is, after all, the International Tunnelling and Underground Space Association

ITACUS's activities are not always as well-known or implemented as they might be. Admiraal says it is an ongoing effort to increase the impact of the group's activities.

And if the ITA is as seriously focused on these activities, and the application of tunnelling to solve our problems as it claims, why not put ITACUS in front of the entire Congress by giving the group a Muir Wood lecture?

It suits the feel of the lecture, and suits an industry looking ever more to the future

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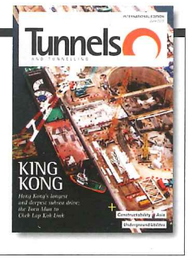
What do you think? Send your views to the editor and join the debate

Alex Conacher
Editor

Cover
The cover shows work underway on the northern portal of the Tuen Mun to Chek Lap Kok Link project



Next issue
In the next issue of Tunnels and Tunnelling we focus on the Australasia tunnelling market, with an insight on grouting, another on pipe jacking and a report from a meeting of the British Tunnelling Society that focussed on deep Potash mining in Canada

This month...

30 YEARS AGO

Russian engineers have had to admit that tunnelling through mixed ground in a seismically active mountain range for the country's new 3,200km-long trans-Siberian railway, called the Bam railway, is not a long term possibility and a detour is now under construction. Great geological problems confounded construction of the six tunnels on the route causing constant delays and collapses (Tunnels and Tunnelling October 1984, p.7). Now, although the nine-mile long Muisk Tunnel is open to traffic, hot spring water seeping into the excavation is causing rapid deterioration of the tunnels concrete lining, particularly where the geology merges from granite to sands. A new double-track tunnel is being excavated as part of the detour.
Tunnels and Tunnelling, June 1985, p.10

40 YEARS AGO

Work has just started on a section of the westward extension of the Brussels Metro being carried out for the Societe des Transports Intercommunaux de Bruxelles. Consulting Engineers for the east-west axis are Mott, Hay & Anderson in Association with Frederic R. Harris. The two contractors for the section are CITEB and SOTRAHY. The extension involves 1.25km of tunnelling.
Tunnels and Tunnelling, July 1975, p.15*

**No June issue printed in this year*

Left: The Chennai Metro project, page 34

News

North America

Insight

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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 Tuen Mun to Chek Lap Kok Link

KEREN FALLWELL
Keren joins the Tunnels and Tunnelling this year as a contributing editor. This issue she is reporting on the HDD market

Jacobs awarded early design work for Heathrow link

GREAT BRITAIN — Jacobs Engineering has been tasked with design and studies work for a proposed Network Rail link to Heathrow. The 'Western Rail Access to Heathrow' project will apply for a Development Consent Order in early 2016. Jacobs will produce the design for the proposal documentation.

The scope of work includes topographical surveys and geotechnical investigations, tunneling design for the new 3.1-mile (5km) route, and railway systems designs for track and overhead line equipment.

The proposed Western Rail Access to Heathrow includes a new direct, double track link between the Great Western main line at Langley in Berkshire (16 miles west of Paddington Station in London) into Terminal 5 at Heathrow airport. The link is expected to provide greater connectivity from south Wales, the west of England and the Thames Valley; making journeys faster, reducing congestion on other routes, and providing significant economic benefits for businesses in the region. The project also aims to reduce CO2 emissions by the equivalent of a million road passenger trips to and from Heathrow.

Jacobs Group Vice President Bob Duff stated, "Jacobs is delighted to continue to leverage our global rail experience on this planned project. We look forward to contributing tangible solutions to support Network Rail's emphasis on sustainable design at the heart of the new rail link."

Jacobs delivered pre-feasibility and feasibility studies in the early planning stage of the project which identified significant potential cost savings. Currently in public consultation, if the Western Rail Access plans are approved, it is expected that the new service would be in operation by 2021.

News briefs

EGYPT

A joint venture of Vinci Construction Grands Projets and Bouygues, with local partners Orascom Construction and Arab Contractors has been awarded the Cairo Metro Line Three Extension contract. The extension, phase 4a, involves 5.15km of tunnel and five underground stations. The USD287M project has a design-build-delivery timescale of 34 months. The project delivery will also involve the modification of an EPBM to operate as a slurry machine.

GREAT BRITAIN

The British Tunnelling Society (BTS) annual dinner was another steaming success. With more than 850 tunnellers and partners attending the dinner at the Brewery in London, the BTS Young Members said on their twitter feed "The question is... Who is looking after the TBMs of London tonight." HS2 chief Tim Smart spoiled the crowd with his after dinner speech with memories of bygone times, but light on divulging project secrets. BTS Chairman Roger Bridge said after the event that there are plans for a second annual social, aimed at individual members as the annual dinner reaches saturation point. The BTS also used the event to launch its campaign for London to be the host of the World Tunnel Congress in 2019, bringing the community back to the birthplace of modern tunnelling.

TUNNELERS TOLD TO STOP USING ORDINARY CEMENT

WORLD TUNNEL CONGRESS — The tunnelling industry should wean itself off ordinary Portland Cement (OPC), argued Anthony Harding of CH2MHill last month. Geopolymer 'concrete' is a cheaper, more practical and more environmentally friendly alternative to OPC, claimed Harding.

Harding told tunneller attending the World Tunnel Congress in Croatia last month that Geopolymer 'concrete' replaces OPC with a geopolymer binder that is produced from industrial waste products such as fly ash.

The benefit is a 70 percent or more reduction in carbon emission, said Harding. "Around 1,000km of tunnel was constructed last year. If we assume a conservative average diameter of 5m, thickness of 250mm, and CO2 emissions of 100k per tonne of concrete, you are looking at 10Mt of concrete cast for tunnel lining alone. And CO2 emissions of 1Mt."

In the presentation, Harding did not just reply on the environmental spirit of engineers, he added benefits that include a 10 percent or more cost reduction when compared with cementitious products; almost no curing required and no requirement for steam curing; less vulnerability to early thermal cracking; possible savings from removing or reducing micro-synthetic fibres for fire performance.

From the audience, Martin Knights, former ITA president and current tunnelling director at Jacobs Engineering, raised the point of cost reductions as an amazing boost to this technology.

ITATECH reports on 2015 progress

WTC — The new chairman of the ITA committee on Technologies (ITATECH) presented the progress made by group at WTC 2015.

ITATECH chairman and Atlas Copco vice president Pauli Arenram said that the key focus of the group had been on the production of guidelines, as well as cooperation with other Working Groups.

A number of guides have recently been completed. These include: a guideline on vibration control in urban tunnelling; a guideline for rebuilt TBMs; a guideline for the frequency of measurements in monitoring; and a guideline for fibre reinforced precast concrete.

Several guidelines were declared ready for review, notably including a document on bolting and arch support. An "extensive training package" on lining and waterproofing also requires only a few final changes before it may be published.

Arenram who was made interim chair in October 2014 was named full chair to applause after his presentation.

SEATTLE DISMANTLES SR99 MACHINE

USA — Seattle Tunnel Partners (STP) has confirmed that dismantling of the SR 99 TBM is complete, and assessment of the damage is ongoing, according to a release from the Washington State Department of Transportation (WSDOT).

In a release issued May 18, WSDOT announced STP will not provide a revised schedule for resuming mining until the JV fully understands the scope of repairs.

"STP has indicated that they will replace the main bearing and outer seals of the machine as expected. They have also decided to replace the inner seals to make them more compatible with the new outer seals and easier to access should the need arise. The new inner seals were designed and manufactured in Japan and are scheduled to arrive in late May."

Damage to the 17.5m diameter Hitachi Zosen machine was more extensive in some areas than anticipated and some minor damage occurred during disassembly. For example, the outer seals and the steel retainers that hold them in place were destroyed. There was also damage to the cutter drive motor pinions and the main bearing bull gear.

Meanwhile the results from two separate reports have been announced, by WSDOT, regarding settlement near the SR 99 tunnel access pit last November.

"Settlement near the pit and in the surrounding neighborhood was caused by a combination of historic and ongoing natural ground movement in the region, dewatering related to tunneling machine repair work and dewatering related to other construction in the area."

One report, conducted by geotechnical firm Shannon & Wilson, Inc. and commissioned by WSDOT, concluded that dewatering related to tunneling machine repairs was the primary cause of the settlement.

A second report, conducted by Brierley Associates and commissioned by STP concluded that natural settlement and other dewatering activities are the primary reasons for the settlement, and tunnel-related dewatering only contributed in areas immediately surrounding the pit. Both of these reports relied on the same data points.

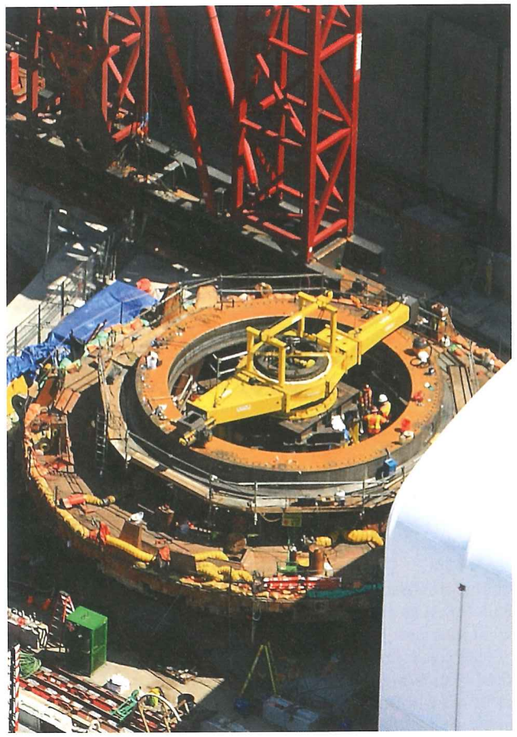
The issue began late last year, when the tunnel project's monitoring system detected settlement in the vicinity of the 120ft-deep pit STP built to access and repair the tunneling machine. In response to the settlement, WSDOT and STP increased the frequency of monitoring – which includes hundreds of instruments near the access pit – and assessed the viaduct and nearby buildings.

Both reports demonstrate that settlement related to dewatering has since stabilized; they also agree the ground movement was minor and caused no structural damage. The Shannon & Wilson report, using in part information from satellites, also identifies settlement in areas surrounding the project – in some cases, outside the ongoing monitoring area.

"Though satellite imagery is helpful to indicate trends, ground monitoring is the most reliable gauge of ground activity, which is why WSDOT's monitoring program relies mostly on ground sensors throughout the project area," the agency said.

"WSDOT and STP are continually evaluating ground conditions and taking proactive steps when needed to prevent further project-related settlement. That includes reviewing existing procedures for reducing dewatering should it become necessary."

For more information see news artilce on page 10.



An aerial view of repairs on the damaged Hitachi Zosen boring machine

Fama awarded Lyon-Turin segment moulds contract

ITALY — Fama has been awarded a turnkey contract for supply of segment moulds, gaskets and connectors to the Lyon-Turin base tunnel project. The It

Fama has been awarded a turnkey contract for supply of segment moulds, gaskets and connectors to the Lyon-Turin base tunnel project. The Italian sealing technology expert won the job in the early months of this year, and the order details have recently been sent.

The company was notably recently awarded an industrial patent for an integrated anchored gasket.

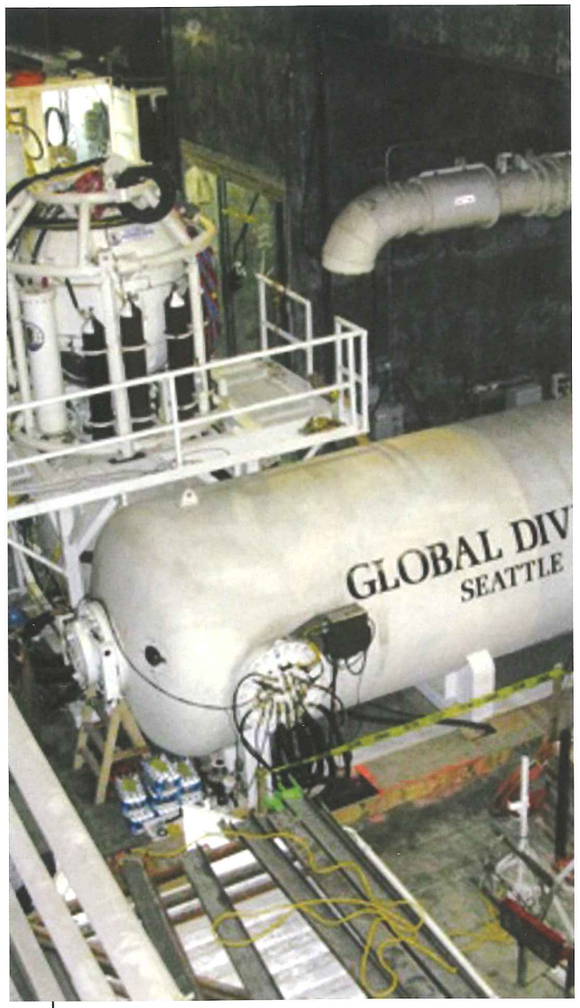
Speaking at the World Tunnel Congress in Croatia, Fama project manager Daniele Nocente said: "This is a major award for us, and a project to be proud of. Breaking into the French market, and in such a good way, is very positive.

