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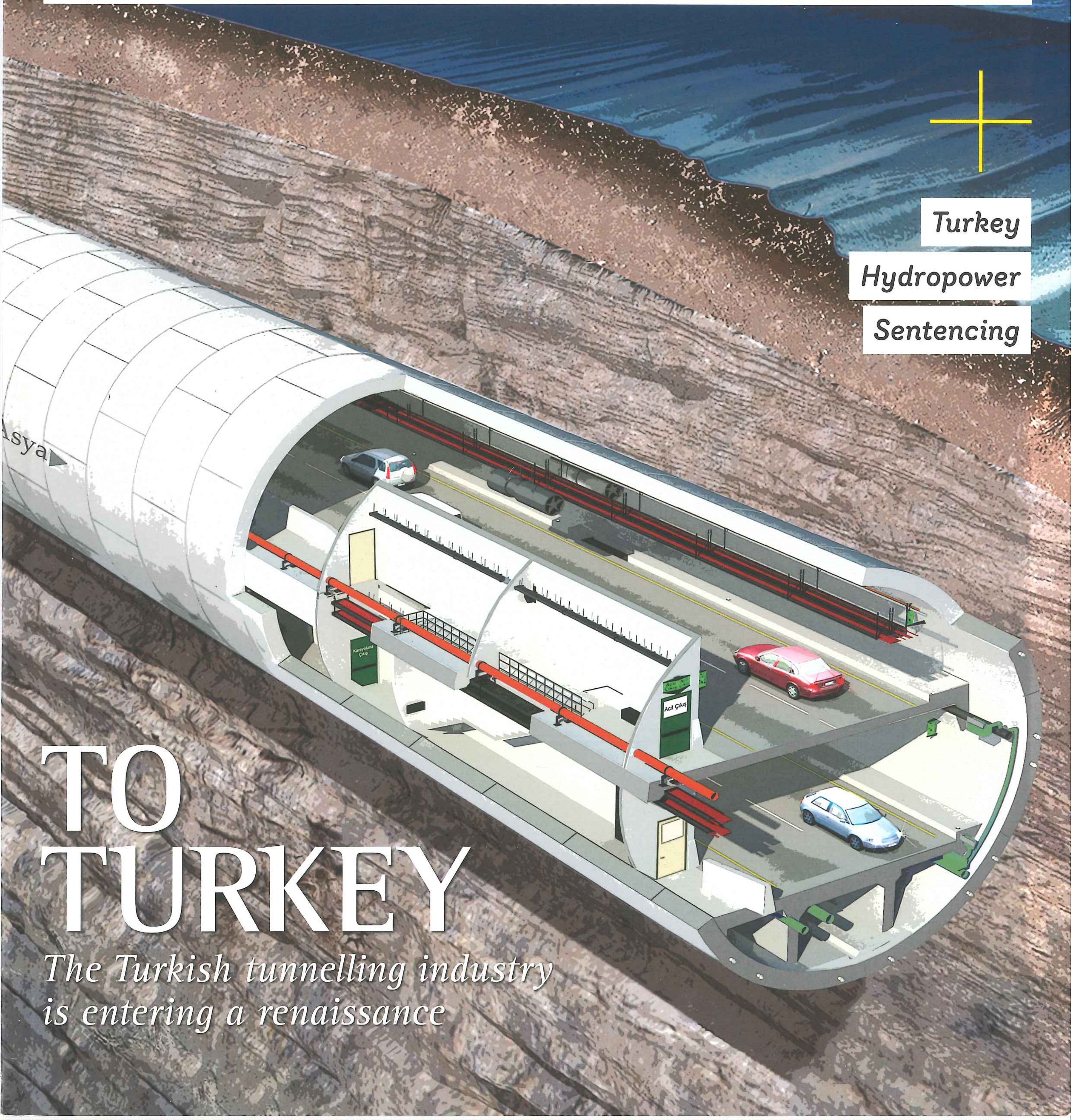
May 2016

Tunnels AND TUNNELLING



Turkey

Hydropower

Sentencing

TO TURKEY

The Turkish tunnelling industry is entering a renaissance

LOOKING FORWARD

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

THIS TIME LAST YEAR I wrote about the impressive amount of tunnelling required to solve the unanswered questions of the scientific community. In recent years, the Large Hadron Collider (LHC) has been the highest profile of these projects. Nestled in the Geneva area of Switzerland, it has expanded humanity's knowledge of the subatomic world by smashing particles together at extremely high energies. For engineers too it is an impressive project. At 3.8m-diameter, the 27km-long circular tunnel was constructed in the early 1980s at depths of 50 to 175m. All in, the entire project required 32.6km of tunnels, 19 shafts and 37 caverns to accommodate the equipment necessary to scoop Nobel Prizes.

But bigger is better, and scientists are looking to the tunnelling industry to help with a new project they have been mulling over. As the subatomic particle 'zoo' gets populated, higher magnetic energies (and bigger colliders) are needed to find new species. So in the next issue of Tunnels and Tunnelling, we will be reporting on plans for the Future Circular Collider (FCC).

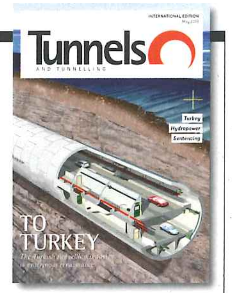
This really will be a big one if it goes ahead. The circumference range being examined is 80-100km, and as expected the physicists are pushing for the 100km option. There is also a cadre arguing that this should be a double ring installation, which would see the project dwarf the Gotthard base tunnel (152km total tunnelling) or the Delaware aqueduct (137km) to become the largest tunnelling project in history.

Mega colliders require smaller colliders to pre-accelerate particles before they enter the main structure. It is much like going through the gears in a car, starting at a low gear first. So locating the FCC near the LHC is desirable to make use of the older collider for this purpose.

However, the sheer size of the FCC makes locating it difficult during feasibility studies. Staying in good rock is challenging, and whatever the depths tunnelling will take place at, the shafts required for this project will be very impressive. The concept currently calls for 16 shafts, of which access shafts will be 12m in diameter. However, other shafts need to be up to 31m in diameter and up to 400m deep. This is because the scientific equipment is so precisely machined it has to be monolithic, and cannot be broken up into sections for lowering.

Construction methodology for the shafts and tunnels varies due to the wildly differing conditions across the project. Read the article for more

Cover
This issue's front cover shows an artist's concept of the Eurasia Tunnel project in Turkey's capital Istanbul



Next issue
In the next issue of Tunnels and Tunnelling we have interviews with the chair and deputy chair of the BTS as the society approaches a handover of leadership. Also from the UK this issue is a report on the traditional BTS Christmas Debate.

This month...

20 YEARS AGO

Bidders for the Botlekspoor rail tunnel in Rotterdam have been asked to retender, combining it with a second tunnel, the Sophia. A spokesman for Dutch Railways said that the decision had been taken in the hope that contractors would be able to cut costs by using the same TBMs and the same precasting yards for segments. Contractors have also been asked to increase the i.d. of the Botlekspoor from 7.6m to 8.6m in order to accommodate double stacking containers. The revised design will also be 500m longer because of its deeper bore to accommodate the increased diameter. Ground conditions are known to be poor and settlement restrictions tight.
Tunnels and Tunnelling, May 1996, p.9

40 YEARS AGO

A TBM equipped with high-pressure water jets, which significantly increase the advance rate, was demonstrated recently in a granite quarry near Seattle, USA. The jets are mounted on the rotary cutterhead of the machine together with the conventional rock cutters. The high-velocity jets are positioned so as to cut narrow slots in the rock in advance of the cutters. To use water effectively as a hard rock cutting device, it is pressurized by a special 1,000hp pumping system producing a 386MN jet which passes through an array of 0.25mm-diameter sapphire pumping nozzles. This is a joint project between the Colorado School of Mines, Robbins, and Flow Research Incorporated.
Tunnels and Tunnelling, May 1976, p.21

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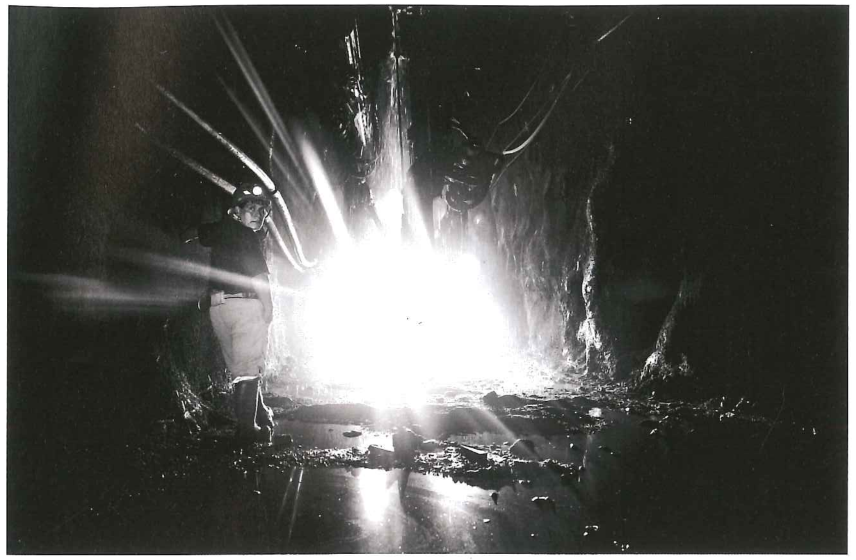

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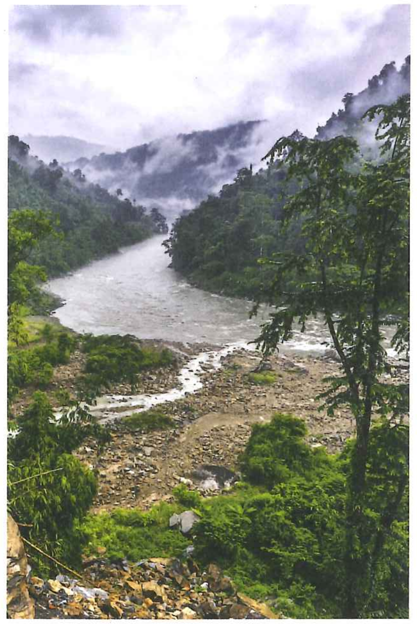

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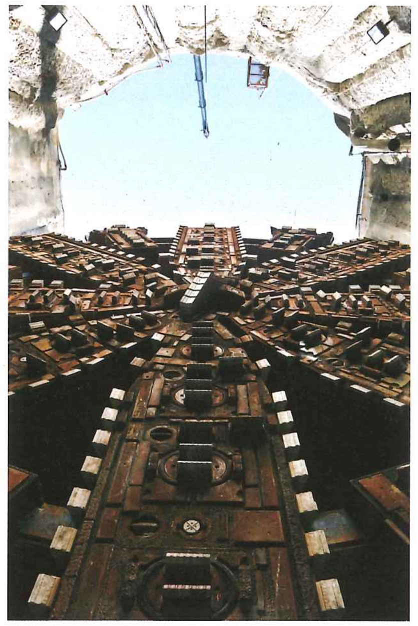


Key people in this issue

JOHN FINCH
John Finch is the commercial director for construction insurance specialist Focus. In this issue of Tunnels and Tunnelling he assesses new health and safety sentencing guidelines in Britain. His comment can be found on page 14.

STEVEN DELFGAAUW
Steven Delfgaauw currently of TEC/Witteveen & Bos was project manager for the Railinfrasolutions, Benthem Crouwel Architects JV, consultant to Pro Rail for the Delft project.

HANS MORTIER
Hans Mortier (DIMCO) was design manager of the CFE/Dura Vermeer/Mobilis joint venturefor the period spanning basic design until end of execution of the first phase of the eastern tube. During the execution of remaining works he acted as advisor to the design manager.

BRITAIN LAUNCHES SEGMENTAL LINING DESIGN CODE OF PRACTICE

GREAT BRITAIN — A specification for the design of concrete segmental linings was launched in mid-April. The document, "Publicly Available Specification (PAS) 8810:2016 – Tunnel Design: Design of concrete segmental linings: Code of practice" was produced by the British Standards Institute (BSI) and lead technical author Arup.

Until now the design of precast concrete segmental linings has been undertaken with reference to a large number of standards and documents. But with the upcoming High Speed Two (HS2) megaproject, it was decided to unify all of this documentation into a single, usable document.

Sponsored by HS2 itself (which is spending tens of thousands to hundreds of thousands of GBP on standards) and also the BTS, PAS 8810 should reduce unnecessary administration and streamline the design process.

At a launch event in April, Arup representatives pointed to the growing status of tunnelling as the "go-to method" for solving an infrastructure requirement and said that PAS 8810 represented a "coming of age" for tunnelling, which can no longer be considered a "dark art".

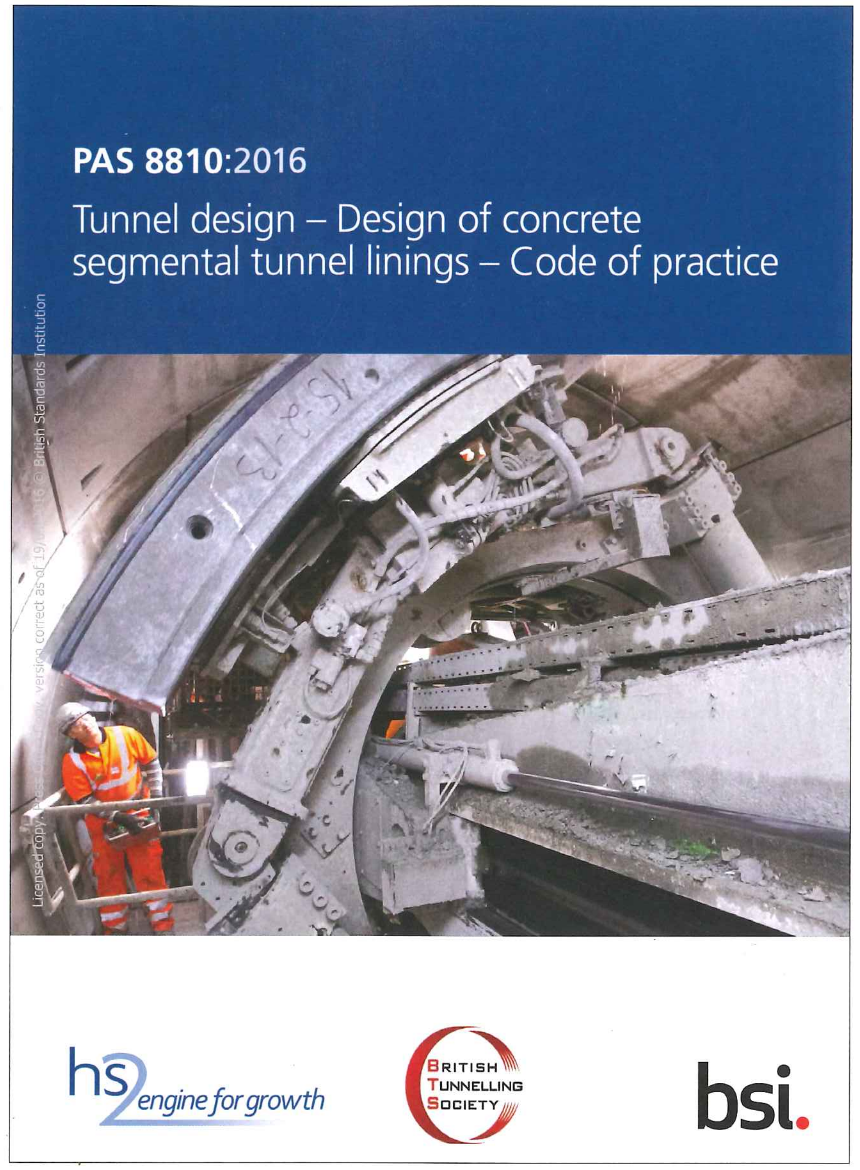
The guide represents two years of hard work and an attempt to capture best practice.

On the scope of the document the BSI details the following: "PAS 8810 covers: functional requirements, conceptual design, characterisation of ground, materials design and specification, material characterisation and testing, limit state design, concrete segmental lining design, concrete segment lining modelling, instrumentation and monitoring, and design management.

"This PAS doesn't cover: sprayed concrete lined tunnels, cast-in-situ concrete lined tunnels, any tunnel lining using material other than concrete, such as spheroidal graphite iron or steel, cut and cover tunnels, drill and blast excavations, hard rock tunnelling, pipe jacking, project planning and management.