According to Nocente, anchored gaskets have four main advantages over glued: cost savings, time savings, superior protection against water infiltration, and the removal of solvent exposure (and the complications of its storage).

He adds: "We are seeing an increased environmental consciousness from our clients for certain, but the practical benefits are also clear in my opinion.

"It has been a case of knowledge transfer from one industry into another – we began work with window sealing products."

Nocente added that there are often technical developments that can be made to established products, and said that the anchored feet of Fama's newer gaskets fold rather than compress, reducing strain and extending product life.



ITA'S COMPRESSED AIR GUIDELINES COMPLETED

WORLD TUNNEL CONGRESS — The ITA's Working Group for Health and Safety has finalised its compressed air guidelines.

Originally identified as an objective at the World Tunnel Congress in Vancouver in 2010, Working Group Five (WG5) defined this as "work in compressed air at pressures above historical statutory limits." In most countries these limits are between three and four bar (gauge) and involve the use of breathing mixtures other than compressed natural air and can involve the use of saturation techniques.

A British Tunnelling Society (BTS) working group had earlier identified a "significant development in the use of compressed air for which no guidance existed," stated WG5.

The first guidelines were published in 2012, were updated in 2013, and have now been completed.

WG5 also commented that although it is not its purpose to give guidance on commercial matters, high-pressure compressed air work requires expensive equipment that can stand idle for long periods. It would be sensible to standardise shuttle dimensions, capacities and pressure capabilities. This would make equipment interchangeable, re-usable and easily contained for transport.

Steel pipe deemed DSC in Seattle's mega tunnel

USA — A dispute review board made its recommendation May 3 that the steel casing encountered by the TBM excavating the SR99 Replacement Tunnel in Seattle in December 2013 is a Differing Site Condition (DSC).

According to a document released by the Washington State Department of Transportation (WSDOT) on May 8, the board found "WSDOT and its consultants were in an excellent position to identify the existence and depth of the steel casing.

"Furthermore, the timing was such that this potential obstacle could have been noted in the GBR before the project went out to bid in June 2010. Yet, WSDOT has declined any knowledge that steel casing existed within TW-2 prior to being encountered by the TBM."

WSDOT installed the 8in diameter steel pipe casing in a test hole in September of 2002. The 57ft (17.4m) diameter Hitachi Zosen TBM hit the casing approximately 870ft from the entry portal of the tunnel on December 3, 2013. In a letter dated December 12, 2013, contractor Seattle Tunnel Partners (STP), a joint venture of Dragados USA and Tutor Perini Corp, claimed entitlement to a Change Order under the following possible entitlements: WSDOT-Caused Delay, Differing Site Condition, Defective Specifications and Breach of Implied Warranty.

The recommendation issue only addresses the specific question of whether or not the 8in steel casing is a DSC under the contract. The hearing and subsequent recommendation did not deal with how the TBM was damaged or the costs associated with repairs.

The board said both the geotechnical baseline report and the environmental baseline report are "silent" relative to the specific tunnel obstruction encountered. The geotechnical and environmental data report prepared by WSDOT in 2010, indicated that observation wells had 2in-diameter PVC casings, which, as STP argues, would pose no substantial problem for the TBM.

"As it turned out, however, TW-2 had an 8in diameter steel casing, which caused a significant problem for the TBM."

The board also said that the contract requirements to investigate site conditions during STP's design and construction efforts were satisfied by the efforts expended in pursuing information through WSDOT and its consultant Shannon & Wilson, Inc.

STP's project manager, Chris Dixon, issued a statement: "Seattle Tunnel Partners has advised WSDOT that Seattle Tunnel Partners has accepted the recommendation and considers this issue to be resolved."

WSDOT's Todd Trepanier, the Alaskan Way Viaduct Replacement Program administrator, said: "WSDOT disagrees with the recommendation and does not consider this issue to be resolved. We are concerned with the reasoning used by the Dispute Review Board in reaching the recommendation. We are reviewing it and will continue to pursue the best interests of taxpayers as we determine the appropriate next steps."

SHORTLIST FOR USD1.5BN PERTH RAIL TUNNEL ANNOUNCED

GLOBAL — Three consortia have been shortlisted to go to the next stage of the tender process to design and construct the AUD2bn (USD1.5bn) Forrestfield-Airport Link.

The consortia are: JHL JV (John Holland and Leighton Contractors); SI-NRW JV (Salini Impregilo and NRW); Forrestfield Connect (ACCIONA Infrastructure, BAM International and Ferrovial Agroman).

The project will provide new rail services and improved bus networks for the Eastern Suburbs, foothills and surrounding community to the Perth CBD and the full Transperth bus and train network.

The 8.5 kilometre rail extension branches off the Midland Line, just east of Bayswater Station, and will be underground for 8kms in twin bored tunnels. It will feature three stations, Airport West, Consolidated Airport and Forrestfield.

The shortlisted consortia will now be invited to respond to a Request for Proposal (RFP) for the project.

Transport Minister Dean Nalder said the Public Transport Authority (PTA) evaluated five proposals.

"The level of interest in designing and constructing this transformational rail line to Perth's foothills via the Perth Airport has been high," said Nalder.

"The five proposals that were submitted were from leading national and international contractors, but only a maximum of three respondents can progress to the next stage."

The PTA will now issue a formal RFP to the three short-listed proponents to develop fully costed proposals.

A contract will be awarded to the successful bidder in mid-2016 with detailed design to begin soon after and construction starting in late 2016.

The first train will operate along the line in 2020.

Forrestfield Station concept design, before the trains head underground

Atlas Copco hires new product manager

SWEDEN — Atlas Copco added Matt Franzel as its new product manager to oversee its hydraulic attachments, including bucket crushers, breakers, cutters, grapples, magnets and pulverizers, the company announced on last month.

Franzel's responsibility covers multiple tasks within Atlas Copco's construction tool division. He will grow the division product lines, as well as use U.S. market information, product knowledge and sales strategy to advise sales staff.

"This is an exciting opportunity since I will be working with one of the largest hydraulic attachment manufacturers in the world," said Franzel. "I am looking forward to working with this great group of individuals and contributing to a quality organization."

Atlas Copco said, Franzel's multiple years within the construction equipment industry makes him a good fit for the role. He has roughly 15 years of experience selling and marketing hydraulic attachments throughout the U.S. Prior to that, he was involved in general construction equipment sales and the construction rental industry.

New addition at Geocomp consulting division

USA — Geocomp announced on May 18 it has hired Matthew Tibbutt as senior project manager for its Consulting division in Massachusetts.

Tibbutt will lead the Instrumentation and Monitoring department for the Boston office. He will support projects including the Los Angeles Metro Crenshaw/LAX Corridor as well as local projects for MassDOT and MBTA.

Geocomp said he has extensive experience in complex system design, instrumentation installation, data interpretation and project management for large civil infrastructure projects. He has worked on signature projects such as London's Crossrail project and the Burj Khalifa in Dubai.

"We are confident that his expertise combined with his past involvement in such substantial projects will be a key resource to our clients."

Geocomp, headquartered near Boston, provides comprehensive geostructural design and performance monitoring services.

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

editor@tunnelsonline.info

Left: On March 5 a Robbins 6.2m-diameter TBM finished boring a 2.8km-long extension tunnel, known as the Eagle Creek Tunnel, for the Indianapolis Deep Tunnel System in Indiana. The contractor is a joint venture of Shea and Kiewit.

BRENNER: A CHALLENGE FOR EUROPE, ENGINEER AND EQUIPMENT

The Brenner Base Tunnel is a massive challenge for all those involved parties. Earlier this year in the run-up to the TEN-T in Action (Trans-European Network-Transport) Roland Herr discussed the project with **Konrad Bergmeister**. Bergmeister has been CEO of *BBT SE* since August 2006. He was previously the technical director and head engineer of the company managing the Brenner highway and was responsible for the planning and construction of new infrastructure and for maintenance of the existing structures. For the past 22 years, he has taught construction engineering at the *University of Natural Resources and Applied Life Sciences* in Vienna

Could you give me a brief overview of Brenner Base Tunnel project?

Bergmeister: The Brenner Base Tunnel is a pioneering engineering project for the 21st century. This underground structure has a total length of 64km and consists of three tubes, the exploratory tunnel and two main tubes with four lateral access tunnels along the whole project. The tunnel itself will become the longest railway tunnel in the world.

Originally, some160 years ago, an Italian engineer came up with an idea to underpass the Brenner Pass. After the Second World War, the project was repeated, restarted and finally, between 1987 and 1989, a feasibility study was carried out for it. The preliminary project was approved in 2002, and between 2005 and 2008 we were working out the so called definitive project, finally

The Brenner Base Tunnel has several stub and exploratory tunnels already constructed

securing the environmental and technical approvals in Austria and Italy in 2009. So we started with the first exploration of the whole rock situation in 2006 drilling vertically more than 28km summing up each drilling depth. And this preliminary information was used to study the final layout of the tunnel and to complete the final design. Approximately 37km of tunnels had been excavated as of March 2015. This means roughly 16 per cent of the total excavation length has already been built.

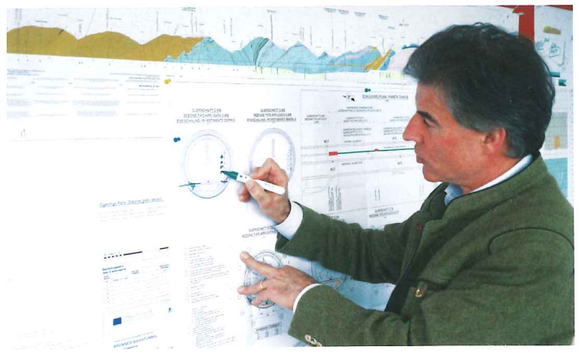
With an eye on the time table, which are at the moment and in the near future the most important steps?

Bergmeister: Technically speaking we will start this spring with some new sophisticated drillings in the Brenner Area to explore the Hochstegener Limestone, which is quite a complex geological area, and the perforation through this complex Limestone zone should give us some hydrological information in order to develop the right methodology for how to drill through this lithology. This is still a challenge for the tunnellers, the geologists and the engineers. In terms of new construction the lots are in a quite exciting phase as we are at the beginning of the biggest construction lots for this project.

This year we will have a very big construction tender for the main lot in Italy. It is expected to cost approximately EUR 1.4bn (USD 1.56bn). This construction lot includes the exploratory tunnel between Mauls/Mules and Brenner/Brennero with a length of approximately 17km, and the main tunnels between the underpassing of the Torrent Isarco and the Brenner with a total length of more than 20km. At the beginning of 2016 we will be publishing the main construction lot in Austria with the exploratory tunnel from Steinach to Brenner having a length of approximately 8km and the two main tunnels from Ahrental to

Above: ***Excavation face on the Brenner Base Tunnel project***

Below: ***Professor Konrad Bergmeister***



Brenner, which will be approximately 25km. The total volume will be approximately EUR 1.8bn (USD 2bn). With these two big construction lots published and tendered, all civil engineering works will be under contract. We are currently working on the tender and the executive planning, which is a very important issue as we have to deal with not only the European regulations, but also with the Italian and Austrian codes. In order to do so, we have been undertaking a guide for design taking into account the different codes and philosophies in terms of planning, and in terms of construction methods. On that basis we developed a new idea, the so called "lifecycle design," which includes in the planning phase already, the inspection programme and the monitoring issues for the whole lifecycle of the structure.

This specific design philosophy also includes maintenance for the whole service life and this means that we have to take into account now specific situations for how we can easily adjust and or maintain certain structural and technical equipment, and this creates additional complexity.

Therefore the actual phase is very important not only to improve the construction quality but also to improve the final service life behaviour of the whole project.

Which excavation method do you prefer?

Bergmeister: This is quite an interesting question. The excavation method should be based on the geology, the hydrology and the site-logistics of the project. Finally it must be based also on the capability and experience of the miners and the engineers. The drill and blast method is an observation method. We are drilling and blasting the rock mass and we are trying to observe the behaviour of the rock itself in order to wait until all the short and the long term deformations are more or less reduced to zero. Afterwards a lining is normally installed. This kind of methodology is excellent for difficult, complex geological and hydrogeological situations.

On the other hand the technologies are progressing very much. We see today TBMs with huge potential to drill and to excavate through very complex geological and hydrogeological situations as well.