"PAS 8810 sets out detailed recommendations by referring existing national and international industry standards. It also includes specific design recommendations for the design items not available in any other standards."

A PAS is not a British Standard. It will be withdrawn upon publication of its content in, or as, a British Standard. The PAS process enables a code of practice to be rapidly developed in order to fulfill an immediate need in industry (in this case, HS2).



Technical author Arup calls the document a "coming of age" for tunnelling

A PAS can be considered for further development as a British Standard, or constitute part of the UK input into the development of a European or International Standard.

The authors credited the input of the members of the steering group, who contributed an extremely thorough 750 comments on the document between them.

The steering group comprised Arup, Atkins, Balfour Beatty, the BTS, CH2M, Costain, Crossrail, Donaldson Associates, Dragados, Health and Safety Executive (HSE), Highways England, High Speed Two (HS2), INECO, London Underground, Mott MacDonald, Network Rail, OTB Concrete, Skanska, Thames Tideway, University College London, Department of Civil Engineering, Morgan Sindall, Vinci, co-opted members

Originally this guide was intended to include other types of lining, but the scope turned out to be too great. At the time PAS 8810 was published, the intention was to follow up with subsequent documents for sprayed concrete linings and cast in-situ linings.

PAS 8810 is available for purchase from the BSI website: www.shop.bsigroup.com

FOLLO LINE TBMS START TO SHIP

GERMANY/NORWAY — Factory acceptance of the second Follo Line TBM took place in early April. The first machine was already being disassembled for transportation from to Norway, while the two final machines were still being manufactured.

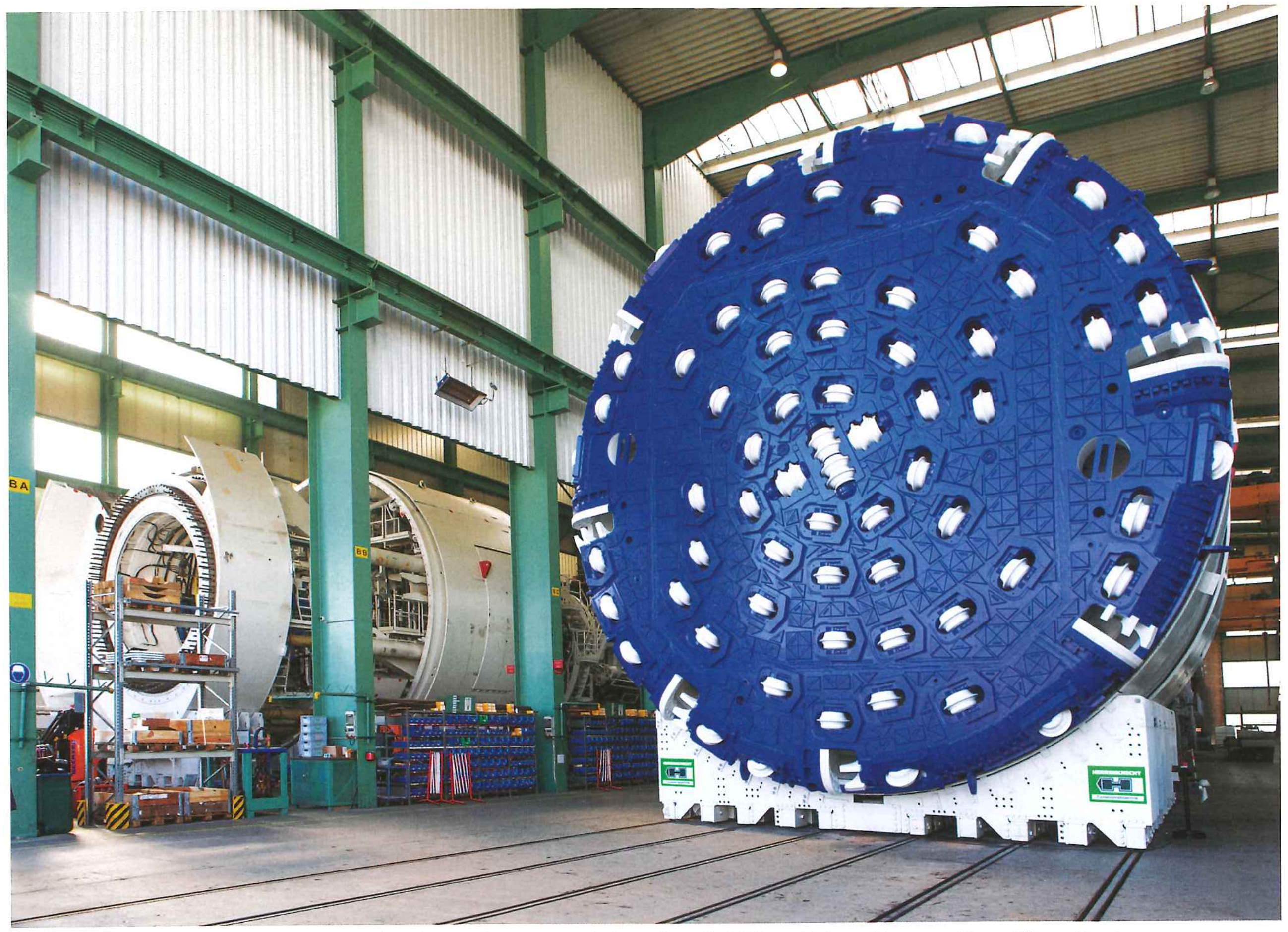
The four Herrenknecht double shield, hard rock machines measure 9.9m in diameter are on track to be delivered ahead of schedule to Norway's largest infrastructure project. The manufacturer stated that it was pleased to have success in a country traditionally dominated by conventional methods.

Anne Kathrine Kalager, project manager for client Jernbaneverket added: "We are quite good in drill & blast technology and proud of it. But for this project TBM-technology was considered the best solution due to the environment and the fact that we have access to one large rig area for the all TBM tunnel construction work."

Each of the four Follo Line TBMs will work its way through 9.5km of Norwegian granite up to 350MPa. Starting from the site in Åsland, two will tunnel northward toward Oslo, the other two will head south toward Ski.

The Follo Line comprises a 22km double track railway line between Oslo Central Station and the new station at Ski, south of Oslo.

The Acciona Ghella JV will construct the main part of the 20km-long tunnel, which will be Scandinavia's longest when it is finalised at the end 2021. The construction of the line will cut the travel time between the Norwegian towns of Oslo and Ski by about half to just 11 minutes.



Norway has had a return to TBM technology after several decades of drill and blast ("conventional") methods

Pipe Jacking Association launches mobile website

GREAT BRITAIN — The Pipe Jacking Association (PJA) has launched a mobile-friendly website. The new site now includes case studies of pipe jacking projects intended to aid utility owners and designers when considering pipe jacking or microtunnelling as a solution. Content also includes details of PJA members, access to publications, animations and presentations, extensive university research and a link to its carbon calculator. The intent is to easily give proponents of the technology easy access to evidence of the up to 75 per cent carbon savings when comparing pipe jacking with open cut techniques.

The case studies are downloadable from the Pipe Jacking Associations website: www.pipejacking.org

The calculator can be found at: www. pipejackingco2calclator.com.

New Cross River Rail plan unveiled

AUSTRALIA — Cross River Rail could be revived. According to the Australasian Tunnelling Society (ATS) a delivery authority has been set up to find the AUD 5.2bn (USD 4bn) in funding for the repeatedly cancelled project.

The 10.2km route would run from Dutton Park to Bowen Hills, with a 5.9km tunnel under the Brisbane River and four stations. The previous plan called for a 7m o.d. through hard rock. Geology is slightly uncertain for the river crossing as investigations were limited to seismic (see feature, January 2011).

VISHNUGAD-PIPALKOTI TBM ACCEPTANCE

INDIA — Factory acceptance for the TBM bound for the 444MW Vishnugad-Pipalkoti hydropower project took place last month. The 9.86m-diameter Terratec hard rock double shield TBM will excavate the 13km of tunnels for the project, which is located in the estate of Uttarakhand, around 500km northeast of Delhi.

Working for main contractor HCC, Seli Overseas will handle the tunnelling which passes through Dolomitic Limestone along one third of the drive and slates along two thirds of the drive. A 150m section of low overburden, five shear zones and three fault zones are known challenges.

The machine will now be dismantled and sailed up to Mundra Port in India, from where to send it by road up to the Project Site. The TBM is expected to commence its assembly at the jobsite in July 2016.

A spokesman for the manufacturer gave these details about the TBM's design, which involved input from Seli: "The critical zones will represent the most challenging ones and for that the TBM has been carefully designed. The cutterhead has a very robust yet versatile concept, mounting Heavy Duty 19" disc cutters but keeping twelve large bucket openings.

"The 4,200kW Electric VFD Main Drive will allow the cutterhead to cut the hardest rock zones at the maximum speed of 6rpm and also to deliver an exceptional torque over 22,000kNm to cope with those fractured parts of the alignment."

The TBM will now be disassembled and shipped out to the site in northern India to bore a low pressure headrace tunnel

Versaflex launches new operation in South America

BRAZIL — Versaflex Incorporated announced on 12 April that Fernando Costa will become the business manager of its newly launched South American base of operations.

Costa has nearly three decades of experience in the chemical industry and more than 10 years of experience in the polyurea and related coatings industry.

He holds a degree in Chemical Engineering and has worked to formulate and manufacture products in a variety of industries, including paints, coatings, ceramics, and nanotechnology. Most recently, Costa was the CEO of Marmai Company. of Sao Paulo, Brazil.

Versaflex said, "Costa has worked tirelessly over the past four years with Marmai to educate, improve, and advance the polyurea protective coatings and linings industry in South America.

Fernando's background will assure a seamless transition to his new role with Versaflex."

Costa's primary objective will be to establish Versaflex South America as the premier polyurea coatings and linings systems supplier in the region.

He will oversee all of the company's South American business from the base in Brazil and will work to further educate and advance the polyurea elastomerprotective coatings and linings industry in the region.

VMT partners with Topcon

USA — Topcon Positioning Group announced the launch of Topcon Delta, its new deformation monitoring solution for construction, tunnelling and mining, in partnership with tunnelling specialist VMT GmbH, on 12 April.

The system of software and hardware components delivers monitoring measurements and associated reporting to provide protection of assets during works. It will be globally distributed by Topcon

"We are very excited to enter into this partnership with VMT and to introduce the all-new modular Topcon Delta product portfolio," said Ian Stilgoe, vice president portfolio management at Topcon Positioning Group. "Integrating VMT's monitoring hardware and software portfolio with our high accuracy measurement sensors, such as the MS AX II monitoring total station and GNSS receivers, we are confident that we will be offering the best solution for all deformation monitoring applications."

"We are pleased to be able to partner with Topcon to bring our market leading solutions to a wider customer base via Topcon's global distribution network," said Alexander Seilert, VMT GmbH general manager.

Doha Green Line tunnelling complete

QATAR — Tunnelling has completed on the Doha Green Line. Qatar Rail announced that the breakthrough of the TBM at Education City station marked the end of tunnelling on the line. The announcement, on 30 March, came just 10 days after completion of the northern section of the Red Line.

Tunnelling on the Doha Metro Green Line began in October 2014 with six TBMs used to complete the 22km operational line which has 10 underground stations and one above ground. The Green Line will run for 19km beneath ground level and 3km above ground.

The next major milestone is completion of tunnelling on Doha Metro's Gold Line later this year.

Letter

Dear Sir

I refer to David Caiden's letter in the March 2016 edition of Tunnels and Tunnelling International where he disputes the term TBM as applied to the Farnworth project tunnelling machine and have the following observation to make:

1. Was it a tunnel? – Yes
2. Was the tunnel bored as opposed to cut and cover or immersed? – Yes
3. Is it a machine? – Yes

Well if it walks like a duck, swims like a duck and quacks like a duck then it's a duck. I would agree that it could have been more accurately described as an "open-face mechanised shield-type TBM" as opposed to closed-face digger shield, rotary open face, rotary closed face, earth pressure balance, slurry, mixshield etc. etc., but they are all types of tunnel boring machines. Remember, the first soft ground rotary shield developed in the UK in the 1950s was referred to as a "drum digger" (and before any fellow pedants chip in, I am aware that the rotary open face rock tunnelling machine was invented in the mid-19th century in the USA).

By the way the International Tunnelling Association defines a Tunnel Boring Machine as: "A machine that excavates a tunnel by drilling out the heading to full size in one operation and often called a mole."

They also define a drum digger as: "A mechanical tunnelling shield having a cutting head mounted on a drum which revolves inside the outer skin of the shield, providing access to the tunnel face through the drum."

I hope this helps to complicate the matter.

David J Hindle, OTB Engineering

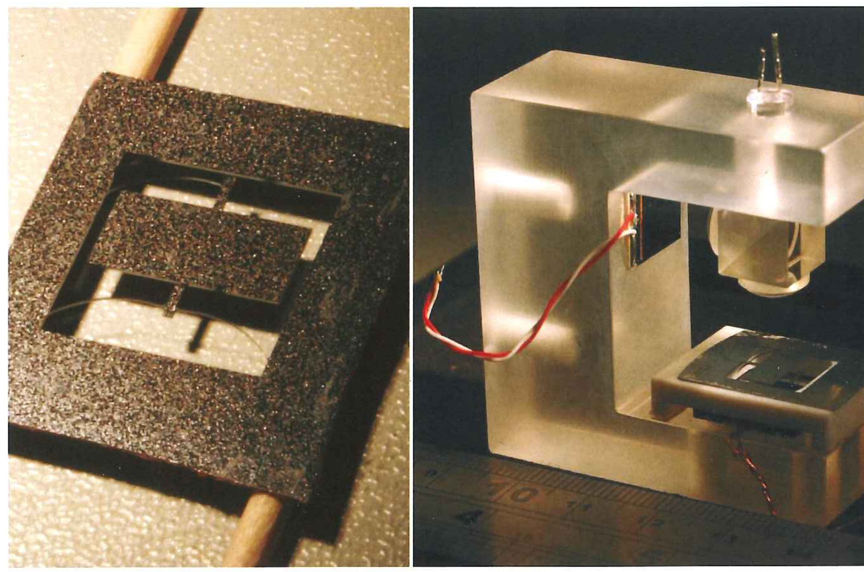
PRACTICAL MEMS GRAVIMETER DEVELOPED

GREAT BRITAIN — A prototype device that detects tiny fluctuations in gravity has been built. The team at the University of Glasgow said that such devices did already exist, but are bulky and expensive. This device, known as a microelectromechanical system (MEMS) gravimeter, has the potential to be very cheap and a 1-Watt field prototype around the size of a tennis ball is being developed.