The second advantage of using mechanised tunnelling is that we have normally many fewer risks for miners. This is an issue that really has to be taken into account. The quantity of miners that are involved and the risks that they normally must undertake are very much reduced using drilling machines with computerised drilling equipment.

In order to respond very specifically on our project: We will

have approximately 20 per cent of drill and blast of the total tunnels that have to be excavated, which is approximately 230km summing up all the different pieces of exploratory, main and access tunnels and so on, and 80 per cent of mechanised excavation. This separation is not only a new situation for Austria, it is also new on an international level because we are trying to use a multi-criteria approach for choosing between drill and blast and mechanised tunnelling.

Certainly some countries in Europe that are very famous for building tunnels, Austria, Switzerland and so on, they are known as the first countries to develope the drill and blast with the observation method. Other countries that came into this business later or where the technologies have been developed, they are much more in favour of mechanised tunnelling, for example Japan or China.

If you choose mechanised tunnelling, which manufacturers are for you the most interesting companies?

Bergmeister: We are developing our tenders for the tunnelling equipment independently of the manufacturers. What we are trying to do actually, is to describe very precisely the geotechnical and logistic constraints in which the machines could be used: an open machine, a shield machine, a double shield machine and so on.

And in order to do so, we have to study very well the geological critical zones, the fault zones specifically, the rock pressure, the hydrological situation, but nevertheless we also have taken into account the logistics on site and the transport mechanism for the excavation material. Finally non-destructive testing to explore the rock mass is an important job for the exploratory tunnel.

So we do have certain interest to do a kind of excavation by using a drilling machine, but nevertheless we have to take into account that we need in some ways some non-destructive sensors, seismic waves, acustic emission system or photogrammatic digital mapping in order to take the information of the rock mass or from the face directly into the elaboration of the next excavation step. There are several companies around the world that are very specialised now in producing mechanised tunnelling machines like Robbins from the US or Herrenknecht from Germany, Mitsubishi from Japan or also, and this is quite interesting, the new Dalian Huarui Heavy Industry (DHHI) Company from China, they are also doing their business quite well, Sandvik Tamrock from Sweden, Seli from Italy, which are able to produce these kind of machines.

"My wish is that the train should drive through the tunnel on 27 September 2025, 200 years after the first steam train was driven by Stephenson"

Why is the exploratory tunnel as important for this project as it is?

Bergmeister: The exploratory tunnel has been discussed at length since this is the only project where an individual exploratory tunnel being excavated for the whole length of the drive. So first of all the exploratory tunnel is meant for geological prospection and is used in order to do all this kind of geological documentations and hydrogeological information, which are used and needed in order to develop the tender for the main tunnels in a better way. Secondly, the exploratory tunnel also has a certain drainage effect. In certain hydrogeological regions or complex situations the exploratory tunnel also functions as a drainage tunnel for the main tunnel, which means that we have much less water in the area surrounding the main tunnel. Third, we can, at least theoretically, use the exploratory tunnel as an access point for upgrading the rock mass ahead of the main drive, to do some injections or to do some non-destructive measurements and exploration. On the basis of the actual experiences, we have drilled at the moment approximately 20km of the exploratory tunnel. We have been able to reduce, specifically in the Innsbruck Quartz Phyllite complex, the construction risk by more than 40 per cent. And this is very important to state since the exploratory tunnel costs a lot of money, but we are able to reduce the construction risk and therefore the construction costs for the main tunnel.

A fourth point is that we will use the exploratory tunnel as a service tunnel. In terms of installing all possible equipment, energy and communication lines that might also be used for the main tunnels for the final operation. This would give us the chance to transfer some technical equipment in the exploratory tunnel, which are at the moment foreseen to be installed in the transverse tunnels similar to the Gotthard, Lötschberg or other Base Tunnels. This would give us the chance to do all these inspections and maintenance without interrupting the operation of the main tunnels.

Fifth, we can use this kind of additional tube as a real transport tunnel for conductors, electrical lines, communication lines. This lies with the owner of the electrical power plants, of both governments, if they really want to install a high voltage electrical line. This would give us the chance to eliminate the big electrical lines that are currently installed on towers along the small valleys with high voltage there. They could be transferred directly into the exploratory tunnel, in a very isolated zone without having difficulties with some magnetic fields (and so on). This would bring an additional value for this kind of service tunnel.

As a conclusion for the reasons to build the exploratory tunnel I would say: The first main objective of the exploratory tunnel is the use for exploration, the second is the use for services and dealing with maintenance without disturbing the operation and the third objective could be that the exploratory tunnel is used in order to transport energy and communication lines.

What significance has the Brenner Base Tunnel for Austria? - For Europe?

Bergmeister: The Brenner Base Tunnel was originally a part of the so called North-South TEN-Corridor Berlin-Palermo and it is now one of the main projects along the Scandinavian-Mediterranean Corridor from Helsinki, Finland, up to Valetta, Malta. Without the Brenner Base Tunnel we'd need at least two locomotives on the historical railway line in order to come to the Brenner Pass since that slope is so steep - it reaches approximately 28 per thousand - which means this is the second steepest railway line in the world. In order to reduce the energy consumption and to be able to transport heavy trucks and goods on the railway, we need a flat system.

And having the Brenner Base Tunnel we will be able to have almost no slope there - we do have actually a horizontal line by approximately a slope of only 7 per thousand. This will guarantee us much less energy consumption, taking all the heavy goods only with one locomotive and being connected directly in the north and in the south to the main railway corridor from north to south of Europe.

If you compare the Brenner Base Tunnel with all the other cross-border projects in Europe within the TEN-T, which one is the most challenging, the most difficult project? Where would you rank the Brenner Base Tunnel?

Bergmeister: Europe has been identifying nine different main corridors, and along these main corridors there is of course the Gotthard Base Tunnel, which will be brought into operation in 2016.

This is one of the most challenging projects ever undertaken in tunnelling because this type of project was the first Base Tunnel crossing the Alps. We are learning a lot from those experiences. There are two other main projects like the Lyon-Turin Tunnel Project, which is not only from the technical point of view a quite complex project but also from the political point of view.

I feel personally that along the North-South Corridor there are two main projects that are in terms of importance quite similar. These are the Fehmarn Belt Tunnel that is proposed to connect Denmark with Germany, and also of course the Brenner Base Tunnel.

In terms of complexity I think the Brenner Base Tunnel is one of the most complex projects in the world, since we do have to overcome not only geological and technical unknown problems, but also we have to work within a framework of various cultures as well as differing languages and within different political realities.

How important is the support of the European Commission for the Brenner Base Tunnel? - For Austria?

Bergmeister: Europe is the driving force for this project. Without the help of Europe we would not be at this stage. Europe is co-financing this project, and I am very thankful to Europe.

They have been identifying a European coordinator for promoting on the European level the whole corridor and the project itself. And finally, only through this extremely highly European co-financing is it possible that two countries, Austria and Italy, are able to share the remaining costs.

Specifically for Austria this project is a Transit-Project and in terms of net-income there is no earning. There is only a tariff, the toll to use this new infrastructure, but they do not profit in a specific way through this tunnel because actually the most industrial areas in Austria are already connected. It brings more or less a possibility to create a unified Europe and to bring the big industrialised centers in the northern part of Italy together with the southern part of Germany and finally it also connects the south and the north of Europe.

Is it difficult to work over the borders, between Italy and Austria?

Bergmeister: This was one of the main issues for why we try to create this kind of Best Practice Seminar here in Innsbruck in March. The original idea was that we have some kind of learning process behind us and have another 10 years to go.

This was the reason why we invited all members of DG-move with all 11 European coordinators and the Alpine transport ministers with the new European commissioner Violeta Bulc to bring all those people together into share the experience and probably to work out some guidelines for developing cross-border projects.

Since the cross-border projects are complex systems in terms of engineering, communication, cultural and lingual understanding and finally in terms of financing as well as in terms of decision making.

Which are the most embarrassing obstacles and problems for you: the ones that are technical, that are financial or are political?

Bergmeister: Answering as an engineer, the most unforeseen problems arrive from the unknown geology, the unclear financial constraints and the fragile political decisions. In order to ensure the continuous realisation of such a project, a clear decision in terms of financing and system related framework (transport logistics, political measures for transferring vehicles from street to the rail) has to be financed up to the end and has to be really supported to the end.

If you have a wish for this project, what would it be?

Bergmeister: My wish would be that the first train should drive through this tunnel on the 27th of September in 2025, which would be exactly 200 years from when Stephenson drove the first steam train from Stockton to Darlington in the UK.

This would be for myself the real dream and I cordially hope this becomes reality

A BREAK WITH TRADITION

The Tuen Mun-Chek Lap Kok Link will mark a change in sub-sea tunnel construction methods for Hong Kong with TBMs being used for the first time. **Sally Spencer** reports

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

Bird's eye view of the northern portal

CONSTRUCTION WORK is under way on a tunnel in Hong Kong that features some notable departures from the norm in that region, both in terms of the chosen method and the excavation machinery used. At HKD 18.2bn (USD 2.35bn) it's also the largest design and construction contract the Hong Kong special administrative region (SAR) government's Highways Department has ever awarded.

The Tuen Mun-Chek Lap Kok Link (TMCLKL) has the aim of improving road travelling time and easing congestion in the western New Territories and will see the construction of twin 5km-long sub-sea tunnels and a 3.5km road section. These will provide the most direct route between Tuen Mun in the western New Territories and the Hong Kong-Zhuhai-Macao Bridge (HZMB) Hong Kong Boundary Crossing Facilities (HKBCF) at Chek Lap Kok on Lantau Island, where the Hong Kong International Airport (HKIA) is located. The tunnel project will also serve as an alternative access road to the HKIA, in addition to the existing North Lantau Highway.

The project is divided into southern and northern sections, with the northern section featuring the sub-sea tunnels link between Tuen Mun Area 40 and the HZMB/HKBCF and the southern section featuring the road linking HKBCF and the road network of North Lantau.

Along with the aforementioned road and tunnels, the project also includes the construction of a reclamation site; the construction of shafts; the installation of an air quality monitoring system; the installation of fire safety systems; the installation of ventilators and construction of ventilation shafts; and the installation of security systems and other infrastructure-related facilities.

STAKEHOLDERS

Aecom Asia was awarded the USD 148m employer's designer and supervising officer contract for the TMCLKL in late 2011/early 2012. It carried out the design of the project from scheme to detail stage and made recommendations to the Highways Department on the preferred tunnel option and alignment.

Aecom completed the full design, which was subsequently regarded as the reference design for the contractor to price for the tender.

In July 2013 the design and build contract was awarded to Dragages-Bouygues joint venture (DBJV), who subsequently engaged Ove Arup & Partners Hong Kong Ltd to be its designer and carry out changes proposed by the contractor.

Stakeholders

Project owner: Hong Kong SAR Highways Department
Employer's designer and supervising officer: AECOM Asia Co
EPC contract (ground investigation works): Gammon Construction
EPC contract (sub-sea tunnel): Dragages-Bouyges JV
Contractor's engineer: Ove Arup & Partners Hong Kong
Consulting engineer (ground investigation works): AECOM Asia Co
TBM manufacturer: Herrenknecht

The 50km-plus HZMB project (*Tunnels & Tunnelling International March 2011*), which TMCLKL will join, is one of the largest fixed links ever realised and comprises bridges, causeways, artificial islands and tunnels, including 6km of immersed tube tunnel.

Immersed tubes are the usual method of underwater tunnel construction in Hong Kong and were initially considered for the TMCLKL project. However, now TBMs are being used – marking the first use of TBMs to construct a sub-sea road tunnel in the region.

ENVIRONMENTAL MITIGATION

This decision was made to save dredging and the disposal of an estimated 11Mm³ of marine sediment. The need to avoid the diversion of several existing power cables serving the Hong Kong International Airport was also a factor.

It is also expected that this method will reduce the impact on the environment, water quality and marine ecology (the endangered Chinese white dolphin is present in the area, with WWF stating that only 62 individuals remain in Hong Kong).

"During the planning stage an Environmental Impact Assessment was conducted and an Environmental Permit (EP) was obtained pursuant to relevant environmental protection regulations prior to the award of the contract," said Siney Kwok, deputy corporate communications director at Dragages Hong Kong.

"Environmental mitigation measures as required under the EP are being adopted during the construction stage," she added. "The use of TBMs to construct the tunnels was driven primarily by environmental concerns and the need to avoid disruption to marine traffic."

The project comprises the design and construction of

Below: ***Figure 1, Various component alignments***

dual, two-lane tunnels, approximately 5km long, of which around 4km will be sub-sea. Each tunnel will measure 14m in diameter.

RECLAMATION WORK

The scheme also includes reclamation work to form a 16.5 hectare platform for the tunnel's northern landfall at Tuen Mun Area 40. The southern landfall for the tunnels is formed by the reclamation of an artificial island, which is being constructed under a separate contract.