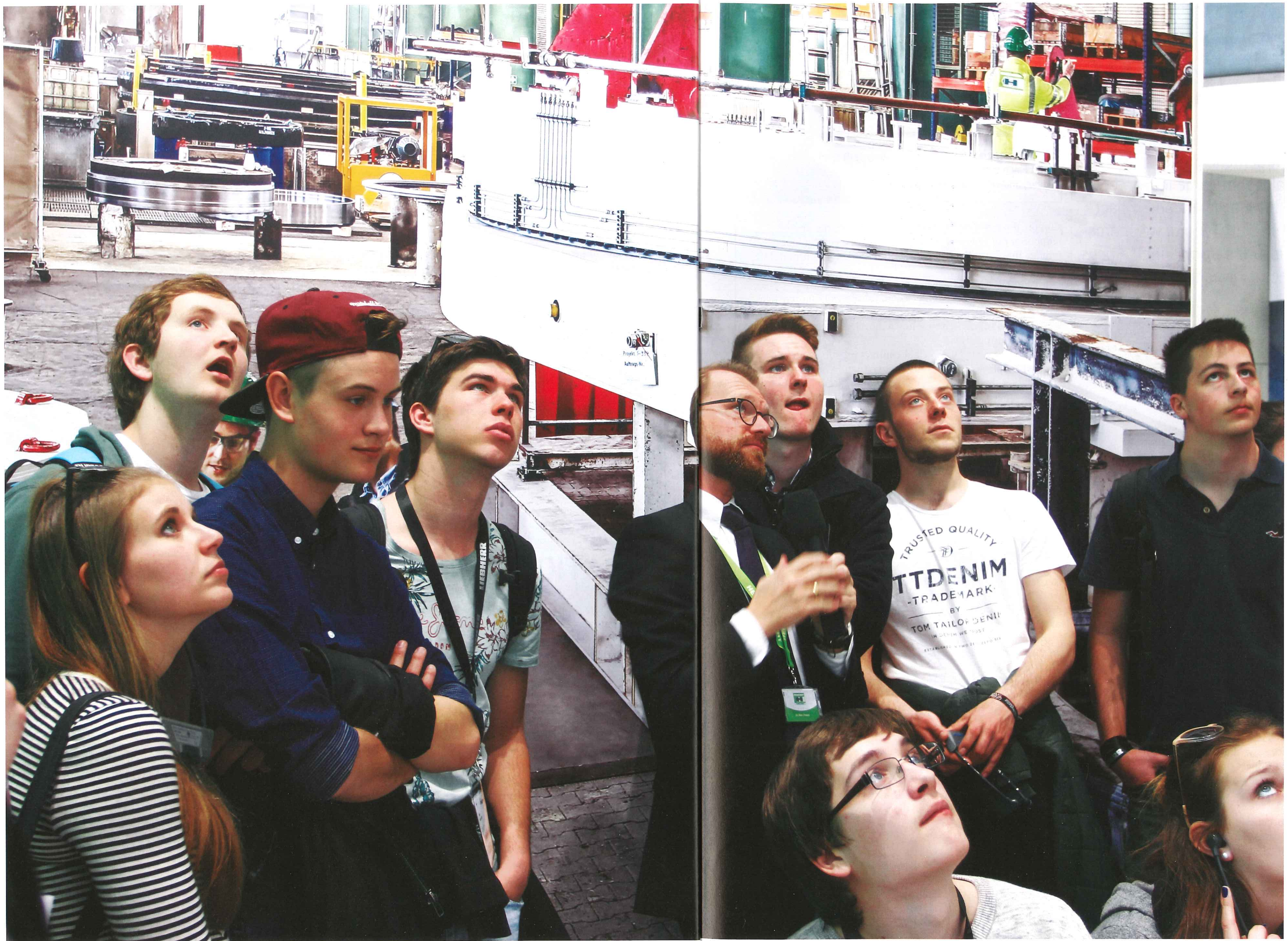
Applications in engineering could include down-borehole exploration; environmental monitoring where networks of sensor arrays could monitor subsurface water levels, or determine the location of landfill sites; tunnel detection; improved mapping of existing utility asset locations.

Existing gravimeters cost in excess of USD 100,000 and weigh more than 8kg. This device is similar to but a leap in the accuracy achieved by the type of accelerometer found in smart phones, which are relatively cheaply mass-produced. A smart phone is triggered by the acceleration due to the Earth, while the gravitational attraction from a nearby human could almost trigger this new device.

The full paper can be read in the scientific journal Nature: http://goo.gl/WnpPlA



A team at the University of Glasgow has developed the highly sensitive device



Left: *One of the Herrenknect booths at Bauma last month. The construction and mining equipment trade show, which is popular with universities and schools, affords an excellent opportunity to bring talent into the construction industry. In the pictured presentation the students are learning about the increasing tunnel diameters in Herrenknecht projects through the years*

UNSAFE WORKSITES TAKE NOTE

Construction insurance specialist *Focus* expects that new sentencing guidelines for England and Wales that came into force in February will have a significant impact on the industry's safety record, workforce, employers and insurers. **John Finch**, *Focus* commercial director, gives this assessment

John Finch
John Finch is the commercial director for Focus, and welcomes the legal changes

THE NEW GUIDELINES from the Sentencing Council are designed to reinforce efforts to improve health and safety standards across a wide spectrum of businesses, but construction will be more affected than most because it is so hazardous in nature.

Widely expected to maintain the trend towards tougher penalties for employers' health and safety failings, whether or not actual injuries result, the guidelines are intended to reflect the degree of employer culpability and the extent of the risk of serious harm.

Penalties are geared to have enough financial impact to impress upon management and shareholders the need to operate within the law. This implies 'the larger the company the bigger the fine' with a GBP 20M (USD 28.2M) fine possible for a serious offence by a major entity.

Where the most serious offences are shown to involve corporate manslaughter, both the financial penalty and the personal consequences are too great for anyone to ignore. A closely implicated director could face charges that carry a possible two-year jail term.

In an ideal world, such a severe regime shouldn't be necessary. You'd surely imagine that the prospect of seeing a worker with multiple injuries after a fall from height would be enough to encourage site safety.

Yet such incidents occur weekly in the industry and many cases are taken to court by the Health and Safety Executive (HSE). Almost invariably the HSE representative will explain how a fall, impact from a heavy load or vehicle, or other incident was wholly avoidable.

That being so, it must be right for workers, employers and insurers to support the new guidelines and try to achieve the desired reduction, not ignoring the many near misses and minor injuries that form the base of a notional triangle with fatalities at its apex.

Health and safety breaches can take many forms: inadequate training and supervision, unsafe working practices, absence of personal protective equipment and outright illegal work such as unlicensed asbestos removal. These are often down to poor planning.

The involvement of principal contractors, sub-contractors and self-employed workers in the construction industry makes site safety a shared aim, but clear responsibility for safety issues must be agreed in order to ensure that none of them gets overlooked.

This need for a joined-up approach to health and safety was behind the Construction (Design and Management) Regulations 2015 that now have effect. These highlight the importance of project planning, risk management and engagement with the workforce.

All these issues also have implications for insurers. Like construction industry employers and workers, insurers have a clear interest in achieving a reduced level of incidents. All claims contribute to the costs of employers' or public liability insurance that firms need.

So, it is not unreasonable for insurers to expect employers to exercise a proper level of care over the safety of their own workers and of others at or near a site. If an employer is prosecuted for health and safety failings, their insurability might be called into question.

In some construction site incidents, employee inexperience or incompetence may be a factor contributing to an incident. That does not absolve contractors or sub-contractors from blame; the HSE may still hold them responsible for not ensuring proper training.

The first step to ensure compliance, avoid site accidents and keep insurance premiums down is a risk assessment. Our online self-assessment tool can aid this process, whether or not an upgrade to a full risk management service is envisaged.

Any site can be vulnerable, as a swift look through cases prosecuted by the HSE in recent months shows. The sheer variety of incidents highlights how crucial a coordinated view of all site activity is to making sure no angle gets overlooked when assessing risks.

Late last year a specialist piling company was fined GBP 16,000 (USD 22,540) for operating a piling rig with an unguarded auger, though no injuries were involved. This shows that the HSE are now being more proactive in rooting out dangerous site practices before people get hurt.

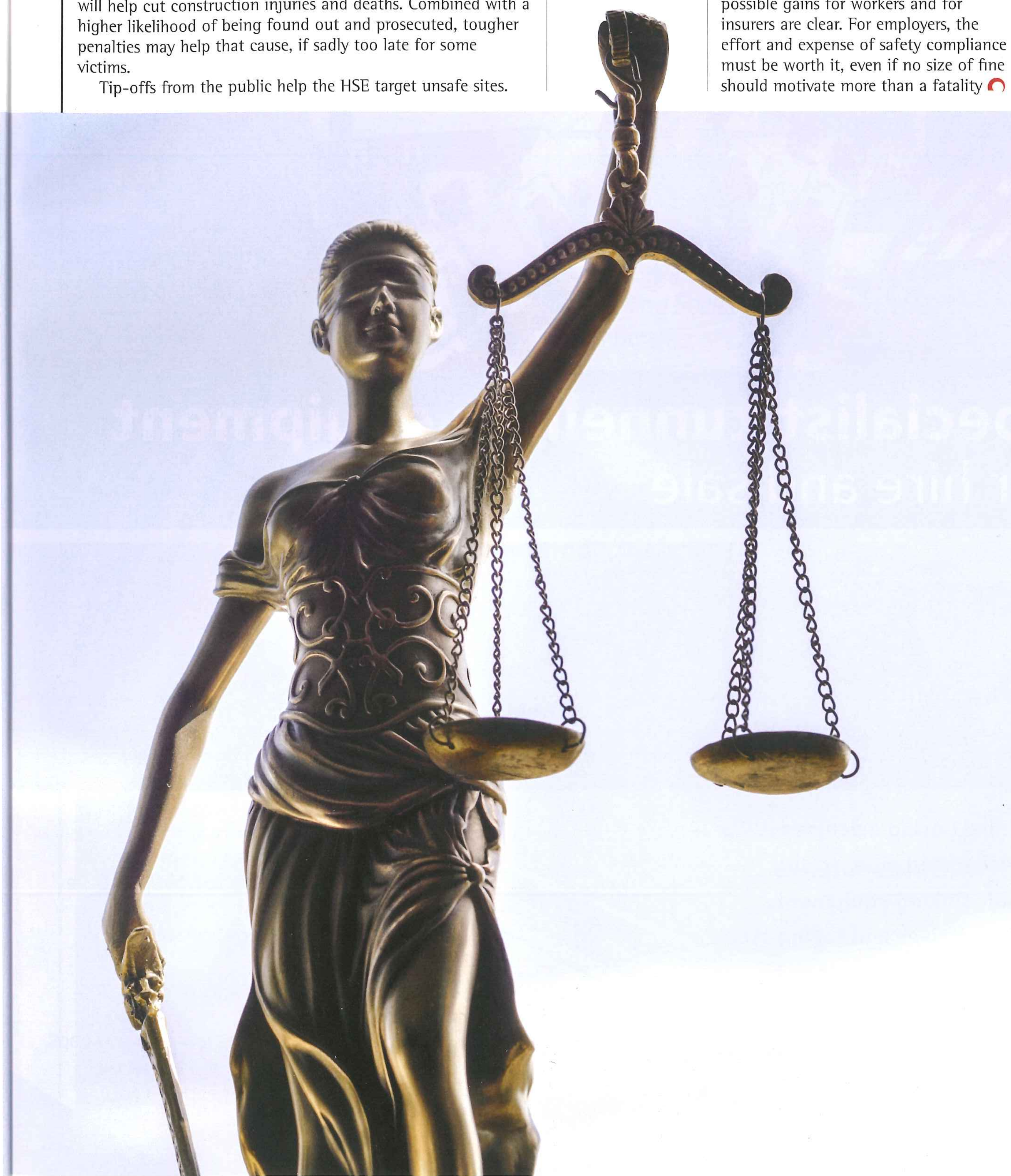
Soon after that case, a contractor faced penalties of GBP 174,000 (USD 245,150) over a worker being fatally injured by a falling fascia during shop-fitting work. Weeks later, three firms were fined a total of GBP 360,000 (USD 507,185) because a lorry driver was killed by an insecure concrete panel.

Though it is not possible to say what fines would have been imposed under the new sentencing guidelines, the likelihood is that they would have been substantially higher. In any event, I am sure the employers involved were deeply shocked by the accidents.

That leads us to the question of whether harsher sentences will help cut construction injuries and deaths. Combined with a higher likelihood of being found out and prosecuted, tougher penalties may help that cause, if sadly too late for some victims.

Tip-offs from the public help the HSE target unsafe sites. The police may also have a role. Just two months ago a builder was fined GBP 13,000 (USD 18,324) after officers saw site workers throwing rubble bags from a height; the HSE were called in and found other breaches.

I see the new sentencing guidelines as a move in the right direction. The possible gains for workers and for insurers are clear. For employers, the effort and expense of safety compliance must be worth it, even if no size of fine should motivate more than a fatality



THE TURKISH BULLET

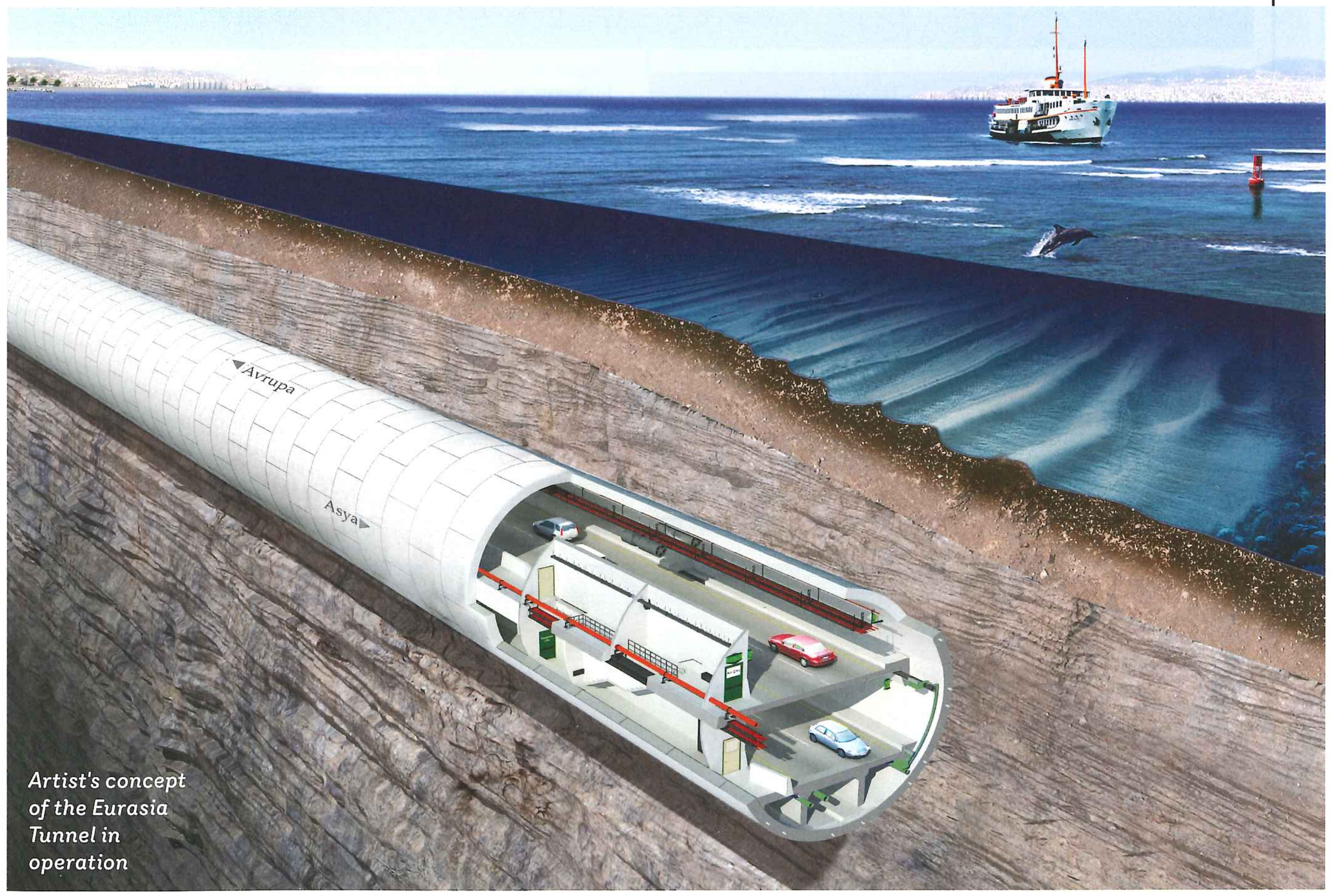
Alex Conacher
The *Tunnels and Tunnelling* editor has been with the magazine since 2010

Less than four years old, the *Turkish Tunnelling Society* represents a sizeable membership, serves a burgeoning industry, and has an active programme of events. **Alex Conacher** speaks to its chairman, **Nuh Bilgin** and fellow professor at the Istanbul Technical University, **Cemal Balci**

THE GROWTH of the Turkish tunnelling industry is "like a bullet from a gun" according to its tunnelling society chairman Nuh Bilgin, "you cannot stop it". In Istanbul alone, as Tunnels and Tunnelling goes to press, seven TBMs are in operation on two metro projects in Istanbul and five TBMs are working through utility projects. A further 14 TBMs are being procured for the Bostanci-Dudullu, Besiktas –Mecidiyeköy, Bakırköy Ido-Kirazlı and Ikitelli-Ataköy sections of the metro. Elsewhere, the Ovit and Zigana road tunnels are progressing well and a great number of hydropower and rail projects are underway.

"The Turkish tunnelling industry really is growing very fast, Turkey needs to be sharing and acquiring experience in every field of tunnelling: planning, management, engineering, rock mass characterisation and also at an academic level," says Bilgin.