The main contractor for the artificial island is China Harbour Engineering, while Ove Arup & Partners Hong Kong Ltd is the consulting engineer.

Work on the northern landfall will include the construction of a ventilation building, a 530m-long approach tunnel (constructed by a combination of TBM and cut and cover) and a launch shaft for the project's two 14m diameter Herrenknecht TBMs. The launch shaft is being constructed using diaphragm walls (100m x 50m x 22m).

Construction work started on the reclamation for the northern landfall in 2013 and is expected to be complete by early 2016.

In the south there will be another ventilation building, a 670m-long approach tunnel (constructed by cut-and-cover methods, with diaphragm walls) and TBM retrieval chambers.

The two ventilation buildings have been designed to qualify for BEAM Plus Gold rating.

The sub-sea excavation will encounter highly variable, soft and mixed ground conditions, said Kwok, citing reclamation fill, marine deposit, alluvium (sand, clay and silt), weathered rock and granite.

And the two identical slurry Mixshield TBMs that will deal with these ground conditions will feature sophisticated new technologies – Mobydic and Snake – developed by Bouygues Construction's research and development department.

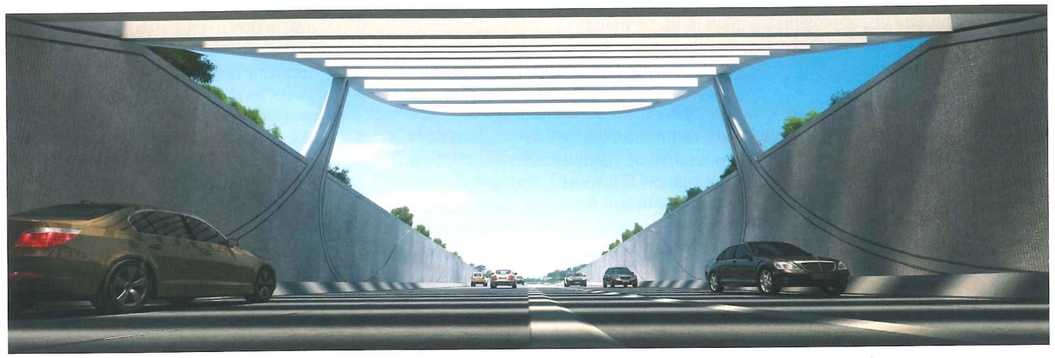
Both technologies were developed in order to reduce the need for manual operations in hyperbaric conditions.

Mobydic is a system of sensors incorporated into the disc cutters in the heads of the TBMs. These enable the ongoing monitoring of wear to the cutters while allowing real-time monitoring of the rock faces.

Snake is a remote control exploration arm equipped with a high-pressure jet, which will clean the TBM cutterheads and eliminate clogging, to enable them

Below (top): ***Lifting of TBM components***

Below (bottom): ***TBM launching shaft is prepared***



to be inspected.

Spoil will be extracted through the TBM slurry system and separated at an on-site slurry treatment plant for disposal off-site.

One of the two 14m diameter TBMs was delivered early this year, while the other is due to arrive in August.

EXTRA MACHINERY FOR LARGER BORE

Already in action, following delivery last December and its launch on March 25, is a third Herrenknecht TBM, which is being used to construct one of the approach tunnels to provide for an additional climbing lane.

This monster-sized TBM – it has a 17.6m diameter – is being used to construct the northbound exit tunnel at the northern landfill. This method is being used to create a larger diameter bore in order to accommodate three lanes, thus providing an additional climbing lane. The gradient here will be about five per cent.

The southbound exit also requires a third climbing lane but this is incorporated in the cut-and-cover design.

The sub-sea tunnels will be segmentally lined with pre-cast reinforced concrete segments with fire protection to the concrete lining and the overhead ventilation slab.

According to Noma Consulting, which was engaged by Ove Arup to lead the detailed design of all the mined and bored tunnel design aspects, the pre-cast concrete lining will consist of nine (including the key) segments with an inner diameter of 12.4m, a thickness of 550mm and a width of 2.2m; and 12 (including the key) segments with an inner diameter of 15.6m, a thickness of 700mm and a width of 1.7m.

The sub-sea tunnels will be connected by cross passages every 100m – 42 sub-sea cross passages and 14 in the approach tunnels.

Above: ***Artist's concept of exiting the tunnel***

Below: ***Artist's concept of greenery around portal***

The cross passages will be excavated using pipe-jacking techniques; possibly with ground-freezing technology to provide a watertight environment to enable these passages to be constructed.

In addition to detailed design of the segmental lining for the northern landfall and the sub-sea tunnel and for the mined cross passages, Noma is also responsible for the co-ordination of interfaces between bored tunnels and cut-and-cover structures, such as the launch and retrieval shaft and the ventilation shafts.

NEW DEPTHS

At 50m below sea level the tunnels will be the deepest, as well as the longest sub-sea road tunnels in Hong Kong. Working at that depth in an environment of up to six times the normal atmospheric pressure is a key challenge as the majority of construction must be carried out in a compressed air environment.

While 50m also constitutes a record depth for the DBJV, the partners have long experience in compressed air works.

The Dragages Bouygues joint venture will adopt a "saturation" technique for maintenance work on the TBM cutterheads. This means that highly experienced saturation workers will stay for up to four weeks at a time in specially-designed habitats, thereby undergoing one decompression every four weeks rather than one decompression every day. The aim of this approach is to maximise health and safety while also enhancing project efficiency, according to a spokesman for the JV.

There are no restrictions on construction work other than the normal statutory and environmental requirements, said Kwok, and the project is targeted for completion in 2018

EAST MEETS WEST

Istanbul straddles the continents of Europe and Asia

This article on guiding and monitoring work on the Avrasya Tunnel project under the Bosphorus Strait was written by **Robert Lensing** and **Manfred Messing** of *VMT*, and **Abraham Corriols**, **Patrick Hartkorn** and **Giuseppe Pezone** of *TC Engineering*.

THE INAUGURATION of the Marmaray Tunnel in October 2013 realised the first phase of the Turkish dream: to achieve a subterranean connection between Europe and Asia. This tunnel has been constructed as a part of the public railway transportation network of the City of Istanbul. The second phase of the Bosporus crossing will be finished on completion of the Avrasya Tunnel for road traffic, to be commissioned in 2016. These two new underground links are necessary to improve traffic conditions in Istanbul, currently with serious problems of congestion due to a lack of a transportation network adequate to current requirements of the city and its metropolitan area.

Avrasya Tüneli Isletme Insaat ve Yatırım (ATAS) is the investor of the Project and founded by the partnership of Yapı Merkezi of Turkey and SK Engineering & Construction of South Korea. ATAS has commissioned YMSK Joint Venture consisting of the same partner companies for the design, construction and commissioning of the Project. YMSK Joint Venture is using a 13.7m-diameter TBM, boring its way through the planned 3.35km-long tunnel at a depth of up to 80m below the seabed according to design specifications--following roughly 2,000m radius left curves with a longer straight, leading into a roughly 1,800m radius right curve in horizontal. Vertically the tunnel will realize a radius of 4,330m. Once complete, the tunnel will be horizontally divided to provide one level for each direction of driving. Segment production is supported by a Segment Documentation System (SDS), which helps engineers in supply and quality management of all segments for the tunnel lining.

With the laser-controlled navigation system the TBM can be guided with millimetre accuracy along the designed tunnel alignment. A Ring Sequencing System supports the calculation. An integration of SDS to the data management system (IRIS. tunnel) saves relevant information from every segment placed within the tunnel, including: ring ID, materials used, damages and pictures.

A ring management system supports the planning and logistics of transporting the needed ring segments into the tunnel. A ring planarity check tool, also integrated with ring sequencing, manages each ring regarding compliance of necessary flatness to prevent spilling form point loads.

The continuous process control of relevant TBM data is made possible via a comprehensive web-based risk and information system. It provides the management team with a detailed overview of the project via the automated data logging, thus improving the performance of shifts and machine activity connected to the planning of maintenance jobs.

LASER CONTROLLED NAVIGATION

A laser controlled navigation system guides the Hydro-mixshield Herrenknecht TBM along the designed tunnel alignment.

Based on a total station and an active target unit installed within the TBM shield, it continuously determines the current advance position. In case of hardware failure it is also possible to determine the TBM position using the last known position and current cylinder extensions, to enable navigation of four to five rings without downtime.

RING SEQUENCING SYSTEM AND INFLUENCE OF SEISMIC JOINTS

Preliminary estimations

The ring sequence prediction is based on ring design drawings and alignment information and focuses on a balanced number of left and right rings used in the tunnel construction. The result of this analysis gives information about the amount of needed left and right rings. The analysis comprises a long-term ring sequence calculation without cross-joints in neighbouring rings. Taper of left and right rings is set to 15mm on the front and back of each ring. No cross-joints were permitted during the sequence calculation.

The maximum tolerance was set to 45mm, which is the theoretical maximum tailskin clearance in case a ring is built perfectly centred within the tailskin, according to TBM design drawings. A maximum tolerance of 100mm is the permissible limit of the clearance, as stated by the joint venture.

The number of calculated left rings is 874 and right rings is 794. These values do not take into account the further 10 rings of special type needed for two seismic joints, which will be further described.

The ring sequence of the prediction starts at chainage 0.0m and ends at 3,349.4m for the Strait Road Crossing Tunnel. It is assumed that the reference ring has its centre on the alignment without horizontal and vertical offset and the ring plane is perpendicular to the alignment without any horizontal and vertical tendency.

The calculation ran with the constraints that left rings and right rings should be used consecutively only on straight sections of the alignment. Those major straight sections are:

- 0+243.80m to 0+874.17m
- 1+922.23m to 2+431.43m

■ 3+163.02m to 3+349.42m

The maximum deviation of the ring centre to the alignment for the horizontal and vertical direction is +26mm and -19mm. For the worst case horizontally the calculation result states out a further vertical deviation of -4mm. This 26mm uses the maximum contractual tolerance of 100mm to 26 per cent. The main reason for this increasing deviation at this range of chainage is seen in the five rings of seismic joints with the additional two fixed left rings, which do not allow a proper tendency correction to follow the curve. This prediction was based on the geometry of ring design and alignment only and did not take into account TBM steering. Therefore deviations from this prediction are likely depending on the actual steering of the TBM and must be corrected on site with the help of the navigation system, as discussed later in this paper.

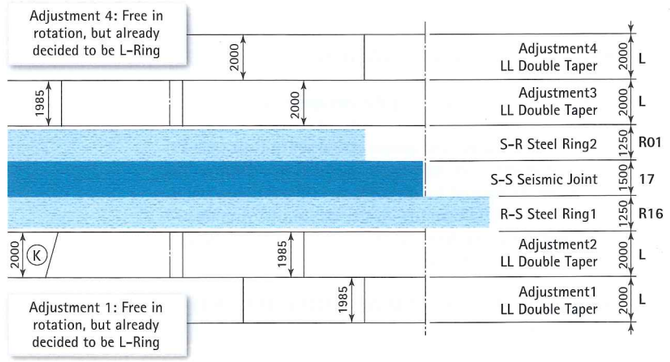
Influence of seismic joints

A further constraint on the ring calculation was the preferred installation of two fixed sequences of seven rings, acting as a seismic joint within the tunnel. A seismic joint is a composite steel-rubber structure with the central rubber part providing the necessary flexibility against possible seismic actions and with the steel rings resisting the ground pressures.

Seismic joints are designed to absorb seismic movements, as they are more flexible than concrete rings. Two joints must be placed in a total of 3,354m of tunnel length. They contain a stiff structure formed by steel rings on the central part, as it can be seen on Figure 1. Five rings are fixed with both taper (L/R) and key position. Further, two additional rings are forced to be left taper rings. The position of each middle ring was proposed by the joint venture and was applied as follows:

■ The rotation of the adjustment rings and the steel rings were already decided in the pre-project phase. Only 'Adjustment 1' and 'Adjustment 4' are free in rotation.

■ Non-tapered ring (seismic joint) as ring no. 429 and 690, enclosed by one-sided, right-tapered rings on each side, each next to a "normal" double tapered concrete ring with an instructed key stone position. Note that the seismic joint (S-S17) and the two transition rings (STR116 and STR201) are of steel and shorter length of 1,500m and 1,250m respectively.



*Above: **Figure 1, Disposition of segments that form seismic joints***

*Below: **Figure 2, Hypothetical deviation scheme of the tunnel alignment for a straight section (left) and a curved section (right)***

A sequence of rings like this was expected likely to increase the deviations to the alignment, as it does not give any option for direction correction, especially as the second seismic joint is placed on a curve. If the TBM has a large tendency, it is possible that the offsets may exceed the construction tolerance. This is one of the reasons why the ring sequencing system is used: to simulate certain TBM drive situations and examine how the steel ring structure might worsen the situation if the TBM does have a bad approach. The aim is to raise awareness of the possibility so it can be managed by engineers on site.

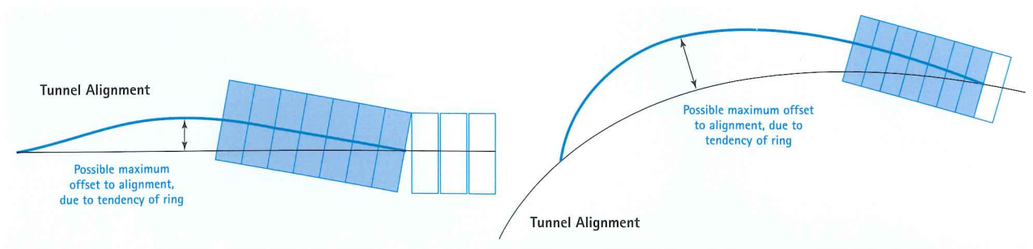
Having limited possibility for tendency correction on a straight line is not an issue when the TBM is approaching the alignment correctly.

Figure 2 (left side) shows the effect of a bad approach. The maximum offset of a ring centre to the alignment could occur after the erection of the seismic joint because for a smooth return to the alignment the ring calculation software will try to initiate a curve.

As the second seismic joint structure will be installed on ring 687 on a curved alignment of radius 2,000.8m, the effect would be even greater as can be seen in Figure 2 (right side)

The drafted issue has been analysed with multiple revisions of a ring sequence study.

In this critical section of a left curve where seismic joint 2 is located, even a slight positive tendency of the rings (TBM facing right relative to the alignment) can have a massive effect on the offsets of the ring to the alignment. A minor tendency of +3mm/m is likely to exceed the tolerance limits. Negative



offsets and negative tendencies as well as the combination of positive offsets and negative tendencies don't harm the tolerance greatly.

A further reason for this study was to improve segment production. It checked the possibility to build the tunnel with a balanced number of left and right rings, which formed the basis for planning segment production. A correct ring building process supported by the ring sequencing calculation is of vital importance, as the TBM advances with underground pressures greater than 10bar and no leaks or cross joints are acceptable.

Control of deviations

Previous sections of this paper covered the theory of why it is necessary to approach the seismic joint regions carefully. However, if something went wrong, the additional module called "Steering Curve" is implemented on the navigation system to ensure that the TBM operator has all the required information to follow the steering curve. The steering curve is automatically calculated to bring the TBM smoothly back to the alignment while following a minimum radius.

A risk exists because seismic joints are only able to realize a certain large radius. Preliminary studies indicate that poor steering could result in the TBM going off the designed tunnel alignment. As it is as "going blind," the TBM operator will need help to ensure that this "going of track" is done driving an actual curve.

This additional functionality of the navigation software shows the offsets of the TBM relative to both the actual alignment and the steering curve. During the ring sequence calculation, position of rings along the ring curve are calculated. It is recommended the steering curve has the same transition point as the ring curve, an option that can be easily activated within this module.

SEGMENT DOCUMENTATION SYSTEM

Besides the ring sequencing system, other software applications can be used to encourage project performance. In the Avrasya Tunnel, a number of segments for the tunnel lining are installed every day. Tracking these segments from production up to installation within the tunnel is of great importance for smooth project process as well as quality assurance. To assist the logistics and quality management tasks, the Segment Documentation System (SDS) has been developed. This is needed to achieve good planning on the job site and to produce the rings that provide the tunnel lining. From pouring concrete until installation in the tunnel, SDS ensures that each segment is produced according to client specifications and that each logistical step in the construction chain is tracked. Customers have access to all material, production, storage and usage data and this functionality enables extension to adjacent processes by means of comprehensive quality management features. It combines gathering data using portable scanners to control systems for segment production including inventory management, transport and time-controlled procurement.

*Below: **Figure 3, Software system for control of deviations by setting a steering curve during TBM progression***

For the Avrasya Tunnel Project, segments are manufactured by Yapı Merkezi's prefabrication branch in their segment production plant located 20km away from the construction site. The ring sequencing system described previously provides an estimation of the type and number of segments needed. However, the final definitive planning is done on site in real time, reacting to the actual tunnel advance. Realistic predictions guarantee a segment provision not further than three rings forward, so the logistics chain can be organized: the segments that form each ring can be sent into the tunnel and arrive on demand. To do so, the system must account for the actual drive and live position of the TBM, not only ring geometry and a theoretical alignment.

One ring consists of nine segments. A maximum of 27 segments may be in a dispatched state between the segment factory and onsite storage, which holds approximately 50 rings. To determine requirements of the following 50 rings, the site planning engineer uses the ring sequencing system to order segments from the factory and maintain work progression.

Aside from the logistical approach provided by the SDS, there is also a more exact geometrical approach through the ring sequencing system: no cross joints and negative machine tendencies can be reduced. Ultimately it increases quality and efficiency.

Other complementary products not described here for monitoring and installation of segments in the tunnel include ring convergence measurement, ring planarity check, grout pressure as well as systems for calculating the available space in the tailskin.

DATA MANAGEMENT

There is an ever increasing flood of information and data in tunnelling,

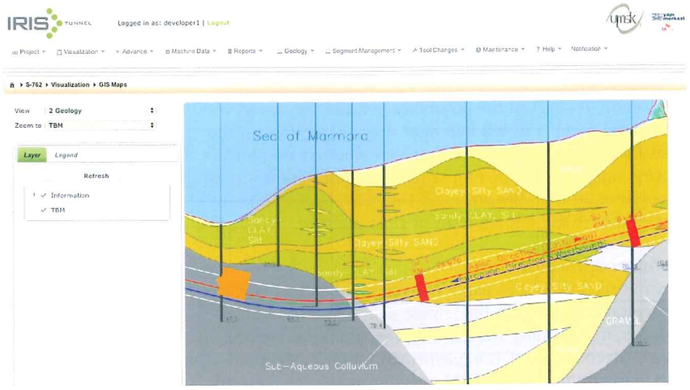
which has motivated the appearance of independent software systems that support the data management and data analysis of construction sites, leading to a transparent construction process.

The evaluation and management of data are integral parts of the process controlling of large construction projects. Such systems support site teams in the evaluation and analysis of tunnelling data. The systematic storage and automated reports provide reliable continuous documentation of the tunnelling process.

The overall data management of the Avrasya Tunnel is done by the use of a web-based platform called IRIS tunnel, which integrates data from several processes, such as the TBM navigation, ring sequencing, interactive map visualization of TBM advance and reporting. Key features of the system include the following:

- Systematic preparation and archiving of tunnelling data from ongoing construction projects in the form of monthly, weekly and daily reports. Shift evaluation takes place in interactive shift logs
- Evaluation of TBM data (e.g., tail grouting, cutter wheel pressure, hydraulic jack forces, cutter wheel revolution, etc.) in combination with geological parameters from preliminary exploration (if present)
- Analysis of survey data to evaluate the TBM position, the driving precision, etc., and visualization of these data in appropriate diagrams.

Figure 4 is a screenshot of the web based data management system showing the TBM position relative to the geology profile. Map visualization provides helpful information for the project team regarding data interpretation and analysis, especially when processes are performed underground in difficult conditions.



*Above: **Figure 4, IRIS tunnel data management system. Screenshot of the geology map visualisation with the TBM position in real time***

An interface exists between the SDS and IRIS tunnel, which uploads data from installed segments to the corresponding "Segment Management" module. This data is available for evaluation and further quality control by the responsible team at the jobsite and technical office. Data from surface monitoring can also be stored within the same database as TBM data to enable a combined analysis if needed.

This is not the case of the Avrasya Tunnel where the alignment is located beneath the seabed, though positively contributes to the development of such data management systems in underground works.

However, it is remarkable that after completion of the double-deck tunnel with single precast concrete lining, it could be possible to install a long term monitoring sensor network to evaluate ring convergence and deformation, plus possible damages due to seismic vibrations, which would be integrated in the shared data management platform for data analysis and risk assessment during maintenance.

CONCLUSIONS

The article presents the practical applications of a number of monitoring systems that contributes to enhanced project performance for the AvrasyaTunnel including: TBM navigation, ring sequencing and segment management for a comprehensive quality management chain manufacturing plant and installation on site. The tunnel includes two seismic joints on its alignment, which represents a challenge for segment prediction.

A previous estimation of ring sequencing was carried out, although the final planning depends on the tunnel progression because unexpected deviations of the TBM track may occur. These must be corrected on site with the help of the navigation software depending on the actual steering of the TBM.

Lastly, a brief introduction of integrated data management systems being extensively used in underground projects is presented. Such systems are very useful to manage the large amounts of data produced during construction and maintenance.

The monitoring activities during construction are essential for challenging projects such the Avrasya Tunnel, as it passes under the seabed crossing the Bosporus Strait, through difficult ground conditions and a high risk seismic area

This paper was written with the permission and kind appreciation of ATAS and YMSK Joint Venture, which hereby is gratefully acknowledged

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CHENNAI CHALLENGE

Can India's coastal city get its subway on track to deal with ageing infrastructure and a rapidly expanding population *Robbins* technical writer **Desiree Willis** investigates

AMID THE hustle and bustle of India's fourth largest city, a pattern emerges: traffic gridlocks the city's arterials. During peak hours nearly half of all roads in the city are at or over 100 per cent capacity. Aging rail lines, built in 1985, are crammed with people. Chennai's eight million inhabitants take, on average, 11 million trips per day, and six million of those are by car.

Despite those challenges, Chennai was named by travel giant Lonely Planet as one of the top 10 cities to visit in the world. The multi-cultural and progressive melting pot on the coast has consistently ranked in news outlets like the New York Times and the BBC as one of the most desirable cities to live in.

Because of these factors, project owner Chennai Metro Rail Limited (CMRL) is faced with a daunting challenge: revamp the city's rail transport system, using underground space where possible.

According to CMRL, the situation is critical: "Chennai Metropolis has been growing rapidly and the traffic volumes on the roads have also been increasing enormously. Hence the need for a new rail-based rapid transport system has been felt and towards this objective the Government of Tamil Nadu have decided to implement the Chennai Metro Rail Project.

"This project aims at providing the people of Chennai with a fast, reliable, convenient, efficient, modern and economical mode of public transport."

To achieve that end, CMRL developed a plan for two new rail routes: a 23.1km-long line from Washermenpet to the International Airport, and a 22km-long line from Chennai Central to St. Thomas Mount. Of those new lines, a total of 24km will be underground, a little more than half of the 45.1km being built. The lines travel through heavily populated zones and through the city's varied foundation of dense clay, shale, and sandstone.

Multiple TBMs designed for mixed ground conditions were sourced for underground stretches between stations.

Desiree Willis
Desiree has covered a range of topics for *Tunnels*, as Robbins' technical writer

GETTING STARTED AND TBM LAUNCH

Line 1 is the priority for CMRL, extending from Washermanpet to the Airport, with a goal completion date set at the end of 2015. Contractor Afcons was named to build two parallel 1km tunnels along the route, comprising Lot UAA-01. The contractor chose a 6.65m diameter Robbins mixed ground EPB for the two tunnels.

The machine was designed to excavate weathered granite, sand, silt, and clay with boulders up to 300mm in diameter. The specialised design uses a combination of 17-inch diameter disc cutters as well as soft ground tools. Small grippers located around the circumference of the machine's shield allow for cutterhead stabilization in harder ground, and additionally react the forces needed to pull the cutterhead back from the face in difficult conditions.

Launch of the machine took place in January 2012 from a 28m deep starting pit, with the machine encountering challenges from the outset including unexpectedly hard rock. "The TBM bored mixed face conditions consisting of varying strengths of granite ranging from completely weathered and highly fractured through to hard granite with strengths estimated at 150MPa. This resulted in high cutter consumption due to impact damage as the cutter discs rotated through relatively soft rock and encountered the much harder rock," explains Jim Clark, Robbins projects manager – India.

Robbins field service personnel and engineers assisted Afcons in remedying the problem. "Robbins India provided a geologist who carried out face mapping for the whole of the first drive, in both hyperbaric and open mode conditions on a daily basis," Clark says. The face-mapping process determined that much more rock was present than expected, and with high abrasivity.

CHANGING GROUND CONDITIONS

In a report, the geologist describes face-mapping at chainage 5,100: "Face mapping of the tunnel face in this area has revealed high grade fresh granite rock on the invert area (180 – 200MPa ball park value), and weathered schist rock on the crown area of the tunnel face, which was unexpected."

At chainage 5050, even harder rock was found: "Fresh and hard granite was found and estimated as around 300 MPa UCS. There were no fracture sets on it, no zones of weakness observed on it."