The Turkish Tunnelling Society (TTS) was established in August 2012 in response to a growing demand from the



Artist's concept of the Eurasia Tunnel in operation

Table 1. Road tunnel summary

Tunnel Name	Explanation
Mount Ovit Tunnel (under construction)	14.7 km, twin highway tunnels between Ikizdere, Rize Province and Ispir, Erzurum Province in Northeastern Turkey, the longest tunnel in Turkey.
Mount Kop Tunnel (under construction)	6,500 m, it is a road tunnel under construction located on the province border of Bayburt and Erzurum as part of the route D.915.
Sabuncubeli Tunnel (under construction)	6,480 m, is a road tunnel located on the Mount Sipylus (Turkish: Spil Dagi) in Aegean Region as part of the Manisa-Izmir highway D.565.
Eurasia Tunnel (subsea-under construction)	5.4 km, is a double-deck road tunnel under construction in Istanbul, Turkey, crossing the Bosphorus strait undersea. The project's completion is expected by October 2016. It will connect Kazlicesme on the European and Goztepe on the Asian part of Istanbul on a 14.6 km route.
Cankurtaran Tunnel (under construction)	5,228 m, is a road tunnel under construction located in Artvin Province as part of the Hopa-Borçka Highway D.010 in northeastern Turkey.
Salmankas Tunnel (under construction)	4,150 m, situated on the Mount Salmankas of Pontic Mountains is a road tunnel located on the province border of Gumushane and Bayburt connecting the provincial roads 29-26 and 69-75.
Sariyer-Cayirbasi Tunnel (2012)	4,020 m, The tunnel is part of a project of the Istanbul Metropolitan Municipality to build seven tunnels for the "City of Seven Hills", which is the nickname of Istanbul, it is a twin-tube road tunnel under the northern suburbs of Istanbul.
Ordu Nefise Akcelik Tunnel (2007)	3,820 m, originally Hapan Tunnel is a highway tunnel constructed in Ordu Province, northern Turkey, The tunnel is named in honor of the Turkish female civil engineer and earth scientist Nefise Akcelik (1955-2003)
Samanli Tunnel (under construction)	3,417 m, is a motorway tunnel under construction located at Samanli Mountains in Marmara Region as part of the Gebze-Orhangazi-Izmir Motorway O-33.
Kagithane-Piyalepasa Tunnel (2009)	3,186 m, is a twin-tube road tunnel under the inner city of Istanbul, Turkey connecting the Kagithane district and Piyalepasa Boulevard in Beyoglu district.
Mount Bolu Tunnel (2007)	3,125-3,014 m, it is a highway tunnel constructed through the Bolu Mountain in Turkey between Kaynasli, Düzce and Yumrukaya, Bolu.

Source: TTS

***Above:* Eurasia Tunnel TBM emerges**

industry. It now boasts 800 individual and 47 corporate members. The group has since organised two expos, four short courses and two international symposiums. In November this year it is hosting the second 'TBM Digs'. The society also began celebrating an annual Tunnelling Day on 3 December last year.

It has a lot to celebrate. According to Bilgin, in three years the industry will be fulfilling some EUR 35bn (USD 40bn) worth of work. This will be across all sectors: metro tunnels, utility tunnels, road tunnels, rail tunnels, hydropower and mining. The TTS takes a close interest in mining in the country and 30 of its members are miners.

"We believe that mining and tunnelling have very common activities, like excavation, ventilation, tunnel support, muck removal, and safet," says Bilgin.

GROWING PAINS

The rapid expansion of the industry brings challenges. In two years around 30 TBMs will be working on tunnelling projects that have not yet broken ground. The TTS is nervous over the requirement for experienced crew, in particular TBM operators, TBM engineers and, especially, mechanical engineers.

To solve this problem, the TTS has ordered a TBM simulator to ramp up the training of skilled operators and engineers. The society will run courses and issue certificates in a few different disciplines.

Table 2. Road tunnel construction targets

Tunnels	Numbers		Length	
	>500 m	Total	>500 m	Total
In roads	46	160	54,300	102,390
In highways	15	25	38,380	45,350
Undergoing and project in progress	34	51	174,940	183,360
Target till 2023	95	238	287,860	330,056

Source: TTS

Table 3. Summary of major rail tunnels constructed and under construction

Tunnel Name	Explanation
Ayas Tunnel (under construction)	10,064 m is a railway tunnel under construction near Ayas town of Ankara Province in Central Anatolia, Turkey. It was initially projected to shorten the railway line connecting Ankara with Istanbul.
Deliktas Tunnel (2012)	5.4 km, Kangal-Deliktas Tunnel, is a railway tunnel near Deliktas village between Ulas and Kangal districts of Sivas Province in Central Anatolia, Turkey. The construction began on November 15, 1973. Following the installation of signalization facilities, and completing the test runs with freight trains, the tunnel was put into service in late 2012.
Marmaray, subsea (2013)	1.8 km , is a partially operational rail transportation project in the Turkish city of Istanbul. It comprises an undersea rail tunnel under the Bosphorus strait, and the modernization of existing suburban railway lines along the Sea of Marmara from Halkali on the European side to Gebze on the Asian side.

Source: TTS

TUNNELLING IN TURKEY

Scope

A key creator of demand – besides the now-familiar growth in population and trend towards urbanisation – is government policy. A trend for Build-Operate-Transfer makes large-scale projects feasible, but there has also been an upturn in investment at a local level.

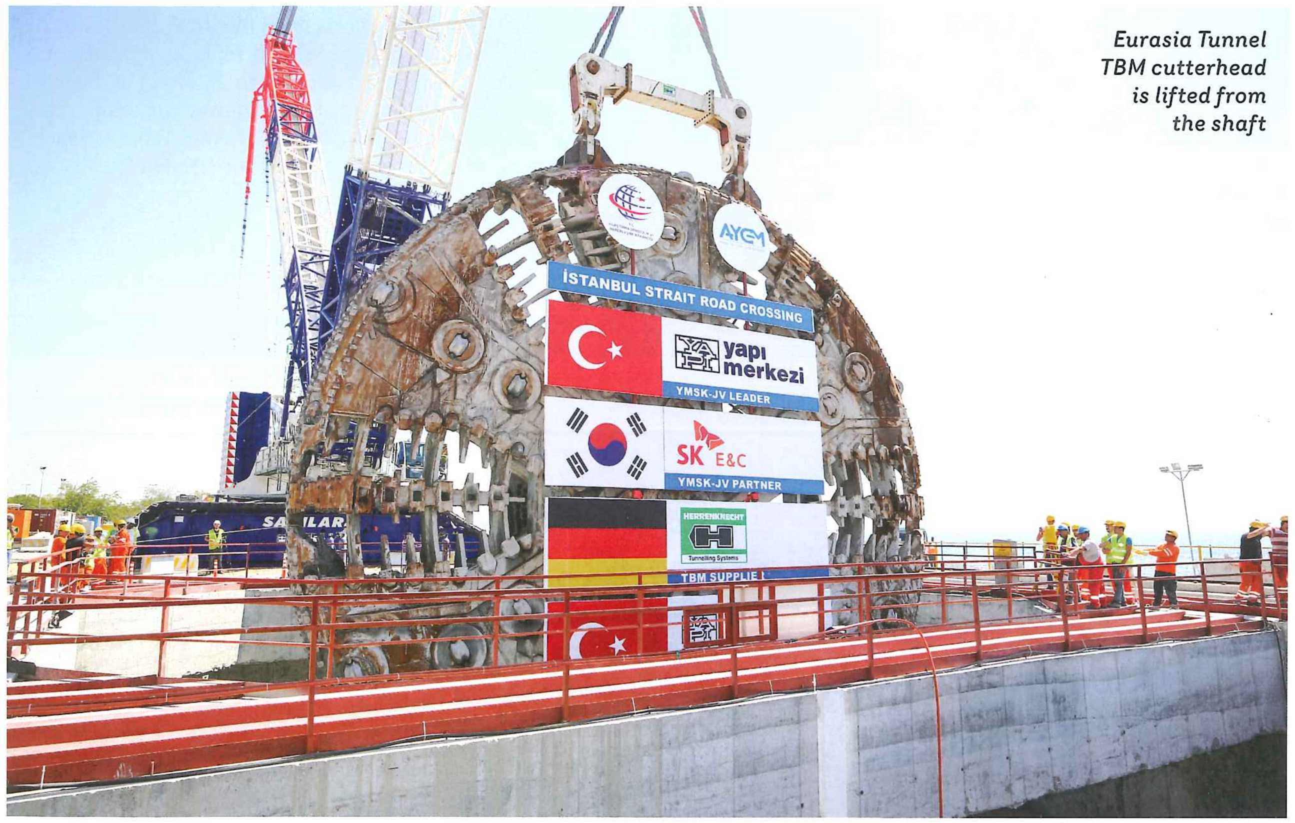
Istanbul is the jewel of Turkish tunnelling. With a more than

Major players

Gülermak, Dogus, Kolin, Kalyon, Içtas, Cengiz Insaat, Enka and Yapı Merkezi are the major national and international players in Turkish Tunnelling Industry according to the TTS.

Notable successes:

- The Bayburt Group (comprising Senbay and Aga Enerji). Aga Enerji recently won two metro tenders in Istanbul (the Bakırköy Ido-Kirazlı and Ikitelli-Ataköy projects). Bayburt Group is also constructing some NATM tunnels.
- The Senbay-Kolin-Kalyon consortium won the tender for Bostanci-Dudullu Metro Project.
- Gülermak has recently finished a metro project in Poland and a hydropower project in Kargi in a very complex geology.



Eurasia Tunnel TBM cutterhead is lifted from the shaft

A history of Turkish rail projects

Construction of the first railway line in Turkey began in 1856, by a British company that had obtained permission from the Ottoman Empire. Later, French and German companies also constructed lines. The motivation was not only economic; the region had a strategically important position as a trade route between Europe and Asia.

As with other countries, rapid expansion followed; by 1922 over 8,000km of lines had been constructed in the Ottoman Empire. In 2008, Turkey had 10,991km of railway lines. As of December 2012, the total railway line length reached 12,008km. Some 888km of this is high-speed. Turkish State Railways (TCDD) owns and operates all public railways in Turkey making it the 22nd largest railway system in the world. The total length of railway tunnels is around 100km. Table 3 gives a summary of some long railway tunnels.

The oldest underground urban rail line in Istanbul is the "Tunnel" (Turkish: Tünel), which entered service on January 17, 1875. It is an underground funicular with two stations, connecting the quarters of Pera (modern day Beyoglu) and Galata (modern day Karaköy) located at the northern shore of the Golden Horn and is about 573m-long. It is the world's second-oldest underground urban rail line – after some London Underground routes which were date to 1863 – and the first underground urban rail line in continental Europe. The first master plan for a full metro network in Istanbul, titled Avant Projet d'un Métropolitain à Constantinople was prepared by a French engineer L. Guerby, in 1912. The plan comprised a total of 24 stations between the Topkapi and Sisli districts and included a connection through the Golden Horn.

Construction works for the first modern mass transit railway system started in 1989. The line M1 was initially called "Hafif Metro" (which literally translates as "light metro"). The first section between Taksim and 4. Levent entered service, after some delays, on September 16, 2000. This line is 5.3 miles (8.5km) long and has six stations.

The length of metro lines, before the 2004 was 45km, between the years 2005-2013 it was 141km and it is expected that the total length of metro tunnels will be 400km between the years 2014 to 2019, final target after 2019 is 776km. It is expected that by the year 2017 around 20 EPBMs will be running in Istanbul.

Above: ***The Turkish industry is growing rapidly***

15 million, and rapidly rising, population, infrastructure is having to grow fast. Before 2004 there were only 45km of metro line. Between 2005 and 2013, some 141km has been constructed, with a further 400km to open by 2019.

According to the TTS more than 800 tunnels are planned for hydropower projects. Some 85km of road tunnels are to be built in the next few years, and for rail around 78km is expected.

A star project for the TTS is the Eurasia Tunnel, completed recently. "Martin Herrenknecht says that the Eurasia project, with its double deck tunnel driven under 11 bars of pressure beneath the Bosphorus Strait, is the most challenging project so far this century," says Bilgin. "The project was realised by Yapi Mertkezi, Korea's SK, and E&C. It won an ITA Award last year. The TTS is very proud of this achievement."

Other road tunnels are necessitated due to Turkey's mountainous terrain. As can be seen in Table 2, the national target for road tunnel construction up to 2023 is 330,056m. A general outlook of recent road and highway tunnels projects constructed and under construction is given in Table 1, which covers tunnels with a length of more than 1.5km

Technical requirements

Tunnelling in Turkey faces some interesting geological challenges. The local geology is particularly complex, with major faults in the countries north and east, which also results in minor faulting in these regions. Projects in these locally notorious areas have encountered squeezing ground making TBM tunnelling difficult, excessive water ingress, TBM face collapses (e.g. the Kargi hydropower project, the Dogancay energy tunnel, the Gerede water tunnel and the Nur Dagi rail tunnel).

Mixed ground conditions with ophiolites, graphitic schists and melanges with boulders are other fundamental difficulties have led to squeezing and blocking of the TBMs, or in some extreme cases have caused complete failure of the segmental lining and evacuation of the tunnel. Notably the Kosekoy high speed rail project needed to be evacuated and the Uluabat hydropower project experienced extreme squeezing problems.

"Dykes in the continental crust are generally found in swarms," adds Bilgin. "Two TBMs were abandoned in Gerede project due to these difficult conditions. The presence of dykes, sills and small intrusions cutting the Palaeozoic sedimentary rocks in the Istanbul region are known all to well to practicing tunnel engineers. These andesitic rocks, which are generally considered to be of Cretaceous age, make fractures in the country's rock and cause several problems during TBM excavation such as blocking the cutterhead and excessive disc cutter consumption.

"Typical examples of this are the Goztepe-Kadıkoy metro tunnels, and the Melen water tunnel. The Beykoz utility tunnel is one of the most difficult tunneling projects in Istanbul. The presence of clay minerals existing within the geologic formations is also one of the main reasons clogging the cutterhead of TBM, as was experienced on the Suruc water project."

The general directorate of state hydraulic works (DSI) is the primary state agency for Turkish water resources. It is responsible for planning, management, execution and operation of projects in this sector. Tables 4 and 5 give a summary of major irrigation and water supply tunnels respectively

Above: ***Seismic joint in the Eurasia Tunnel***

Table 4. Summary of some major water supply and irrigation tunnels

Tunnel Name	Explanation
Sanliurfa Irrigation Tunnels	26.4km, The tunnels run in the Sanliurfa Province of Turkey. The water supply is the water reservoir of ATATURK Dam on Firat River (Euphrates). There are two parallel tunnels, the length of each being 26,400m. The outer diameter of each tunnel is 9.5m and the inner diameter is 7.62m. The flow rate is 328m³/s. With these figures, the tunnels are the largest in the world in terms of length and flow rate.
Suruc Water Tunnel (2014)	17.185km, The purpose of the tunnel is to provide irrigation for the Suruc Valley from ATATURK Dam. The water tunnel was commissioned by the State Hydraulic Works (DSI) on 25 December 2008. The construction of tunnels was carried out with a double shield TBM of 7.83m. The construction was finished in 1913.
Bosporus Water Tunnel (2012)	5.51km. is an under sea waterway tunnel in Istanbul, Turkey, crossing the Bosphorus strait. It was constructed in 2012 to transfer water from the Melen Creek in Duzce Province to the European side of Istanbul. The tunnel was constructed.

Source: TTS

Table 5. Summary of some current and future tunneling projects to be executed by DSI

Project name	Tunnel name	Excavation Diameter (m)	Length (m)	Excavation method	General Information
Tunnels to be opened by General Directorate of State Hydraulic Works, Diyarbakir Silvan Project 1.section	Babakaya Tunnel	7.80	10,556	NATM and TBM	Ongoing
Diyarbakır Silvan Project 2. Section	☒letim Tunnel	7.80	20,420	TBM	Irrigation tunnel
Kahramanmaras Kilavuzlu 1.	Belpınar Tunnel	6.80	5,500	Single Shield + EPB TBM	Ongoing Irrigation tunnel
Ankara domestic water transfer 2. Melen Project	Gerede Tunnel	5.3-5.2	31,592	3 TBM	Ongoing
Konya Afsar (Hadimi)	Hadimi Tunnel	5.2	18,140	TBM	Waiting for TBM
Mersin Tarsus Pamukluk Project	Pamukluk Tunnel	-	4,809	NATM	Ongoing
Kayseri Koprubasi Ekrek	-	-	3,075	NATM	Ongoing Irrigation tunnel
Adiyaman Kocali Dam	Kocali Tunnel	-	5,376	NATM	To be tendered Irrigation tunnel
Adiyaman Kocali Dam	Kuyucak Tunnel	-	2,440	NATM	To be tendered Irrigation tunnel
Kahramanmaras Menzelet	Tunnel 2	-	5,450	TBC	To be tendered Irrigation tunnel
Malatya Yoncali Dam	Yoncali Tunnel	4.20	9,480	NATM	To be tendered Irrigation tunnel

Source: TTS

ARUNACHAL GENERATION

Indian electricity company *North Eastern Electric Power Corporation* (Neepco) outlines the challenges associated with construction in the Himalayas

Bernadette Ballantyne
Bernadette is a regular contributer to *Tunnels and Tunnelling*

Which methods do you use most frequently for boring tunnels and why?