Opposite, both: TBM factory inspection

Below: An Auto Rickshaw (or Tuk Tuk) on Chennai's busy streets

Face-mapping continued to find fresh, hard granite in key sections of the tunnel route.

The data not only assisted the crew in operating the TBM, but also provided a comprehensive geological record for the second drive.

With the data gleaned from the geological investigation, Robbins was able to advise Afcons on the optimal operating parameters to get through the difficult conditions, including cutterhead RPM, thrust pressure, penetration rate, and cutterhead torque.

"Once these parameters were implemented, the cutter consumption was drastically reduced," said Clark.

As an example, he describes the changes in cutterhead RPM and Rate of Penetration (ROP). "In the residual soil at the start of boring, cutterhead RPM was set to around 2.0.

In the mixed face conditions of hard rock and soft ground, the cutterhead RPM and ROP was reduced to prevent impact damage to the cutter discs. A baseline speed of 15m per minute for the outer diameter of the cutterhead was used as a guideline.

This equates to an RPM of approximately 0.75 for the sections of difficult ground. The baseline ROP was approximately 12mm. These parameters were increased as the machine entered a full face of rock and the risk of impact damage lessened."

Robbins field service continued to assist throughout the drive, training the crew and acting as mechanical and electrical/PLC supervisors on the project. Ultimately, the bore was a success, with the TBM achieving rates of up to 44.8m per week.

On 8 July 2014, the TBM broke through at Chennai Metro, capping a challenging drive that saw a full spectrum of difficult conditions. The 1,063m long drive ended in a receiving shaft so the machine could be removed and readied for its second parallel drive. This time, many parameters were known.

SECOND SET

After refurbishment to the screw conveyor and cutterhead, the machine was launched to bore its second tunnel in February. As of late April, the TBM was at ring 90 and encountering similar conditions to the first drive. "From the machine launch to its current position the machine has gone

in a lot faster on the second drive," says Chennai project manager Paul Imri.

"We hope we have solved many problems from our experience at the previous drive."

Imri estimates the machine will take about eight months to complete its second tunnel, however even though the geology is known, that doesn't mean that tunnelling activities are easy. "The parameters are constantly changing, just like the first drive.

"The ground condition now is sand at the top, compact sand in the middle and soft rock at the bottom [of the excavation face].

"We try to run at less than 3,000kN torque and 18,000kN thrust in such conditions."

The new tunnel route, traveling just 9.5 to 26m below houses, buildings, and a river, also brings the TBM closer to sensitive structures.

"The machine will pass below an old historical church and many houses. There are many bore holes being taken to check for water.

The drive is also being monitored from the surface by surveyors who are checking for settlement. If they detect any problems at all, action will be taken," Imri says.

Despite the areas of difficult work ahead, Imri is confident that the new operational parameters and previous knowledge will see the complex job through to success.

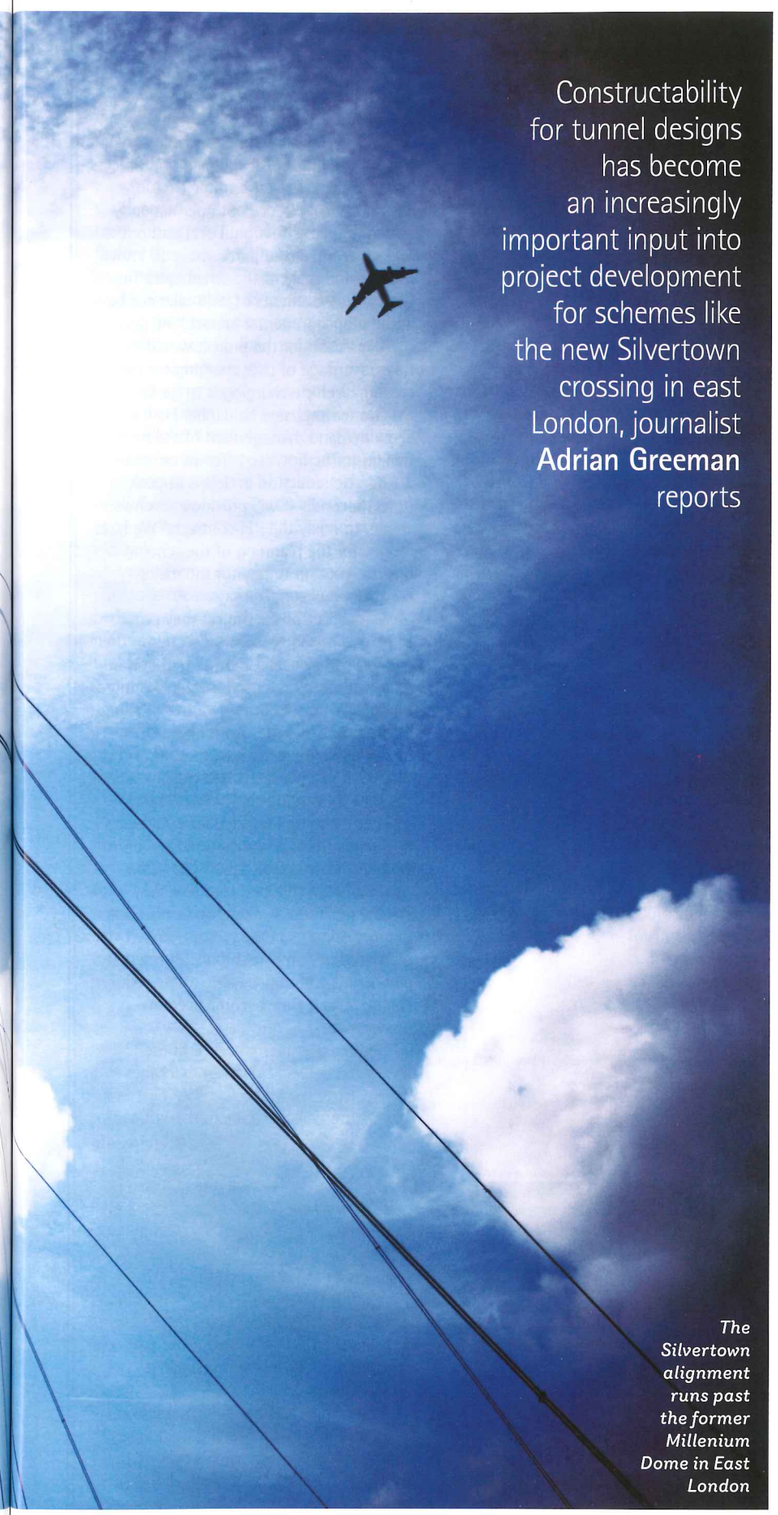
"We have face mapped the entirety of the first drive so we can anticipate any problems.

"We will adjust and be watchful in particular zones of concern. We believe we now know the geology and can act accordingly"

SILVERTOWN CONSTRUCTABILITY

Adrian Greeman
Is a former editor of and long-standing regular contributor to *Tunnels and Tunnelling*

Constructability for tunnel designs has become an increasingly important input into project development for schemes like the new Silvertown crossing in east London, journalist **Adrian Greeman** reports



The Silvertown alignment runs past the former Millenium Dome in East London

A NEW TUNNEL crossing of the Thames River, proposed for the Greenwich peninsula in London, will go to public consultation later this year, prior to seeking a development consent order or DCO. Assuming the go-ahead work could begin in around three years' time on the first road tunnel crossing on this side of the UK capital for nearly 50 years, and one of the most significant, it's enough to make it a 'Nationally Significant Infrastructure Project' (NSIP).

The scheme has been under development for several years and just how it will be built, or can be built, has been a key factor in selecting options and working them up. Input for design options has come from several constructability experts, looking at bored and immersed tubes.

EASTERN EXPANSION

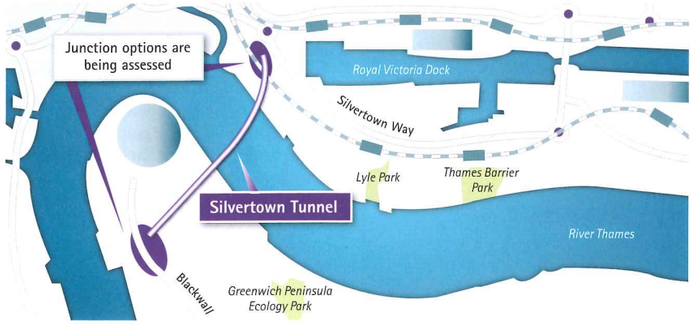
The project is important. London's centre of gravity has been shifting a little eastward in recent decades, first to the Isle of Dogs docklands financial district, then in redeveloped dockland downstream and around the Olympic Park. A new buzz of technology and media industry has revitalised Shoreditch and Hackney. The process is likely to continue with the Mayor of London's office identifying east London as a growth area over the next few decades.

But there is one major constraint, the river Thames. Downstream of the famous Tower Bridge and the narrow Victorian Rotherhithe Tunnel, last of a score of crossings in the capital, the river widens out considerably into its tidal estuary. This has limited the number of downstream crossings, keeping north and south sides of the city separated. River width goes from 200m upstream at Putney to 490m at Charlton. Even at the chosen Greenwich location it is 450m across the river.

"There have been some new public transport crossings built, including two tunnels across to the Isle of Dogs for the Jubilee Line of the London Underground and one for the Docklands Light Railway extension" says Jason Saldanha at Transport for London (TfL), the body responsible for much of the city's transport infrastructure. He is project manager for the crossing.

"But road traffic has only had the option of crossing on the M25 ring road further out at Dartford or through the Blackwall Tunnel," he says. The latter, a twin bore crossing at the end of the Greenwich Peninsula, is extremely busy and usually congested at peak hours, jammed northwards in the morning and south in the evening.

"On top of that the northbound is 120 years old, built in horse-and-cart days," says Saldanha "which means it cannot



handle many modern trucks or buses." The result is frequent tunnel incidents, some 1,000 annually, involving the need to head off over-high HGVs. Although there are "escape lanes" on the tunnel approach, it takes time to divert vehicles onto other roads, snarling traffic.

Even then, enough big vehicles make it through the height gauges to get stuck and sometimes damage the tunnel cladding, with repairs adding even further closure times. "Sudden unplanned closure can cause massive congestion especially at busy times," he adds.

Aware of the need TfL has been looking at options to relieve the Blackwall Tunnel and provide better cross-river highway connections for some time. Possibilities included additional bores for Blackwall and even a ferry link as at Woolwich, but strategic studies suggest the best connection would be separate, but close, to the existing Blackwall Tunnel. It would carry a route from the A102, going across to Silvertown on the north bank to reconnect into the main road. The crossing will be just where the river bends south again around the Greenwich Peninsula, at the same point where the cable car crosses the river.

"A bridge was ruled out," says Saldanha. At this point the river can carry significant marine traffic including fairly large vessels and clearance requirements demand at least 55m over the river.

"Pylons would be even higher and climbing approaches long, with the whole structure out of scale with local development and infrastructure, especially planned residential schemes for Greenwich," he says. A lifting bridge was examined but would cause too many road closures, which rather misses the point of the project.

So a tunnel then. But again there were options, specifically an immersed tube or a pair of bored tunnels. They would need to be substantial in size, with room for most modern high trucks and with twin lanes in each direction, for both capacity and safety redundancy. The size would also allow for double decker buses and tall HGVs, to greatly expand the east London route network north to south.

DUAL DESCISIONS

Making the choice and then working up the final option has seen schedule and constructability issues come into play. Two different consultancies have been working on the project, the first Mott McDonald and finally Atkins, which is refining the concept stage bored tunnel design. They have both developed their schemes with input from construction specialists, Mott with London Bridge Associates (LBA) and Atkins with input from Balfour Beatty's tunnel specialist, Roger Bridge, who is also chairman of the British Tunnelling Society.

The current design requirement is for as generic a scheme as possible, says Saldanha because the intention is to award the project as design, build, finance and maintain contract, probably on a private finance initiative concession basis. The project's detailed design will be carried through by the winning contractor and the aim is to keep the reference design as open as possible to allow for innovation and contractor refinements.

"But at the same time it is necessary to present the project for the planning process in sufficient detail for sensible decisions about its local effects, both permanently and during construction. Local authorities and other interested parties have to know the size and scale of the scheme, traffic changes, assessments of land take needs, and the environmental impact," he says.

A PFI basis for the project would take advantage of user charging for the crossing. Vehicle charging is to be imposed for two reasons, says Saldanha. First is to allow demand management of the route, freeing traffic flows to offer an estimated 20-minute reduction in delays at peak times. Secondly it will provide a revenue stream to repay the PFI contract. "We have money for the planning of the scheme but not enough to pay for the major construction itself," he says.

This aspect of the project may prove to be one of the contentious issues in the coming period because it will go hand in hand with a toll imposed on the existing Blackwall Tunnel, currently a free crossing of the river. "But you cannot control overall demand at the new crossing if the Blackwall alternative remains free," he says, "as vehicles would simply divert there."