All of the hydroelectric projects of Neepco are located in the Arunachal Himalayas, Shillong Massif, Naga Patkai Range and Mishmi Hills region of north eastern India. This region is tectonically active in nature and comprises large numbers of active shear and fault zones. Here, geotechnical parameters such as RMR, Q value etc. of rock type encountered during tunnel boring varies considerably for one tunnel length. Therefore, conventional drilling & blasting and NATM methods have been used.

In the Arunachal Himalayan region, the rocks of Siwalik Formation, were folded and uplifted to give rise to Sub Himalayan ranges and demarcated by the HFT (Himalayan Frontal Thrust) from the alluvial of Brahmaputra. Gondwana sediments of lesser Himalaya are separated by the Main Boundary Thrust (MBT) from the Neogene sequence of Sub Himalaya. MCT (Main Central Thrust) separate the lesser Himalaya from the central crystalline zone of Higher Himalaya.

The compressional tectonic stress regime in the Himalayas has resulted in intense deformation of the rock mass, making it highly folded, faulted, sheared, fractured and deeply weathered. This complex geological setting has caused considerable stability problems and is a great challenge for successful tunnelling. The complexity is represented mainly by four engineering geological characteristics,

Neepco tunnelling statistics

Tunnelling work undertaken: 19.39km
Tunnelling work currently underway: 17.55km
Tunnelling work planned: 2.62km

which have caused major stability problems during tunnelling. These are:

- Weak rock mass quality,
- High degree of weathering and fracturing,
- Rock stresses,
- Groundwater effect.

The location makes ground investigation studies difficult. How do you research the conditions before tunnelling?

The Arunachal Himalaya, Shillong Massif, Naga Patkai Range and Mishmi Hills region of north eastern India is a mountainous terrain (sometimes the overburden is over 1,000m) and full of vegetation which made the geotechnical investigation prior to tunneling very difficult. Due to tough terrain and heavy vegetation, the detail surface mapping throughout the tunnel length is nearly impossible. Therefore, the geotechnical data such as lithology, faults, folds, joint sets, dip and strike direction of the geological features, RMR, etc. are gathered through the surface geological mapping from the exposed areas throughout the tunnel length and by drill hole data. This geotechnical information is further used to extrapolate the probable geology throughout the tunnel length to prepare the probable L Section, X section of the tunnel and geological plan.

What is your experience of TBMs - do you use them and will you use them in the future?

All of the hydroelectric projects presently executed and to be executed by Neepco are in the Arunachal Himalayan, Shillong Massif, Naga Patkai Range and Mishmi Hills region of north eastern India. The terrain here is mountainous and full of vegetation. Most of the areas in this region are widely inaccessible for detail pre-construction geotechnical investigation along the tunnel alignment. In some cases the overburden is more than 1,000m and therefore pre-treatment of the tunnel is practically not possible. Heavy ingress of water through weak or shear zones make the tunnel boring more difficult. The existing roads in these hilly regions are very narrow and with lot of sharp bends. Therefore, at this stage economic viability for using of TBM is a matter of concern. However, in course of time improvement in road communication, using of state of art technology for geological investigation in such a difficult terrain and TBM equipped with a provisions for effective advance pre injection grouting, wet shotcreting, advance fore-poling, bolting and probe drilling etc., tunnel boring by TBM can be used in future projects.

CASE STUDY: KAMENG HYDROELECTRIC PROJECT, ARUNACHAL PRADESH

Various geotechnical problems, from cavity formation and blow out, to water ingress and faulted distressed rock, challenged Neepco during construction of the 14.5km head race tunnel for the 600MW Kameng Hydroelectric project. The 6.7m dia modified horseshoe shape tunnel was designed to carry 140 cumecs, and the construction called for four adits of varying lengths to accelerate progress.

The first major issue was an 8m long, 5m wide, 4m high cavity, angled at 45 degrees upwards away from the centre line, which opened 422.6m into the tunnel at face number 2. This section was a shear zone within banded quartzite. To arrest the cavity muck was dumped at the heading and steel canopy provided. Concrete backfilling was then undertaken with erection of two half arches on the left side. Further backfilling was undertaken behind the new arches before much below the canopy was removed, extending the half arch. However after much removal a small opening formed at the far right of the cavity through which heavy pressure mud flowed into the tunnel damaging the new supports. The loose muk was a mixture of angular to medium coarse quartz and kaolin clay. Water seepage was also observed.

By drilling 21 probe holes the team determined the extent of the loose muck at around 4-5m from the loose zone, which was over 7m from the face. Restoration required a host of measures and took around 7 months to complete. Initially grouted forepoling pipe rings were placed followed by box girder steel supports. The tunnel alignment itself was slightly lowered and steel lagging was used in the new support system for placing the concrete. As kaolin clay was present in the critical zone chemical grouting was required for stabilisation and prevention of water ingress rather than ordinary cement. Perforated forepoles of 100mm diameter, 12m in length were placed at 500m centres with microfine cement grouting undertaken through these. A secondary ring was placed between the first providing further stabilisation.

Blow outs too were an issue on the project with significant incidents at chainages 616m and 1,337m. In both cases the blow outs were combined with major water ingress flooding the tunnel. At chainage 616m the tunnel encountered a major fault zone along the axial plane of a major syncline fold. A large accumulation of groundwater in the core of the syncline fold was put under additional pressure due to the gradual rise of the tunnel cover, triggering a blow out. Consolidation grouting was undertaken as a preliminary measure, and drainage holes placed in the heading to channel away the water. Remediation included pipe forepoles with cement grouting and took 9 months to complete. The second blowout was completed in 5 months.

A number of key lessons were learned from this scheme including the need to allocate sufficient time and resource to determining the geotechnically critical areas during design stage and ensuring that remediation measures are included in the contract documents. The inhospitable terrain, poor infrastructure and limited time and budget meant that this was not done for the Kameng project which posed contractual problems during execution of remedial works

This case study was taken from the paper "Geotechnical problems encountered and remedial measures undertaken in excavation of head race tunnel of Kameng Hydroelectric Project, Arunachal Pradesh" by Ranendra Sarma of Neepco

HIMALAYAN SURGE

Contractor *High Himalaya Hydro Construction* (3HC) tells **Bernadette Ballantyne** that after years of delay Nepal is finally heading for a boom in hydropower projects

"NEPAL IS VERY BUSY FOR HYDROPOWER and more projects are coming," says Tara Nath Sapkota, managing director of contractor High Himalaya Hydro Construction Pvt. Ltd (3HC). "Our company is growing very fast and we are purchasing new equipment. Last year we spent 115 million Nepalese Rupees in equipment (> USD 1M) and still we will be purchasing more. As far as manpower is concerned we will be taking on more as well."

Among the purchases in 2015 was a Sandvik DD321-40 2 boom drill jumbo with telescopic boom, and the firm says it plans to buy another jumbo to meet the growing tunnelling demand. "One is not enough to serve the market and we want to grab the market opportunities. We will also buy more haggloaders and more batching plants as well," says Sapkota.

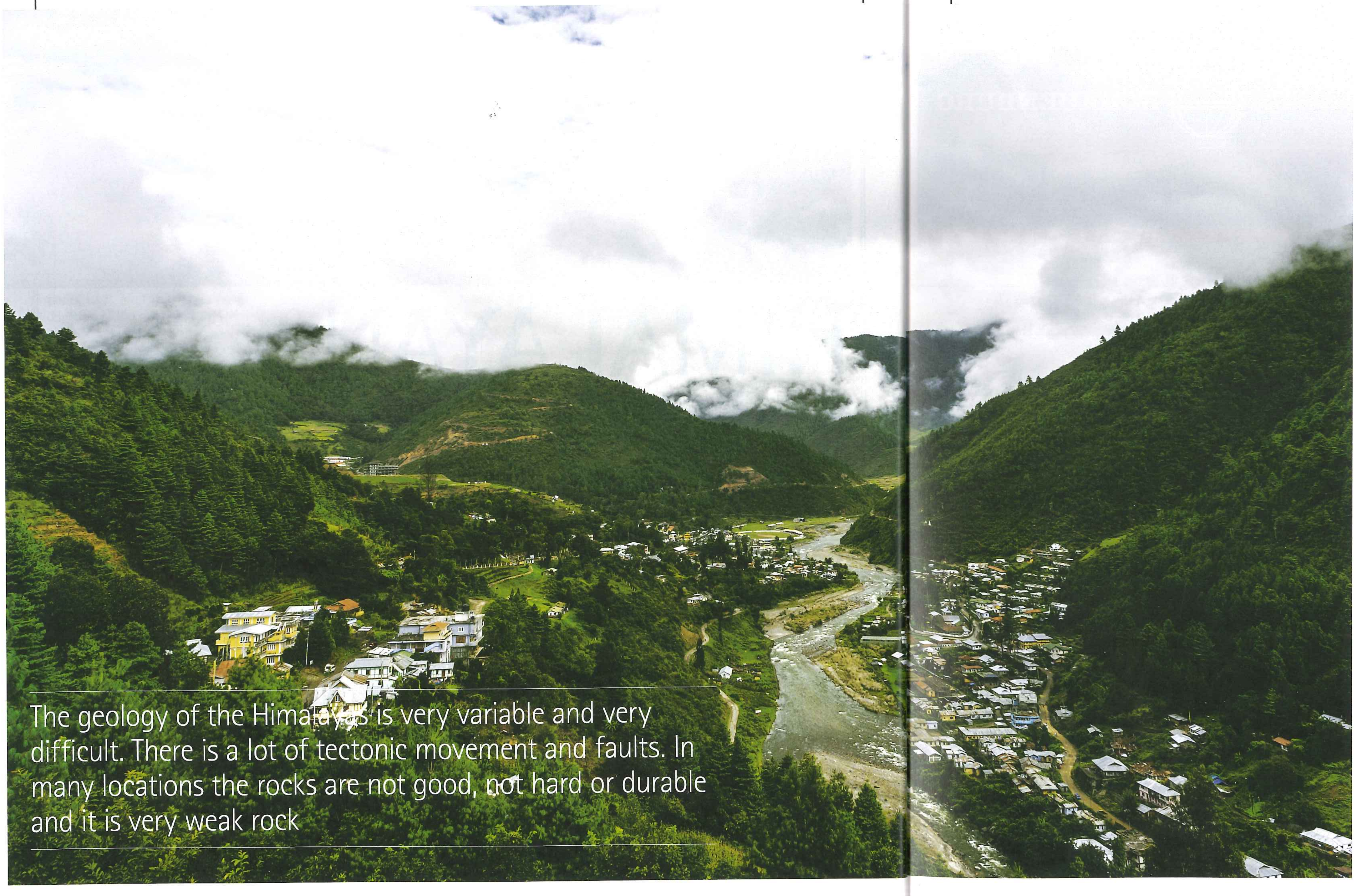
Despite the huge potential for hydropower in Nepal, estimated by the Nepal government-owned Hydroelectricity Investment & Development Company to be 83,000MW, installed capacity today is only 700MW. At the same time neighbouring states have developed vast quantities. "We have to use more clean energy," says Sapkota explaining that political instability had previously held back development but that the adoption of Nepal's new constitution in September 2015 means that the country can now move forward on its projects.

One such scheme is the Mistri Khola hydropower project in the Myagdi district, which will add 42MW of clean energy to Nepal's system. Civil works will be carried out by 3HC for client Robust Energy Pvt. Ltd under a contract worth 1.4 billion Nepalese Rupee (USD 132M). "The geology of the Himalayas is very variable and very difficult. There is a lot of tectonic movement and faults. In many locations the rocks are not good, not hard or durable and it is very weak rock but this project Mistri Khola where we are working the rock is relatively good," says Sapkota.

That is not to say that there will not be challenges. The 2.3km headrace tunnel in particular is set to be the most difficult aspect of the works. "The geology of the headrace tunnel is not good, we might get some moving ground, we might get some shear zones and some water inflow. This might take some time to stabilise the rock so it is going to be challenging. We plan to have some umbrella grouting to make the rock more stable," says Sapkota.

Basic rock conditions throughout the project are gneiss and quartzite with schist, and as well as the head race tunnel 3HC will build the intake structure, weir, diversion tunnel, underground settling basin, access tunnel, surge shaft, valve chamber, anchor blocks, saddle support, power house, switch yard and tailrace tunnel. At peak there will be 500 men on the scheme. For tunnelling drill and blast will be used for the larger tunnels such as the headrace tunnel which, which is an inverted D shape with a cross sectional area of 14.3m². For smaller sections such as the 44m inlet tunnel or the 60m tailrace, pneumatic jack hammers will be used.

Temporary support for the tunnel will consist of shotcrete and support bolting to hold the face for between 4 and 8 hours. Final lining for good to fair rock includes 100mm to 250mm thick steel fibre/mesh reinforced shotcrete with pattern rock bolting. For poor rock concrete lining with reinforcement will be used. The lining has been designed by Hydro-Consult Engineering.



Sapkota estimates that the project will take 30 months to complete. "Thirty months is enough time but if there is difficulties in the tunnel and it takes more time to stabilise then it might take more time but otherwise 30 months is enough," he says.

Beyond the Mistri Khola scheme 3HC is working on a host of other smaller hydroelectric projects in the region. The 15MW Hewa Khola A project is in the completion stage; in Eastern Nepal another project of 6MW is at peak construction, "It is going full swing so it is very good," says Sapkota. The 7MW Mai Khola is now complete and the Medi Khola 3MW project is also under construction. "Soon we will be starting another 15MW project in the western part of Nepal, Rudi Khola."

These projects may be small compared to some of the larger projects underway in the Himalayas but they represent progress for Nepal. With potential for an enormous 83,000MW, and power a much needed development, the opportunities for contractors are vast, but so are the challenges. As Sapkota points out many of his employees have decades of experience of working in the unpredictable rock of the region.

"There is competition and some new firms entering the market, but experience counts. Our engineers have 35 to 40 years of experience," he says.

This experience will no doubt be tested if Nepal follows through with delivering its hydroelectric projects in the volatile and unpredictable rock of the Himalayas in the years ahead

Mistri Khola Hydroelectric Project

Basic features
Dam crest level: 1562.85 masl
Turbine centre level: 1260.10 masl
Gross Head: 302.75m
Design discharge to turbines: 17.1m³/s
Installed capacity: 42MW

River Diversion
Cofferdam type: Gabion box with impervious core
Width: 10m
Height: 7m
Length: 28m at top
Crest level: 1554.35 masl
Diversion tunnel shape: interted D
Diameter: 2.8m
Cross-sectional area: 7m²
Length: 126m

Inlet Tunnels (2no.)
Shape: inverted D
Length: 44m
Diameter: 4m
Cross-sectional area: 14.28m²

Headrace tunnel
Shape: Inverted D, shotcrete lined
Finish diameter: 4m with 20cm thick invert concrete
Cross sectional area: 14.28m2
Length: 2285m

Surge Shaft
Diameter: 5m
Height: 56m
Inclination: 74.5 degrees
Horizontal connection tunnel: 10m long, 4m diameter.

Tailrace tunnel
Type: Freeflow box culvert
Length: 61m
Size: 3.5m x 2.3m

Other key features include dam, undersluices, intake structure, settling basins, penstock, powerhouse, turbines, generators, transformer, and transmission line.

SEATTLE START UP

Repair work for giant TBM "Bertha" finished earlier this year. **Patrick Reynolds** reports on the two-year-long process

Patrick Reynolds
Patrick is a technical journalist and a long-standing freelancer with *Tunnels & Tunnelling*

BY EARLY 2016, the giant TBM "Bertha" in Seattle had resumed boring on the central waterfront section of the USD 3.1bn Alaskan Way Viaduct Replacement project, following repairs to the 57.5ft (17.53m) diameter machine.

To prepare, Bertha has undergone an unusual, if not unique, experience for any TBM, not least the world's largest: she is being buried to commence boring.

A 120ft- (36.5m-) deep shaft was constructed to reach the TBM, allowing its vital front section to be brought to the surface for repairs. Following the work, the TBM was reassembled, the cutterhead was turned and other no-load tests were completed. The last task is load testing to relaunch the TBM for its drive below the viaduct.

To that end, the shaft has been backfilled with sand and controlled density fill, allowing Bertha to bore once more.

Slowly. For a few hundred feet only, at first.

Even though the TBM, first launched two-and-a-half years ago, still has most of its relatively short, 1.7mile- (2.7km-) long tunnel drive yet to finish.

While only just repaired after a two-year stop, Bertha is to be checked once again. The TBM is stopped in a "safe haven," which is a pre-planned, jet-grouted zone designed to allow last checks and adjustments before Bertha bores below the elevated highway.

Fortunately, perhaps, the troubles that brought Bertha to a halt in late 2013 occurred shortly before the machine moved under the seismically-weakened viaduct. Performing a TBM recovery under the viaduct could have been much more difficult.

Even outside that zone, the investigation and repairs undertaken presented 'a significant challenge,' says Chris Dixon, project manager with Seattle Tunnel Partners (STP), the design-build JV contractor comprising Dragados and Tutor Perini.

Coincidentally, Bertha is preparing to resume boring around the time when, as per the contractor's original schedule target, tunnelling was to have been finished. The giant single tunnel with its double-deck road structure would have been carrying traffic. Then, the eyesore that is the viaduct would be demolished, reclaiming a view of the Pacific Northwest coast lost since the 1950s.

That vision is still coming, of course; currently, it is expected to emerge around the beginning of 2017, according to the latest construction schedule issued in November 2015 by STP. The entire Alaskan Way Viaduct Replacement project is to be finished by April 2018.

But while the focus shifts from repairing the Hitachi Zosen TBM, and with both the tunneling industry, the coastal city and the state hoping for untroubled progress ahead, the beginnings of legal fights and insurance liability debates over blame have started.

The complex arguments over fault, liability and financial consequences are contested between the project owner – Washington State's Department of Transportation (WSDOT), the JV contractor and TBM manufacturer, and various insurers. Lawsuits have been submitted over recent months.

Over the two-year standstill, STP and Hitachi Zosen received no payments from the client related to the TBM recovery costs. STP has only received payments for progress achieved on the many other continuing works, such as around the tunnel portals and concreting of the decks within the tunnel bore so far.

But, finally, the project looks set to change gear as Bertha prepares to build the rest of the 52ft (15.85m) i.d. tunnel below the waterfront during 2016.

Above: ***The view from the repair shaft***
PHOTO: MAMMOET

RISE OF THE TBM OPTION

The aim of the redevelopment project at the waterfront is to improve Seattle's overall transport and economy. Debate over how to do so ran for years, and a host of studies were performed on realizing a fresh infrastructure vision and removing the seismically vulnerable viaduct on state highway SR99.

Back in 2008, the leading alternatives did not include the TBM option, especially to construct a large single tunnel, although all possibilities had had reviews.

The long-term vision was to create an 'incredible' waterfront for the city – ideally one with minimal traffic on the surface. Putting as much as possible underground was elected to be the way forward, and the deep bore option became a late stage winner in early 2009.

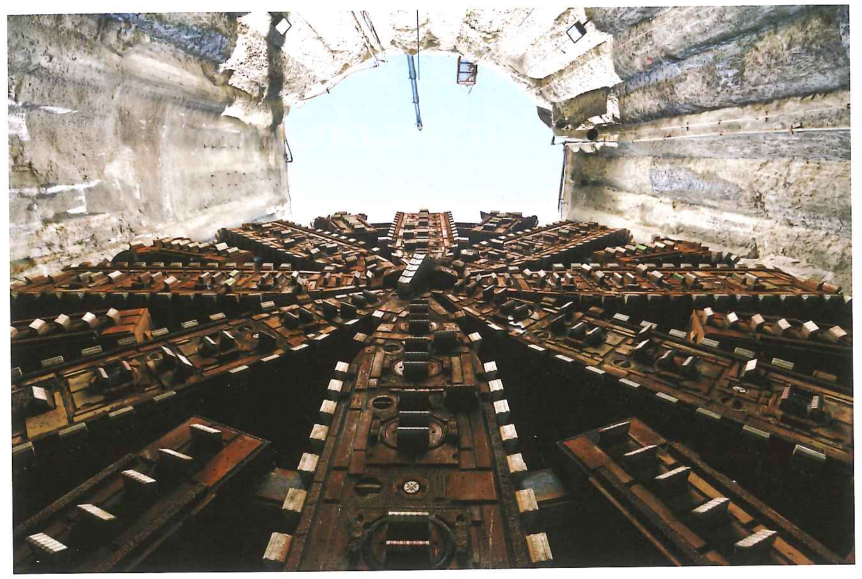
The replacement program, including the tunnel, would be co-funded with the city, county, port authority and a federal contribution. A prequalification call went out in 2009, and WSDOT signed a USD 1.35bn contract with STP in early 2011.

STP's subcontractors include local firms Frank Coluccio Construction and Mowat Construction, and also HNTB Corp and Intecsa-Inarsa. The JV contractor proposed building the tunnel with an earth pressure balance TBM, and aimed to have the tunnel open to traffic before the end of 2015. The owner's contract performance deadline was late 2016 for substantial completion of the SR99 tunnel, with performance bonus and penalties either side of the target.

STP hired Japan's Hitachi Zosen to manufacture and supply the EPB TBM.

Washington state set up an Expert Review Panel (ERP) to look over key assumptions in cost estimates, identify risk during the construction phase, comment on development of funding sources, and consider the project's schedule.

In their second report, in February 2013, the panel said the contractor's plan to open the tunnel before 2016 was 'very aggressive.' It added that the risk register did not lend itself to quantitative description, such as for TBM function and first use of technology. The greatest potential risks of increased costs and delay were around the TBM, the panel added.



Above: The TBM in the access shaft
PHOTO: WSDOT

Below: A crew member makes changes to cutterhead teeth
PHOTO: WSDOT

Under the design-build contract, the panel said, it is set out how the contractor can design and complete the work, and that STP is responsible for the means and methods of delivering works on the project, including repairs to the TBM.

WSDOT's project management team is charged with oversight only, verifying performance and quality. It also reviews, but does not verify, the contractor's schedule though does check that technical requirements are met. As the panel notes, though, overall management of project risk rests with the state. Therefore, the panel urged WSDOT to work proactively throughout the design and construction processes, pursuing effective risk management.

LAUNCH... THEN STOP

In late 2011, construction staging commenced in Seattle and manufacturing efforts got underway for the TBM in Japan. The TBM was assembled in dry dock in late 2012, before it was shipped across the Pacific Ocean to Seattle.

Many activities in both Seattle and Japan were on the critical path of the project schedule, the ERP cautioned in its February 2013 report. It issued an opinion that the target launch date of June 2013 was not expected to be achieved.

However, the TBM was assembled in Seattle over April-July at the south end of the tunnel alignment, and then formally launched at the end of July 2013.

Bertha's 2-mile- (3.2km-) long drive was expected to take about 14 months. In its following report of February 2014, the ERP noted that early operation of the TBM had delivered better than expected performance.

Previously, the panel had noted its opinion of the planned "learning curve" for the TBM tunnelling as being 'very lengthy,' but considered this as reasonable and prudent, especially given the size and unique features of the machine.

The tunnelling plan was to set off slowly. The TBM would stop early to perform planned maintenance and checks at key "safe havens" along the first 1,500ft (457m) of the northward drive before then diving below the elevated highway.

By early December, and despite the late start in mid-year, the shield had advanced more than 1,000ft (305m), reaching where it was expected to be against the schedule, the ERP reported. The panel also said the shield had advanced 'more quickly' than expected by the project team, and pulled back time against the schedule.

But then trouble struck. The machine overheated and progress slowed as 'unanticipated and increasing resistance

Above: Deck casting formwork in bored tunnel
PHOTO: WSDOT

Below: The gantry crane
PHOTO: WSDOT

was experienced,' WSDOT reported. The TBM was stopped on December 6, 2013.

At that point, as per the contract between STP and Hitachi Zosen, STP was about to take ownership of Bertha from the TBM manufacturer. Hand-off was planned to follow after the first, proving and settling, stage of tunnelling, constructing the tunnel up to Ring No. 200, as WSDOT had noted in a statement on December 5, and Dixon confirms.

INVESTIGATION AND RECOVERY PLAN

With Bertha stopped under cover of 60ft (18.2m), the contractor lowered the high water table around the TBM. Drilling wells to a depth of approximately 120ft (36.5m), water pressure was reduced to enable the TBM crew to safely start inspecting the machine's excavation chamber in early January 2014. Probe holes were also bored ahead to check for potential obstructions.

The investigation of the top 15ft (4.6m) of the chamber revealed a piece of 8in (200mm) diameter pipe – a section of steel well casing – in a cutterhead opening, WSDOT reported at the time.

In late January, a programme of hyperbaric interventions allowed inspections into more of the excavation chamber. Many of the cutterhead openings were found to be clogged, which was then viewed as the more likely cause on the mining difficulty and not major obstructions – none of which were found inside or in front of the TBM, WSDOT said in February 2014.

Then, as a trial, STP restarted the TBM to build a ring. More high temperatures were recorded, like before the December stoppage. Investigating further, STP found damage to the main bearing seal.

Laura Newborn, spokeswoman for WSDOT, has expanded on the initial information, explaining to *Tunnels & Tunnelling North America* that the well-casing was found inside the material blocking a cutterhead opening.

"The cutterhead was clogged," she says. "The piece of metal was not blocking the opening."

She adds that the metal detected in front of the cutterhead turned out to be the nose of the cutterhead. "There was no metal found in front of the machine," she adds.

WSDOT said at the time that the steel pipe found in the cutterhead was a well casing, installed in 2002 and used by geologists to study groundwater flows following the 2001 Nisqually earthquake. The owner added that location of the pipe was included in reference materials in the contract.

However, according to JV contractor member Tutor Perini's third quarter-2015 results, presented in its 10-Q filing to the Securities and Exchange Commission, STP claims the steel pipe to be a "differing site condition that WSDOT failed to properly disclose." Tutor Perini added that the Disputes Review Board had said the pipe was a differing site condition, but noted that WSDOT has not accepted the finding.

WSDOT's spokeswoman told *Tunnels & Tunnelling North America* the "root cause of the damage to the TBM is still under investigation."

REACH AND REPAIR

Significant repairs would be needed at the TBM. The ERP said the stoppage to TBM tunnelling would throw out the project schedule by some months. It called on the client and contractor to stay away from debates over blame and financial liability, and keep their focus on investigating and resolving the technical problems.

In its February 2014 report, the panel advised that the contractor be given appropriate time to develop a recovery plan. "Returning the TBM to operation should be everyone's primary objective," it added.

During the halt in work, the contractor undertook wider inspections and also maintenance work, including replacing damaged cutter tools. But the discovery of damage to the bearing seal system also called for replacement of the main bearing. With such major works required, it was decided that the TBM could not be repaired underground. The shield had to be accessed from the surface and opened up to retrieve the cutterhead and cutter drive unit. STP developed a recovery and improvement plan, which it believed would allow the repaired TBM to resume tunneling in March 2015.

STP's plan was to sink a large diameter access shaft a little ahead of the halted TBM. The 80ft- (24.3m-) wide shaft was built through much of 2014 and readied to receive the TBM.

The dormant machine was restarted in February 2015. It broke into the shaft and came to a rest on a concrete cradle, cast on the base of the shaft. Hitachi Zosen hired a heavy lift contractor to extract the front sections of the TBM, and this was done in late March using a large crane gantry straddling the shaft. Mammoet designed a modular lift tower capable of sliding over the 120ft-deep shaft and repair area.

Soon after, in its April 2015 report, the ERP said that while reasons for the TBM problems were not yet clear, and also were subject to ongoing legal and commercial debates, the contractor had been constructively using the stoppage period.

It said that STP planned "to apply some lessons learned" from the tunnelling work done up until then. The resulting work, it added, could possibly include:

- Increasing the stiffness of the TBM;
- Changing the configuration of the cutterhead;
- Potentially changing the type of screw conveyor; and,
- Modifying the allowable range of operational parameters during mining.

Works then carried out under the Recovery Plan involved, principally:

- Replacing the bearing seal with one that is more robust and easier to access from within the shield; and,
- Installing the spare main bearing that was manufactured under the contract.

STP's Dixon, speaking in October 2015, said Hitachi Zosen manufactured a new bearing block, a new outer seal ring to create "a new seal system that is much more accessible in the event we need to access it for maintenance or repair."

The center pipe was also found to be damaged and was replaced, he added. Also, some new pinions were attached to the drive motors, none of which were themselves replaced.

A number of other enhancements were made to the machine, such as:

- Welding on steel stiffening plates;
- Adding new monitoring systems; and,
- Upgrading the soil-conditioning system to help prevent clogging.

In addition, the soil processing capability of the TBM was further improved under the enhancements programme by:

- Widening the opening at the center of the cutterhead
- Installing bit- and wear-resistant steel on the cutterhead; and,
- Extending the agitator arms in the mixing chamber.

The ERP, through its discussion with project parties, said in its April 2015 report that the recovery plan for the TBM "appears to be viable," adding it was reasonably confident the machine could be repaired.

The panel added that STP and WSDOT had shared information – "without direction from WSDOT" – on how to improve the TBM's function. "It appears that many of WSDOT's comments have been considered in the redesign and repair plan," ERP said.

WSDOT had formed its own Restart Team to monitor the contractor's work and risk and mitigation efforts.

"Fully disassembling and assessing the machine was always the key to determining how long the repairs would take," said Dixon, in mid-2015.

REVISE AND RE-SCHEDULE

The ERP commented the stoppage was "unusually long" due to the scale of investigation and repairs needed, and the area was a congested urban environment with geotechnical challenges.

Working around the core recovery challenge, the contractor examined and re-programmed a number of other tasks for the tunnel, such as manufacturing all of the precast segments needed for the entire tunnel and storing them, ready for use.

Other re-programmed construction activities, helping to offset some of the effects of the TBM stoppage, have included, says Dixon:

- Completing the underground structure of the south operations building;
- Constructing the interior cast in-place concrete roadway structure within the completed portion of the bored tunnel;
- Advancing north and south cut-and-cover sections enough for their handover to other works packages; and,
- Redesigning M&E systems, installing and commissioning them faster in sections instead of keeping with the original plan of doing everything in one go after excavation is completed.

By the time of ERP's report in April 2015, the panel had learned the contractor then expected a later restart of the TBM – in August.

In mid-July, installation of the new main bearing commenced. But the schedule was pushed back further with TBM restart then pencilled for late November.

Hitachi Zosen completed the above ground repair works in mid-August, allowing the heavy sections to be placed back down the shaft for reassembly at the open front end of the TBM. Finally, in late November, the cutterhead was rotated and system checks performed in a "no load" test. With those successes, the access shaft finally could be backfilled.

WSDOT announced on 7 January that the SR 99 TBM had returned to tunnelling in Seattle soil after breaking through the access pit wall, noting the TBM is digging well below the area's "notorious fill soil."

The top of the machine is approximately 80ft (24.3m) below the surface in a mixture of glacially compacted material. TBM will mine to a planned underground maintenance stop where crews will perform final maintenance before the machine tunnels beneath the Alaskan Way Viaduct. WSDOT will fully close SR 99 through downtown Seattle for approximately two weeks while the machine passes beneath the viaduct

POWERING PERU

With a burgeoning market for hydropower development, tunnelling work is seeing an uptick in South America's third largest country. **Nicole Robinson** looks at two recent projects

Nicole Robinson
Editor of *Tunnels and Tunnelling North America*
Nicole is based in Minneapolis, Minnesota

THE WORLD BANK released a report in 2010 to help the Peruvian government in assessing the potential role of hydropower in the energy sector and the measures that could be taken to encourage its continued development as appropriate.

Hydropower has been the major source of electricity in Peru, traditionally supplying more than 80 per cent of requirements, and serving as a source of independent generation for major mines and industries.

However, the report explains, in the early 1990s efforts turned to natural gas and the government began providing incentives for its use in power generation. "This resulted in a virtual moratorium on hydropower development as a result of the very low price of natural gas (below economic cost)."

Over the next decade, with the development of export markets for gas and increased attention to the impacts of climate change, the Government returned its attention to hydropower. The Peruvian government completed its National Energy Plan 2014-2025, which calls for electricity to comprise 60 per cent renewable sources by 2025, with 54 per cent coming from hydropower.

The International Hydropower Association called Peru a regional leader in small hydropower projects. In its 2015 Hydropower Status report it estimates Peru has hydropower potential of at least 70GW, "of which only 3.8GW have been tapped so far." In 2014 Peru added 199MW, ranking it among the top 20 countries installing capacity at number 17, (Canada comes in at number three and the US at number 16).