User charging levels are likely to be at a similar level as the current Dartford crossing, around GBP 2.50 (USD 4) for cars, probably collected by a free flow system similar to the London Congestion Charge, using technology like number plate recognition combined with Internet payment. Users may be able to get reduced charge rates if they become account holders.

That comes later however. In the meantime the various design packages have whittled down the choices. First task was to compare the immersed and bored options, a project carried out by Mott, with LBA input.

"Our role is to provide the knowledge of practical difficulties and constraints on the actual construction of any design," says LBA managing director David Sharrocks.

The consultancy comprises a mixture of "old hands" from well-known tunnelling firms such as Nuttall and Taylor Woodrow, as well as calling on a network of particular contacts from grouting firms, pile contractors and such.

Such input, to keep designs down to earth and to eliminate "can't be done" tooth-sucking, is increasingly part of development work for projects, using such methods as early contractor involvement,

Above: The planned alignment of the new Silvertown crossing

for example, or simply arising from a more realistic understanding of construction practicalities within the design community, "not least because of CDM (construction design and management) safe working requirements," says Balfour Beatty's Bridge.

Construction issues in design typically take into account factors such as practical space constraints, mucking out routes and methods, supply lines, and a host of other factors like necessary machines, their sizes and the needs they impose for temporary works. Site working safety is also a factor.

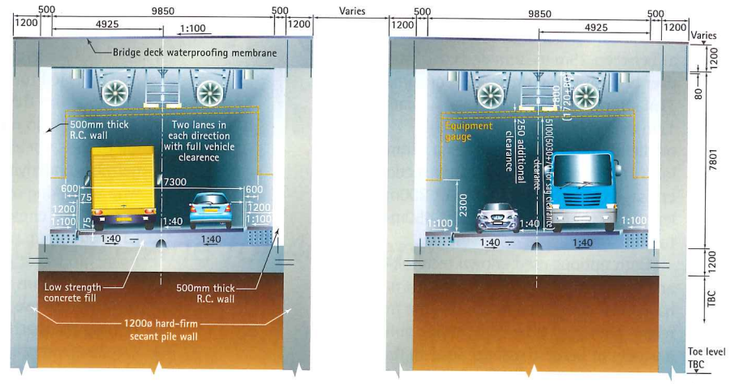
But there are limitations to designer capability and ECI does not always suffice, suggests Sharrocks.

"A designer simply does not have the detailed experience of construction on site, which allows for all the factors affecting work to be taken into consideration. But a contractor may not be suitable either, firstly because you might want the input at an earlier stage, as with Silvertown for example."

Very often a contractor will have very particular ideas about the constraints, perhaps relating to the use of a specific piece of kit he has sitting in the yard or methods he does not want to divulge for competition reasons.

"But advisers like ourselves, mostly drawn from the contracting world, can provide a more general idea of what is neededm" Sharrocks says.

Beyond the ideal design for construction there is a skill in assessing just what compromises might be possible between, say, providing a generous space for a TBM starter pit, and limiting its size perhaps to reduce excavation, necessary side wall thicknesses and propping requirements, and thereby costs. Temporary and permanent strutting might also need



Above: Cross-sections of the two options for the tunnel: an immersed tube, or a bored solution

to be juggled to cope with the need for movement of equipment and positioning of supply lines during construction.

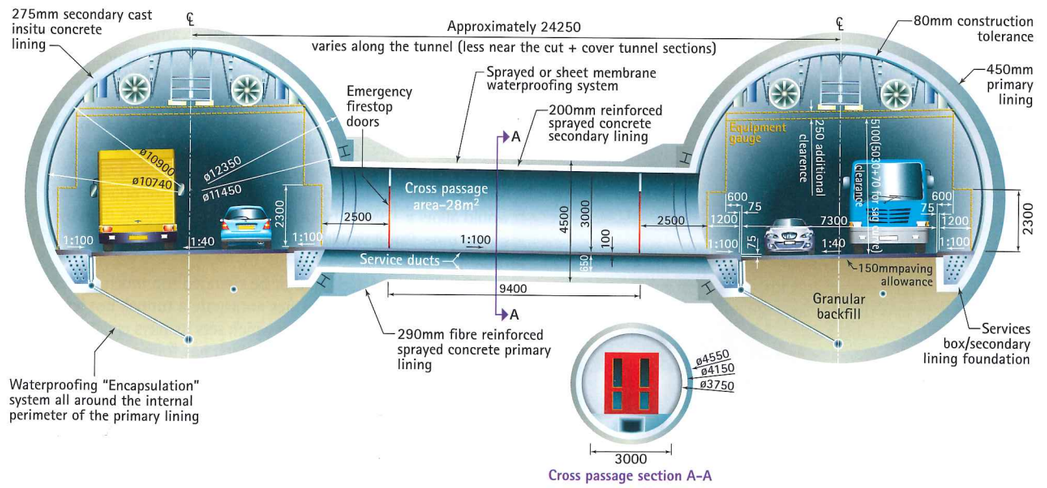
The aim is not simply to see the practical issues for site work, but to judge carefully how such factors and their interactions affect scheduling, project costing and the optimisation of the design.

For Silvertown these factors and many others have had a significant effect in assessing and comparing the two options for a tunnel, as designs for an immersed tube and a bored tunnel were run in parallel. While the immersed tube was potentially slightly more economic for example, the impact of its construction was greater.

Multiple factors are involved but some of the critical ones include the land availability for the work site, geology, spoil removal, possibilities for alignment modifications and fire and safety considerations.

The alignment is in fact set fairly tight, says Ken Spiby, Sharrocks' colleague at LBA also involved with the Silvertown scheme. "The client is responsible for the overall road network and gave Mott an envelope for the tunnel and its connections into the network at the end."

The immersed tube option examined was an approximately 500m length box tunnel to run under the river bed, comprising four immersed concrete boxes with twin rectangular road sections, connected by cut and cover approaches at the ends. At a higher vertical alignment than the bored option it would have needed



Cross passage section A-A

shorter approaches to the bored alternative.

The conventional tunnel needs to run at between 25m to 30m deep to clear the river bed with twin drives of approximately 11m internal diameter, needing a nearly 12m diameter TBM. To stay within gradient limits each is just over a kilometre long and there are cut and cover sections envisaged at either end of about 200m length, to complete an overall 1,450m-long tunnel.

Both options used known technology and several past projects of a similar nature have been completed in the UK; the most recent immersed tube on Tyneside and a variety of bored crossings done in the last 20 years under the Thames, for tube lines, Crossrail and high speed rail into Paddington.

For both cases much of the work is envisaged as taking place at a main construction site on the north side of the river, where there would be a casting and float out yard for the concrete segments for the immersed tube, or the main access point for the tunnel drives. "There is not sufficient room for a large worksite on the south side and no easily accessible wharf," says Saldanha.

IMMERSED VS. BORED

Critical factors for the immersed tube would be finding space for the casting yard and the impact of the work on the river regime, says Spiby.

"The river has to be dredged to form a flat bottomed trench for the concrete segments, and that has an impact on the environment, for example in causing silt to move downstream. The casting yard would also have to have access to concrete casting materials, probably brought in by barge on the river, the method favoured by the city mayoral office for all major projects." Truck movement is possible but more difficult.

Dredging would disrupt river traffic and so too would placing operations for the box float outs, each requiring a river possession as the boxes are moved into position and lowered to the river bed. Spiby and Sharrocks visited the Port of London Authority at Gravesend to discuss how that could be done.

The immersed tube would also require breaking the river walls and reinstating them around the new entrances, with significant environmental and river regime effects.

For the bored tunnel there is less direct river impact but factors include locating sufficient space for an operating yard and spoil handling. Again river transport is envisaged for the spoil removal and also the import of segments and other materials for the tunnel drives, which would be carried out by TBM, almost certainly starting from the north.

Barge loading and unloading requires berthing and, Saldanha says, that there are options on the Silvertown side.

The bored tunnel is likely to be carried out by an EPBM since the drive runs through mainly London clay and some sands and gravels. "We do not go as deep as some of the recent high speed rail tunnels, for example," says Saldanha, "and therefore do not get near underlying chalk." According to Balfour Beatty's Bridge, who is working as constructability adviser with Atkins on the next stage of the chosen bored tunnel option, the ground is mostly clay, Lambeth group mixed clay and sand, "and river terrace gravels and made ground at the portals."

Drive options were examined by the Mott study but the obvious method is to use a single machine, driving southwards, then turning the machine and returning. A variety of questions arise for the advisers in this, particularly on the structure of the starter pit, and especially for dimensions of the southern reception and turning box. Just how the machine is supplied and spoil removed were factors affecting sizes, possible land requirements and dimensions for cross walls and so forth.

Supplying the machine is also important, with the most likely method being delivery through the first bore for both the initial and the return drive, and with spoil conveyors passing back that way too.

"Another important issue for comparison was the fire safety and evacuation provision," says Spiby. Standard Highway Agency regulations are for cross passages to be provided every 100m. But this could be quite expensive and entails some risk, particularly as each must be hand excavated.

Sharrocks explains, "You have to break through the lining which means a weak point in both temporary and potentially the permanent tunnel and there remains uncertainty about just what the local geology will be."

Bridge also points out that a decision to impose a 30mph speed limit would de-risk tunnel operations, potentially allowing an increase in the spacing of cross passages.

For an immersed tube on the other hand it is fairly simple to provide a central escape gallery into which any number of emergency doors can be provided at relatively little cost.

Examining the possibilities of reducing the cross passages, by using enhanced safety detection systems, active ventilation methods to isolate fire, and other technology is part of studies.

The result of Mott's' study in 2012 was selection of the bored tunnel as the preferred option, with some additional elaboration worked up in a subsequent design contract.

But the finalising of the design is being carried out by Atkins, which won a competitive tender last year. "Atkins is finessing the bored tunnel design," says Bridge. One change for example is to move the north end of the bored tunnel slightly riverwards to make sure it does not sit over a backfilled lock to the Royal Docks. Although there are "as built" drawings, says Bridge, it is not sure how far they accurately show what obstacles might be there. Another aspect is considering further the river transport, which would allow a TBM to be delivered in larger sections than by truck, saving time. But it would in turn mean providing for larger lifting capacity.

The alignment itself cannot be changed too much however as some recently built structures anticipate a tunnel, not least a viaduct on the DLR extensions, which sets its piers wider apart at this point, and the cable car, too, which has foundations nearby.

Next steps for the project are due this summer, he says. Under the DCO process the statutory consultation can be relatively short – though about eight weeks are allocated rather than the minimum four. There was a 10-week local public consultation last year as well. An application may be submitted to the Planning Inspectorate at the beginning of next year

HDD DRIVERS

The current market for horizontal directional drilling (HDD) may be reflecting economic and political issues around the world but there's no doubt that underlying demand remains strong. **Keren Fallwell** reports

HDD IS AN established and popular method of laying pipelines underground as it can navigate below obstacles, such as roads and rivers, without creating disturbance above ground. This has the added benefits of reducing the environmental impact and the cost.

The technique uses a rig at ground level to launch a pilot bore that drills an arc along an underground trajectory. A reamer is connected to the drill rod at the exit hole and reverses back towards

A typical HDD drill head

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

the rig, opening up the bore to create a hole to accommodate the new pipeline. The pipeline is then connected to the back of a cleaning reamer and it effectively slides into the new path.

The fall in the price of oil, the delayed impact of the global financial crisis and political uncertainty are having some impact on projects requiring HDD but this is merely a pause.

"With the lower oil price and lower energy prices in general, a lot of people are holding back on oil and gas pipelines to see what shakes out," said Dan Billig, EU operations director at Prime Horizontal.

The HDD sector had been rather insulated from the immediate effects of the global financial crisis as in many cases funds were already committed to projects. However, as economies in Europe have been slow to pick up, infrastructure spending is feeling the delayed effects. With the exception of some electricity installations in Germany, and gas works in eastern Europe, the European market has quietened while, in contrast, the UK is fairly steady.

"Out of all the markets in Europe it seems to be the most buoyant," said Billig. "Perhaps people are a bit more confident and are willing to sign off on big projects."

The oil price drop has also affected demand in the US where, over the past few years, shale gas operations had Prime Horizontal busy.

Crossing the Yangtze

Alluvial sediments, a high tidal flow, heavy shipping traffic, 3,000m crossings and a strict six-month deadline all contributed to a complex pipeline installation under the Yangtze River.

The combined challenges meant that conventional crossing methods to install the three parallel gas pipelines were limited and so CPP Crossing Company and Prime Horizontal decided on the intersect method. Intersect drilling from entry and exit effectively halved the length of the traverses and reduced the entry and exit angles, reducing the risk of becoming stuck. With no surface cables or obstruction it also posed no problems for shipping traffic.