The market potential for hydro construction in Peru has captivated the likes of Odebrecht, whose subsidiary Empresa de Generación Huallaga (EGH) is developing the 462MW Chaglla power plant, which will be country's third biggest hydropower project upon opening, scheduled for this year. Norwegian company Statkraft opened its ninth hydropower plant in Peru, the Cheves Hydropower Project, this autumn.

"The opening of Cheves consolidates Statkraft's position among the largest power producers in Peru," says Statkraft's executive vice president of International Hydropower, Asbjørn Grundt. "It also underlines our ambition to further strengthen our position as a leading international provider of pure energy. Our efforts in South-America play a very important role in this strategy,"

CHAGLLA'S BYPASS

Located between the districts of

Chaglla and Chinchao, some 420m from Lima, the Chaglla Hydroelectric Power Plant has 406MW of installed capacity. The plant is the result of an investment made by Odebrecht Energia of USD 1.bn, with support from the Brazilian Development Bank, and the Inter-American Development Bank among others.

Water from a 199m-high dam with a 273m-long crown will be diverted through a 14.7km intake tunnel to the main powerhouse, which will be equipped with two Alstom power transformers with a nominal output of 225MW. The project will also feature a small power house, including a power transformer with an output of 6MW.

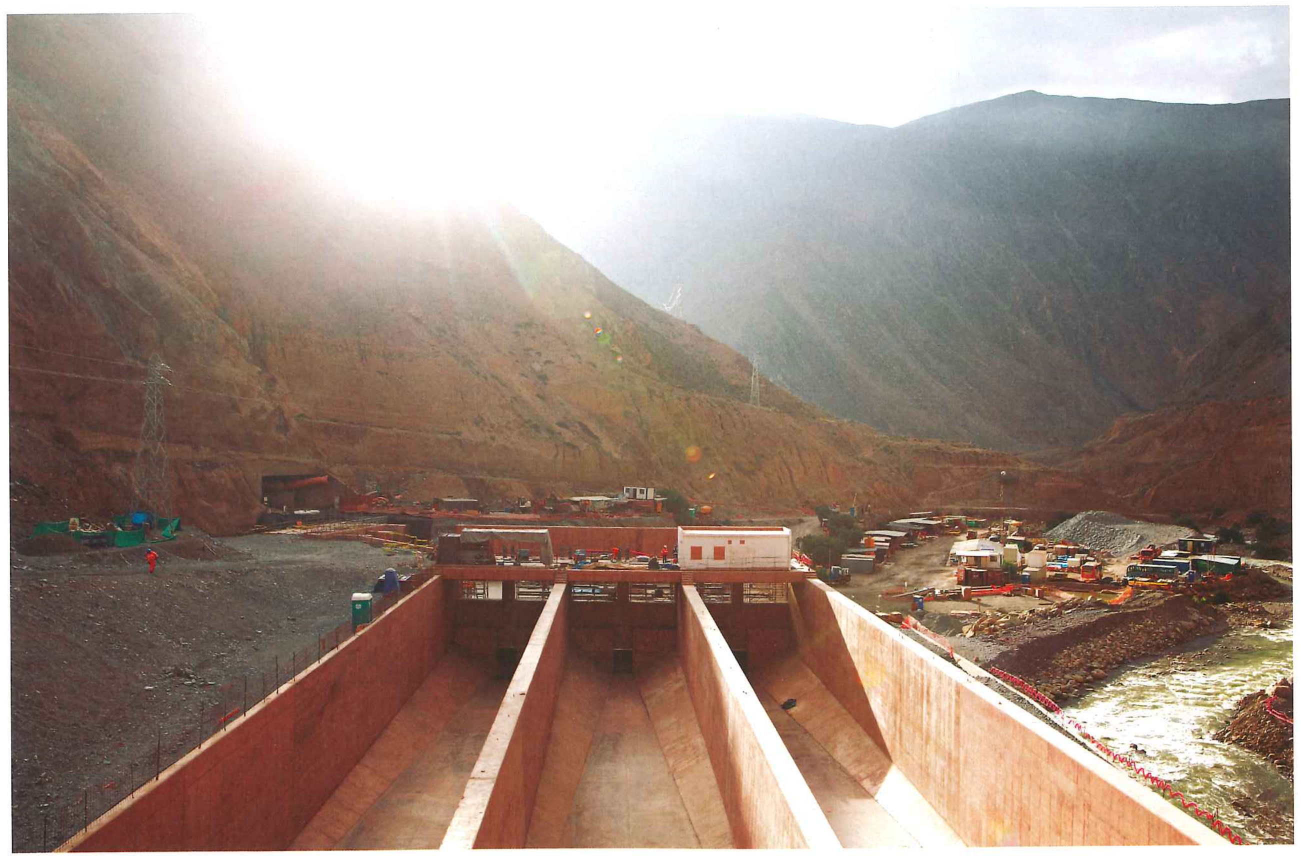
"Chaglla will be one of the largest hydroelectrical power plants in Peru and it will represent almost 8 per cent of the current consumption of energy of this country," says Erlon Arfelli, manager of Odebrecht Energia in Peru.

Construction started in May 2011 and Sandvik supplied six DT820-SC tunnelling jumbos for the excavation at Chaglla. Underground construction includes a spillway composed of three tunnels for a total length of 2,838m, 14.5m x 12.6m-high. The 14.7.km-long intake tunnel is horseshoe-shaped with a 7.6m diameter.

One of the most important works in the project is bypassing the Huallaga River, which contractors performed through a trunk tunnel of 12.5m diameter, 1,125m long. Odebrecht says the work concluded nine months prior to the scheduled date. The bypass tunnel is significant step for the project, allowing the dam to be constructed in the former riverbed.

Sandvik says the type of rock encountered made rapid progress difficult. Drill and blast excavation has been carried out mainly in grade 3-5 rock hardness, with grades 4-5 predominating. Crews were working two shifts per day and while typical advance rates depended on the rock encountered, they could be as high as 6-8m/day, with 3-4m/day the average. Rock support varied according to the geology with steel arches and mesh on class 4 and 5 rocks, while rock bolts and mesh were used on class 2 and 3 rocks.

Above: The Chagalla plant is expected to begin operating in 2016
PHOTO: ODEBRECHT



Below: The Cheves project is located on Peru's Huaura river
PHOTO: STATKRAFT

Odebrecht says EGH began filling the reservoir on September 1, 2015, and expects the process to last between 45 and 60 days. The project's lenders appointed Mott MacDonald in 2013 as independent engineer to monitor construction.

TUNNELS FOR CHEVES

Statkraft developed the Cheves Hydropower Project through its subsidiary Empresa de Generacion Electric Cheves S.A., which started commercial operations in late August 2015. Located 130km north of Lima, on the Huaura River, the power station consists of two aggregates with a total installed capacity of 172MW.

As reported previously in this magazine, underground works dominated the infrastructure of the Cheves project, having a total of approximately 18km of tunnels (see "Crafting Cheves," p34, *Tunnels and Tunnelling International* May 2012).

Among the tunnels there is a 2,580m-long, horseshoe-shaped cross section transfer conduit; and a 9,693m-long headrace tunnel, which has an upper section at a grade of two per cent and a lower section at 14 per cent grade. These sections are 5.5m wide and the upper and lower sections have heights of 4.5m and 6m respectively. Downstream, the flow is discharged into the 3,312m long tailrace tunnel.

The project's designer is Norwegian consultant Norconsult. The main contractor and manufacturer is Constructora Cheves, a JV led by Hochtief (65 per cent) with Salfa (25 per cent) and Ingeniero Civiles y Contratistas Generales (ICCG) (10 per cent) to perform the civil works.

Sandvik also supplied machines for this hydropower project, with at least seven DT 720 twin boom jumbos, and a DC 301 rubber-tyred bench drill. In June 2015, Ontario-based ASI Marine conducted a remotely operated vehicle (ROV) underwater inspection of one of the tunnels on the Cheves project, saying the work broke the company's record for the deepest flooded tunnel inspection at 570m water depth.

Above and Below: The Cheves power plant is the first greenfield project developed and constructed by Statkraft alone in South America.
PHOTOS: STATKRAFT

The tunnel inspected is approximately 9.8km in length, with a 35m² area horseshoe profile. The purpose of the inspection was to collect data inside the newly-constructed tunnel for general assessment of rock stress incidences.

The Mohican ROV collected full coverage data at the headworks and downstream to the powerhouse. ASI says, "this data was required for the client to undertake an engineering structural assessment of the tunnel and detect significant anomalies; such as deformations, major cracks, rubble, partial collapses, and rock accumulations."

The project met its structural assessment deadline in summer 2015, and the plant officially opened on September 15, 2015

FIRST TRAINS THROUGH DELFT

The construction of a four-track railway tunnel in Delft in the Netherlands has reached an important milestone. From March 2015, trains have been running on two tracks through the tunnel and station. The 2.3km-long tunnel runs through the historical city center and replaces a fly-over, which caused major nuisance due to noise and vibrations. This article addresses a brief history and description of the project, some main design risks (safety, vibrations, pressure waves, building damage control), the geological and geohydrological conditions and the construction methods

Steven Delfgaauw
Steven worked as project manager for the consulting joint venture at Delft

Hans Mortier
Hans worked as design manager for the contractor, then as a design adviser

THE RAILWAY LINE through the city of Delft dates back to 1847. It ran along the city's western border. Since then, the city has grown substantially to the west, making the railway line a great barrier through the centre.

Because of increasing rail traffic, a two-track rail fly-over was built in the 1960's. With its construction, an historic canal, once bordering the city, disappeared. Since the 1960's rail traffic has further increased. Some 350 trains pass through Delft every day, and in the rush hour this reaches one train every 3 minutes. This has created significant nuisance from noise and vibrations. Legal noise standards were exceeded for more than 700 buildings. The capacity of the two-track line is almost fully occupied, and the future growth of rail traffic demands expansion to four tracks.

PLAN DEVELOPMENT

After various feasibility and environmental impact studies by Railinfrasolutions and Benthem Crouwel Architects the decision was made to build a 2.3km long four-track tunnel next to the rail viaduct. This tunnel enables the development of 800 houses and 40.000m2 for offices. Upon completion, the tunnel structure will be sufficient for four tracks. In the first stage only two rail tracks are to be built. In the future, the expansion to four tracks will occur without further disturbance to the city. A new underground station has been situated next to the old station building, and contains a parking facility for 7,000 bicycles. Several underground car parks further add to the quality of the new developments. Part of this project is a two-story parking for 450 cars, located

underneath the re-constructed city canal. The total cost of the plan is approximately EUR 1bn (USD 1.13bn).

The project is divided in several contracts. The largest contract contains the tunnel structure, the tunnel installations, the underground station, an underground car park and the reconstruction of the public spaces. This project was tendered as a design and construct contract. In order to give the contractors the possibility to optimise, all specifications, apart from aesthetic specifications and the development plan, were functionally described. The client, ProRail (Netherlands Railway authority) awarded this contract to Combination Cromme Lijn, a JV of CFE, Mobilis/TBI and Dura Vermeer. These works will be completed in 2017. Full four-track operation requires expansion of adjacent tracks and is expected in 2023.

Above: ***Historical drawing of the Rose Windmill***

Below: ***Numerical model of the tunnel***

UNDERGROUND STATION AND CITY HALL

The new underground station is catered for the transport of 39.000 passengers each day. It comprises two platforms, located at 8 m below surface and 340m long. A lot of effort is made to create a pleasant, secure environment for the passengers. Optimal transparency is created by avoiding columns at the platforms, making the roof span 2x20m. With its 9m height, the underground station is very spacious. Natural daylight accentuates the central staircases. A special artificial light design was made to further improve the traveler's orientation. From the platforms, stairs lead to an intermediate level, the mezzanine. From here, passengers can either continue to the bicycle parking at the same level or go further up, to the station hall. The hall has no columns, spans over 40 m and is integrated with the new city council building. The six-story building is founded on the tunnel walls.

SAFETY CONCEPT

The tunnel consists of four separated tubes, one for each rail track. In an emergency passengers flee to an adjacent `safe` tube. This tube is reached through emergency exit doors that are present every 75m. Longitudinally placed ventilators create an air overpressure in the adjacent tubes, preventing smoke from entering through the rescue doors. The rail traffic is stopped automatically. Passengers flee through the safe tunnel to the portal or to the station, which is regarded as a safe haven.

Since the station has no separating walls, a different concept in chosen to create a safe and smoke-free area. In case of a fire incident in the station, a smoke and heat discharge system, positioned at the top of the station walls, will create a smoke free situation for at least five minutes, which allows passengers to flee to one of the five regular or emergency exits. Glass smoke screens (downstands) protect the staircases from smoke entry. Several simulations with a three-dimensional Computational Fluid Dynamics (CFD) model are performed to check the proper functioning of smoke and heat discharge system.

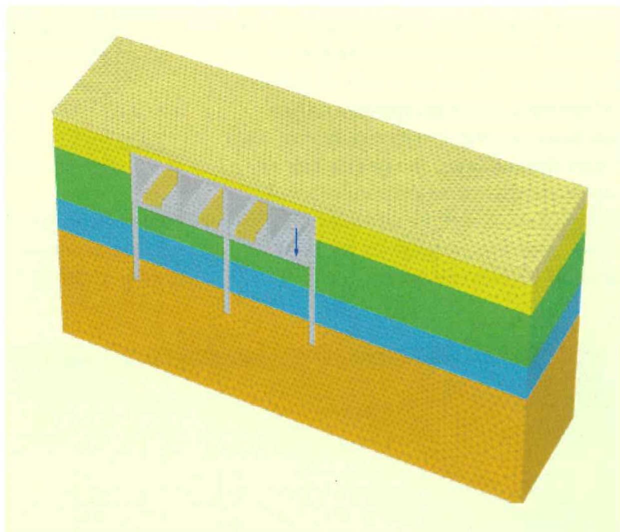
PRESSURE WAVES AND DRAUGHT

About 10 per cent of the trains will not stop at the station, but pass the tunnel and platforms with a speed of 140km/h. The resulting pressure waves are a possible nuisance to train passengers. Also, draughts at the platforms and the stairs to the station hall should be limited. Both aspects were studied through numerical modeling and scale tests. From these studies, it followed that several measures are necessary to create an acceptable wind climate. These include air release points in the tunnel, wind guiding structures at the platforms and airtight revolving doors in the station hall. Now the train services have started, the measures prove to be effective for limiting pressure waves and wind speeds.

However, station doors are not able to withstand pressures in extreme situations. Currently measures are taken to strengthen these doors.

TRAIN INDUCED VIBRATIONS AND LOW FREQUENCY NOISE

As the tunnel ameliorates the environment with respect to airborne noise significantly, vibrations and low frequency (ground borne) noise are



known to potentially cause a larger environmental impact. Extensive numerical and analytical analyses have therefore been performed to assess the noise and vibration impact of the new tunnel. The different components of a noise and vibration analyses, namely the source, the transmission paths, and the different receiver characteristics have been identified by several measurement campaigns and numerical studies.

The vibration source of the trains was back calculated from measurements at a nearby tunnel with a comparable structure and geological conditions. The transmission paths from tunnel floor to adjacent building (receivers) have been calculated by numerical models and compared with the results of several impact tests. A prediction of vibration and low frequency noise levels has been made and several types of mitigation measure have been studied. Based on the results of the different analyses, a ballast mat has been installed in the tunnel. This was expected to fulfill the required reduction of both vibrations and low frequency noise.

The different measurements and validation tests showed that the prediction of vibration and low frequency noise levels included different uncertainties. This resulted in a statistical approach of the prediction results for residences on both sides of the tunnel separately, using a lognormal distribution. In this way expected values as well as variances have been identified. After completion of the tunnel both vibration and low frequency noise measurements have been carried out in several residences. Preliminary results show good agreement with the predicted levels.

GEOLOGICAL AND GEOHYDROLOGICAL CONDITIONS

The geological layers encountered in the Delft region are typical for the river delta in the western part of the Netherlands. The top layer is a rather thin layer of sand and recent debris. Under this top layer, the geological profile consists of an accumulation of almost 20m of soft soil of Holocene origin underlain by medium to dense sands of Pleistocene origin. The thickness of the Pleistocene sand layer is generally more than 15 to 20m (thus to a depth of approximately 35 to 40m), however at a few spots along the project, the underlying overconsolidated clay layer (Kedichem strata) is already found at a depth of 30 to 35m.