Two self-contained DD90 and DD1100RS drilling rigs from American Augers were used and the guidance system was Prime Horizontal's ParaTrack-2 (P2) with two magnetic sources. A conventional wire coil, installed with conventional methods, was used for the first part of the crossing; and a rotating magnet (RM) sub was installed behind the drilling motor when the intersect approached closure of the two drill pipes.

Using a conventional coil with ParaTrack-2 enabled the coil to generate AC magnetic fields, rather than DC fields used by conventional tracking systems. The coil was implemented as two parallel single wires rather than one closed loop with two sides.

The two 2,900m source cables were parallel, 100m apart and 58m at closest approach. They were installed 1-1.5m above the river bottom.

The three gas lines used 3.3km pilot holes drilled using a 6.75in mud motor equipped with a 9.875in drill bit. Although a mud motor is not usually necessary for drilling in soft sand and clay, the mud flow to clean the hole and the lengths of the pilot holes made the equipment essential.

An American Augers HDD rig in action

Vermeer UK also reports a boost in demand for drilling equipment in the UK in response to an increase in civil engineering work and the release of projects put on hold during the recession.

"Rigs are now being renewed and upgraded; ancillary equipment such as mixing systems, recycling units and location equipment are also being replaced," said Matthew Izzard, trenchless technology manager at Vermeer UK.

The renewable energy market was a major new market, and contractors were also taking on more challenging projects, such as rock drilling.

"This has pushed us as manufacturers to develop our cutting tool technology and continue to make equipment as cost-effectively as possible," said Izzard.

American Augers, which manufactures big machines of around 100,000lb pull force, has also noticed a slowdown as a result of the oil price.

"Business has generally slowed across the board," said Rob Verwilligen, director of sales and marketing. "Some of it is directly related to the oil price, while in areas like Russia it's also related to the rising tension with the west."

The European market, which was "not an investment friendly environment" at present, had been quiet for a few years and, while a tough winter had cooled the North American market, where the bulk of American Augers' work is in the energy sector, customers there were confident about the year ahead, said Verwilligen.

However, overall, he believes a market pick-up is evident. "It's going to be slow but steady growth, partly because so little has been done over the last couple of years. There's a breaking point for everything and some projects need to be done," he said.

In New Zealand, the global economic crisis, reduced local government spending and the Christchurch earthquake in 2011 have all affected HDD business.

"The NZ economy has had a bumpy ride since the global economic downturn in 2008. Work has been hard to find at times and some well-established trenchless construction companies have gone to the wall," said Neil Vanner, contracts engineer at Universal Underground.

The rebuilding of Christchurch's infrastructure did provide some uplift but it also became a "feeding frenzy for contractors".

The NZ government's Ultra-Fast Broadband Initiative to expand broadband services through fibre optics provided a bonanza for the HDD industry, which doubled in size in a short time, but it wasn't all positive. The start-ups were "falling over each other" to win contracts, the shallow drilling often conflicted with existing underground services and the financial viability was marginal. Now the work is nearing completion, the start-ups, and everyone else, is looking for new work.

"Some will go to the wall and others will compete for work in an already crowded market," said Vanner. "HDD contractors are now like lawn mowing contractors – they're everywhere."

On projects around the world, the cost and lower environmental impact are big factors in choosing HDD.

"Sometimes microtunnelling is the sensible thing to do but sometimes HDD is the logical alternative," said


Prime Horizontal's AC Beacon, a two solenoid AC system for tracking the directional drilling of pipelines

Powering New Jersey

Horizontal direction drilling has been used to install more than 11,000ft of high-voltage transmission lines for a new 700MW gas-fired power station in New Jersey.

The HDD contractor, Carson Corporation, drilled six directional bores in three locations for the 11,000ft of 30in fusible PVC (fPVC) casing to cross two wetland areas and the Raritan River. Each of the locations required parallel crossings of the casing pipe, which housed three 230kV elecrical cables, each producing enough electricity to power more than 700,000 homes.

The 30in fPVC casings each housed four 8in fPVC condits to cary three 230kV cables, two 2in HDPE conduits for ground and fibre optic lines, and a 3in HDPE grout delivery tube.

The project used three American Augers drills – DD1100 (1.1 million lb), DD440 (440,000lb), and DD140 (140,000lb) – two Tulsa Rig Iron 750 Recyclers and INROCK and SlimDril International steering hands.

Installation for most of the project was via overhead towers and direct burial.

"About one mile of the entire project needed to be installed using the trenchless technology of HDD because the terrain was either wetlands or river," said Carson Corp vice-president Scott Murray.

Before drilling could commence, the Carson crew constructed a mile of timber mats in the wetland areas to support the heavy drilling equipment.

On the final two boreholes, the narrow right of way the drilling crew had to work in meant there was no room for error.

"With the first four drills there was a 40ft right of way but the last two had only a 22ft right of way," said Murray. "The electrical manufacturer required that the drills be 19ft apart to prevent the lines coming too close together and heating up. We had to drill both drills perfectly along the right of way."

Verwilligen. "In certain applications, such as road and river crossings, it's much less disruptive than excavating or trenching, and if you had to close a river to do drilling the costs would be significant."

Billig believes that HDD's cost and cleaner working, coupled with its ability to accommodate long crossings, means it is now competing with microtunnelling. It was a low-impact solution for environmentally-sensitive areas and, he added, in Nigeria HDD was being used to bury oil pipelines to improve their security.

Price was also the overriding driver in New Zealand – sometimes at the expense of realistic expectations.

"New Zealand designers and clients demand micro tunnel accuracy. I still see tenders asking for a 0.2% grade by HDD," said Vanner. "Generally speaking, some of them don't understand how trenchless technology works. What they do know is that HDD is widely accepted as the preferred way to put a pipe in the ground and in most cases it's cheaper than open cut and far cheaper than microtunnelling."

Tooling and equipment manufacturers are now working to make HDD even more efficient. Prime Horizontal, one of two worldwide distributors of the ParaTrack underground magnetic tracking system, is now offering an automatic mud viscosity and specific gravity measuring and logging system, replacing the need to manually check the all-important key parameters for mud fluids, which is usually done several times a day.

"This system takes a reading every 10 minutes and cleans itself. It stores the data and transmits it to the drilling cabin so the driller can see what the parameters are for the fluids at any one time," said Billig. "The fluids can change as you're drilling and if you're not keeping a constant watch you can have problems in the hole. For example, if the viscosity drops there's a risk that the hole won't be clean enough and the tooling could get stuck. If the viscosity is too thick you can have problems with down hole pressure and quality issues."

Another development is the ProData which reads the rig's parameters, such as the push/pull torque and carriage position, and transmits it to a web portal. The data is also stored for reference on future projects in the area.

Providing data is a big focus for Prime Horizontal and Billig believes it will be a big driver for more developments in the coming years.

"The more information you get either from the rig or down hole, the more contractors can avoid problems," he said.

Vermeer also has online 'live' reporting from drill rigs and is increasingly being asked to advise customers, for example on tooling and mud mixing, before the project's start.

"The nature of directional drilling is that every single shot is unique; there is no 'right' formula," said Izzard. "The key to a successful project is getting the combination of drill rig, mud mix and tooling right – one won't work without the others."

Vermeer has also developed Armor tooling to make it easier to change drill heads for different ground conditions; has an online tooling and accessory shop (www.borestore.eu) where customers can log their rigs and find what tooling is available; and a registration service (www.myvermeer.com) where customers can download data about their rigs, as well as parts and operation manuals.

A development noted by Vanner is that specifications, from drill size to pipe diameter and length, are getting bigger.

"Everthing is getting bigger and the jobs riskier. However, the margins are getting tighter because of competition from the newer HDD companies that don't price the risk," he said.

He also noted that drill fluid recycling was becoming more prevalent and "shots are getting deeper, requiring involvement from specialised steering subcontractors".

New HDD projects around the world include the relocation of five pipelines as part of the re-routing of the A9 motorway in the Netherlands. Waternet commissioned Visser & Smit Hanab to perform five parallel drills, each 730 long, to accommodate two raw water pipelines and three for potable water. Each pipeline was 1,200mm in diameter.

Universal Underground is currently working on a gravity wastewater project near Auckland.

"Constructing a pump a station is a last resort and if a long, deep drill shot can be achieved this takes precedence," said Vanner. "We've completed a continuous 632m-long drill shot at 1.2% grade, intercepting four fibreglass manholes up to 28m deep. A decade ago a job like this would not have been conceived."

The Hong Kong Airport Authority has recently tendered for the construction of two 5km undersea aviation fuel pipelines to connect the existing aviation fuel system on Airport Island with the Aviation Fuel Receiving Facility at Sha Chau Island. The pipelines will be installed through bedrock and each will have a 500mm diameter. The project is due to be completed in 2017.

The joint venture of Volkerinfra and VBMS has been appointed by DONG Energy to complete the export cable landfall installation for Burbo Bank Extension offshore wind farm in Liverpool Bay in the UK.

HDD will be used to install two 600m duct, both intertidal and onshore, between Rhyl and Prestatyn

Vacuum lifting

American vacuum lifting equipment manufacturer Vacuworx has launched a lightweight pipe handling system to lift and position drill stem in HDD operations.

The HDD Pipe Handling System uses wireless remote controller operation and vacuum-lifting technology to tilt and place the drill stem at angles between 0-30 degrees without the use of ropes or slings.

Suitable for use with Vacuworx MC Series Lifters, the lightweight HDD unit requires only one person to lift the drill stem and transfer the pipe into the drilling rig.

The system features a 360 degree hydraulic rotator that gives operators complete control over the drill stem and enables for the precise placement of pipe joints with fewers workers on the ground.

The HDD unit handles single joints of steel pipe from 76-457mm in diameter, with lift capacities ranging from 771-2,449kg.

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What's on

2015

RETC
7-10 June 2015
New Orleans, USA
The biennel American underground construction conferece will be held at the Sheraton Hotel in New Orleans, Louisiana this year. The organisers have announced that the 2015 show should be as successful as the 2013 event which boasted the largest number of attendees, exhibitors and papers in the show's history.
www.retc.org

49th US Rock Mechanics / Geomechanics Symposium
28 June-1 July 2015
San Francisco, California
The 2015 program will focus on new and exciting advances in rock mechanics and geomechanics and encompasses all aspects of rock mechanics, rock engineering, and geomechanics.
www.armasymposium.org/

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

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. The trade show is organised by Restec.
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 2015.
www.tunnelcanada.ca

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.

Tunnelling in the Lambeth Group: how can we stop it going wrong?
18 June 2015
A presentation by a leading geologist with expertise in the interpretation of complex soils and rocks as well as the geology of London and Southeast England. This talk will examine why the Lambeth Group is so complex and variable; what risks and challenges it presents to tunnellers in London and how training in the stratigraphy and the development of more accurate ground models is contributing to mitigating those risks.
Speaker: Jackie Skipper

BTSYM presentation: Fastenings in tunnels
25 June 2015
A presentation by speakers from specialist design company Dr. Sauer & Partners and supplier Fischer Fixings. The two speakers have in previous years hosted succesful workshop sessions on this subject.
Speakers: Panos Spyridis and Mirka Valovicova

BTS Design and Construction Course
29 June - 3 July 2015
The course aims to cover all the major aspects of an underground project's life and contains worked examples and workshop sessions to allow improved interaction between delegates and speaker. It is aimed at the wide range of professional services that support the tunnelling industry, including clients, tunnel operators and members of the financial and insurance sectors that may have a vested interest in tunnelling enterprises, as well as young tunnel design and construction engineers. The course speakers are all recognised industry experts in their own fields, and the BTS Tunnel Design and Construction Course is recognised within the industry as providing the highest standard of technical content, with the course material being presented in a format designed to engage and inform attendees from a wide range of backgrounds..

Five BTS-sponsored spaces were made available.

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
Speaker: Anthony Harding

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

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

Greg James: greg.james@ice.co.uk
Dave Terry: david.terry@lbassoc.co.uk

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

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Subscription prices for 12 (24) months:
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Tunnels & Tunnelling International is printed at Stephens & George Print Group, Merthyr Tydfil.

Tunnels & Tunnelling International ISSN (USPS 7330) 1369-3999 is published monthly by World Market Intelligence, Progressive House, Foots Cray, Sidcup, Kent, DA14 5HZ.
The US annual subscription price is $283.49. Airfreight and mailing in the USA by agent named Worldnet Shipping Inc., 156-15, 146th Avenue, 2nd Floor, Jamaica, NY 11434, USA. Periodicals paid at Jamaica NY 11431.
US Postmaster: Send address changes to Tunnels & Tunnelling International, Worldnet Shipping Inc., 156-15, 146th Avenue, 2nd Floor, Jamaica, NY 11434, USA.
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