Three different water tables were detected within these soil strata. The phreatic water level is at about -0.4m NAP (NAP is the national reference water level in Amsterdam). In the deeper Holocene layers a hydraulic head of approximately -3.75m NAP was measured, in the Pleistocene sands this varies from -6 to -9m NAP.

This particular geohydrological situation is for the greater part caused by a factory at the northern end of the tunnel, which extracts large amounts of brackish groundwater from the Pleistocene sands. The extraction results in very low water tables in the Pleistocene sands thus forming an advantage during construction as it reduces the risk of uplift of the bottom of the excavation. As it is uncertain whether this situation will remain during the 100-year tunnel lifetime, the final structure is designed for both circumstances, with and without the present ground water extraction. Simulations with a regional geohydrological model predict that, without extraction, the head in the Pleistocene aquifer will rise to the level of approximately -2m NAP. As the very heterogeneous Holocene formation is a sequence of peat, sandy clay and clayey sand layers, a great number of piezometers are installed to measure the water pressures.

CONSTRUCTION METHODS

For most tunnel sections, diaphragm walls form the retaining walls of the building pits. As the tunnel is often situated at a mere 3m from the surrounding historical buildings, this method was selected since it causes minimum noise and vibration disturbance. Moreover, as these diaphragm walls have a higher bending stiffness, the deformations due to excavation of the building pits are strongly reduced compared to traditional sheet pile retaining walls. Naturally, the diaphragm walls also serve as walls of the final structure, otherwise they would not be economically attractive.

The tunnel is constructed in two stages. As soon as the eastern tube could be carry train traffic, the second stage, starting with the removal of the old railway fly-over, was executed. Once the railway viaduct was removed, the western tube and an underground parking are realized. Due to the scarcity of the public space where roads, tramways and pedestrian roads should continuously be assured, a top-down building method was chosen. In this way, the roof could be used for storage of construction material and equipment.

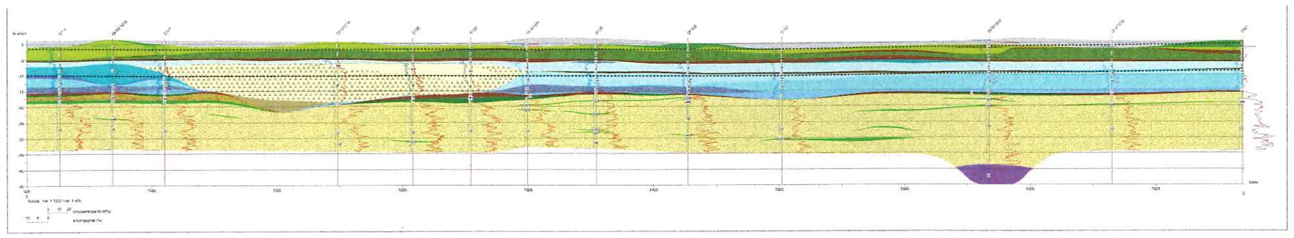
The building sequences throughout the whole process strongly depend of the robustness of the nearby historical structures. The optimum width of the diaphragm walls is 7.3m. In such panel widths, two reinforcement cages with a maximum width of 3.1m each (necessitating transport by lorry in an urban environment) can be installed, resulting in a better ratio of reinforced width to total width of 85 per cent compared to the 81 per cent for 3.8m panels.

By doing this, the amount of panel joints, and therefore the risk of future leakage is reduced by half. However, during the stage when the excavation of the diaphragm wall is supported by bentonite mud, wide panels produce larger ground deformations. For particularly close passes to buildings, a maximum panel width of 3.8m was chosen.

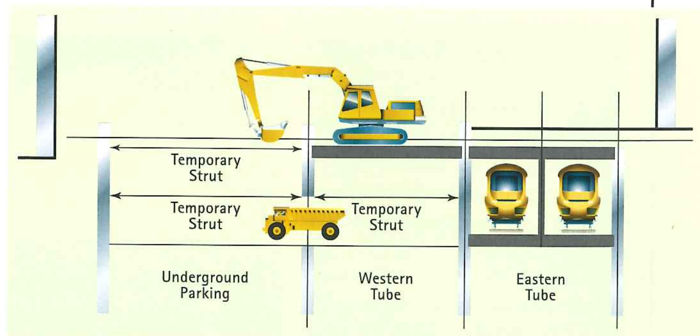
At critical sections, the first excavation down to bottom level of the (future) tunnel roof could not be done without the installation of supplementary struts above the tunnel roof. Once the roof concrete is poured and hardened, excavation under the roof could take place to an intermediate level where struts, formed by steel tubes, were installed. Finally, excavation to the final level and the subsequent pouring of the tunnel floor were realised. During all excavation works, the water table inside the building pit was lowered to 0.5m below excavation level in order to reduce deformations of the retaining wall and nearby structures. Once the eastern tube was ready for trains, a similar building sequence could take place to realise the western tube and the underground parking.

The underground parking is executed simultaneously with the western tube. Therefore, the diaphragm wall between the western tube and parking space was replaced by an alternation of previously installed barrettes and afterwards poured in situ walls. These in situ walls only reach from floor to roof level, thus reducing the amount of concrete works. Moreover, as the underground parking was to be built in a bottom-up sequence (due to the greater width between the diaphragm walls, which would cause thick roof and intermediate floors), the excavation of the western tube could be done through the left open spaces between the yet installed barrettes.

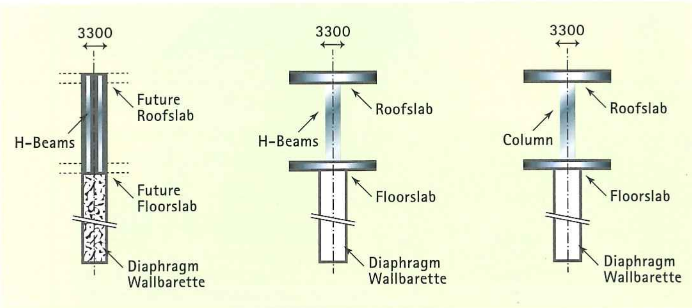
Leakage problems with diaphragm walls are mostly related to discontinuities in the concrete works, often related to a



Below: ***Geological section along the tunnel alignment***



Below: ***The second stage of construction, after the eastern tube could take train traffic***



Above: Diaphragm wall barrettes

too dense reinforcement grid, especially in the coupling area between the diaphragm wall and connected horizontal slabs. Therefore, during execution of the eastern tube, a redesign of the western tube and parking lot was performed introducing hinged connections between slabs and diaphragm walls instead of the previously implemented rigid connections. This resulted in much better rheological circumstances for the bentonite concrete exchange process of the diaphragm wall execution. After a thorough check whether this change would not affect the deformations of the adjacent buildings, this redesign was successfully implemented.

In the underground station area, concrete columns are foreseen at the middle of the cross section. Due to the large vertical forces, resulting from the office building on top of the station, foundations by means of diaphragm wall barrettes (points bearing in Pleistocene sand layers) are designed. As the demolition of the barrettes between floor and roof level of the station is very time and money consuming, the barrettes are filled with gravel over the height between these two horizontal slabs. To ensure the stability of the roof during excavation, steel H-beams are installed in the reinforcement cages of the barrettes. Once the total excavation was done, final concrete columns could be poured around the H-beams.

SETTLEMENT RISK ASSESSMENT AND BUILDING DAMAGE CONTROL

At the northern part on the project area, the distance between the tunnel walls and adjacent buildings varies from 3 to 10m. The allowable deformations of the contiguities are small. The buildings are divided into four different quality classes (indicated by their colour) on the basis of the actual condition and the related allowable additional deformation. The criteria are set as per the graph in fig. 6, according to the Limiting Tensile Stress Method (Boscardin), where the angular distortion and the horizontal strain have to be under or to the left of the boundary line of the respective building class.

These parameters are determined by FEM-calculations. The model includes the tunnel and surrounding soil. The building is only modelled through its weight. No interaction between building and soil is taken into account: the assumption is that the building will completely follow the soil deformations. This is a conservative assumption.

The 2D-FEM calculation includes all stages of construction, excluding the construction of the D-wall. For this, a separate 3D analysis is performed. Calculations were carried out both for average and lower boundary values of soil and structural parameters. When using lower boundary values, more measures like an extra strut level above the tunnel roof and the introduction of pre-stress forces in the struts were required to fulfil the requirements. Therefore, the tunnel construction was prepared for these measures. The validation of these measures happened on basis of observation and analyses of the monitoring data during all construction stages. The angular distortion and horizontal strain were translated to front wall movements. These movements were the key day to day monitoring parameters. Robotic total stations continuously measured prisms, attached to the facades, in all phases.

For each stage of construction, limits were set. The maximum displacements depend on the classification and the exact location of the building in the settlement trough. Typically, limits are set to about 6-18 mm both vertically and horizontally. Apart from building measurements, also water pressures and soil movements were measured. Water pressures were measured in all three aquifers, horizontal soil movements were measured through inclinometers behind the D-walls. It can be concluded that, for the buildings adjacent to the top-down diaphragm wall tunnel, the measured vertical deformations mounted up to 60 per cent of the predicted values while the horizontal deformations were very often up to 100 per cent of the predicted values. However, for the buildings close to tunnel sections built inside temporary cofferdams comprising sheet pile walls two cases of significant excess of predicted values were encountered.

In one case a moderate settlement of 30mm led to some unforeseen damage and the observational method was successfully implemented as best way out strategy, while in the other case a significant deformation of 80mm was absorbed without any damage due to the rigid behavior of the building. Each execution stage was evaluated on beforehand on basis of a LTSM level III model (FEM including masonry and soil).

THE ROSE WINDMILL

A major challenge was the crossing of the windmill "the Rose". This monument dates from 1679 and is right in the middle of the tunnel trace and therefore a huge obstacle for tunnel construction. It is a highly sensitive building. Due to several reconstructions over the centuries and the poor soil conditions the building has tilted fivedegrees.

The presence of attached living quarters further adds to the complexity. Because of the monumental status, it was demanded to leave the entire structure intact. Below the mill and attached living quarters a reinforced concrete foundation slab was cast and after hardening of this slab the subjacent existing foundation was separated from the structure above, which – in the mean time – was taken over by a previously installed temporary pile foundation. Then, the monument was lifted over a height of 1m to make space for the construction of the tunnel underneath. Upon completion of the tunnel, the entire structure of the windmill and its attachments lowered back upon the tunnel roof while assuring a perfect load exchange without the slightest deformation of the foundation slab

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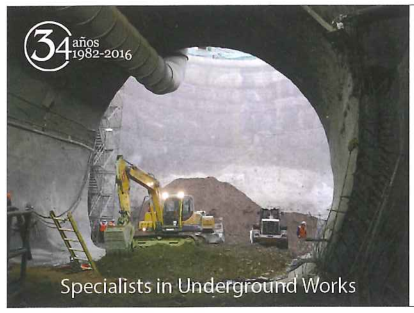

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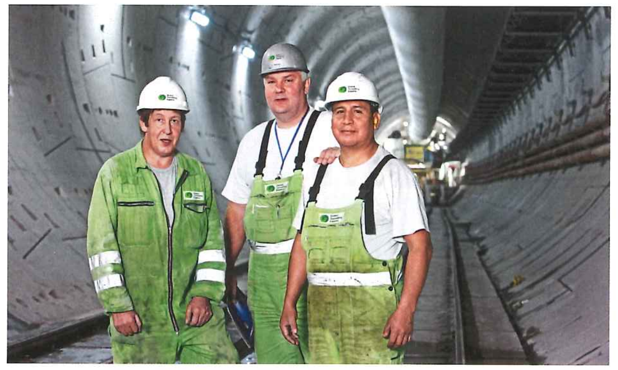

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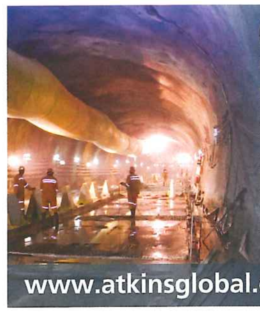
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What's on

2016

Seventh International Conference on Mass Mining
9-11 May 2016
Sydney, Australia
The Mass Min series of conferences remains the pre-eminent global bulk mining event, attracting hundreds of delegates from all major mining companies and countries. Mass Min 2016 will bring together researchers, engineers and practitioners to present the latest accomplishments, innovations and potential future direction in mining.
www.massmin2016.com

Underground Construction Prague and EETC
23-25 May 2016
Prague, Czech Republic
This is the largest Czech tunnelling conference, which is held regularly every three years. Past conferences, especially Underground Construction Prague 2010 and 2013, confirmed that the Prague conference thanks to its scientific programme, venue and social programme found a firm position among similar European conferences
www.ucprague.com

National Congress on Tunnelling and Underground Space
26-28 May 2016
Bergen, Norway
The Turkish Road Association invites representatives from the civil, mining, geological and geophysical engineering departments of universities, relevant units of stakeholder institutions and organizations and all parties from tunneling sector to send their papers to and to participate in the first National Congress on Tunnelling and Underground Space where tunnels will be addressed from different perspectives.
www.utyayk.org/en/

TBM Applications II Seminar
6-7 June 2016
Bergen, Norway
This seminar will highlight the development of the mechanised tunnelling technique over the last 20 years and show tunnelling professionals the possibilities of this method. TBM use is growing in Norway.
www.tunnel.no/events/

Swiss Tunnel Congress 2016
15-17 June 2016
Lucerne, Switzerland
The annual Swiss Tunnel Congress (STS) is organised by the Swiss Tunnelling Society and is the premier event for tunnelling in Switzerland. Approximately 800 delegates attend from around 15 nations to take in the high quality presentations.
www.swisstunnel.ch/en

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

Urban Underground Space & Tunnelling Summit
6-9 September 2016
Singapore
Asia's Leading Urban Underground Space & Tunneling Summit will return to discuss leading practices, innovative techniques and sustainable solutions for Design, Engineering & Construction of Underground Space and Tunneling Projects
www.equip-global.com

No Dig Live UK
20-22 September 2016
Peterborough, UK
Following the success of No Dig Live UK held in September 2014, the 13th biennial trenchless technology exhibition, outdoor demonstrations and seminars will return to Peterborough.
www.nodiglive.co.uk

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

Nordic Grouting Symposium
26-27 September 2016
Oslo, Norway
The Norwegian Group of Rock Mechanics (NBG) and the Norwegian Tunnelling Society (NFF) have the pleasure to announce that the 8th Nordic Grouting Symposium will take place 26-27th of September 2016. Nordic colleagues are invited to present papers and exchange experiences.
www.nordicgrouting.com

BTS Conference and Exhibition
11-12 October 2016
London, UK
The British Tunnelling Society is pleased to announce the highlight of its 2016 events calendar, held at the QE2 Conference Centre in Westminster. Presentation synopses of 250 words are now being accepted for consideration with a deadline of 26 February. For more details please visit the society website.
www.britishtunnelling.org.uk

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

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

TBM Digs
16-18 November 2016
Istanbul, Turkey
Turkey has a great potential for tunnelling work, and in the near future the country is expecting to see upwards of USD 35bn of investment in the underground. The Turkish Tunnelling Society is also rapidly expanding its membership. This looks to be an impressive event.
www.tbmdigsturkey.org

Bauma Conexpo India
12-15 December 2016
Delhi, India
The International Trade Fair for Construction Machinery, Building Material Machines, Mining Machines and Construction Vehicles—provides the construction industry in India with a professional platform for networking, investment and the exchange of ideas and information.
www.bc-india.com

2017

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

Geo M East 2017
15-19 July 2017
Sharm El-Sheik, Egypt
Recent rapid construction in Egypt has provided great opportunities for tunnel engineers to use their knowledge and talents to solve many challenging problems with innovative solutions and cutting-edge technologies.
www.geomeast2017.org

Stuva Expo 2017
6-7 December 2017
Stuttgart, Germany
The 2015 trade fair accompanying the Stuva conference exceeded all expectations. With 1,850 conference delegates and more than 550 trade visitors, around 2,400 experts visited Stuva Expo 2015. Preparations are already on the way for Stuva Expo 2017, which will take place in Stuttgart
www.stuva-expo.com/en/

2018

World Tunnel Congress
20-26 April 2018
Dubai, UAE
The World Tunnel Congress heads to the United Arab Emirastes in 2018, and demonstrates the rise of the Middle East to the centre stage of the global tunnelling market. The region boasts a number of impressive megaprojects.
www.uaesocietyofengineers.com

The British Tunnelling Society

The BTS has a membership of over 814 individual and 266 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. Regular BTS monthly meetings are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month. In recent years, the BTS Young Members (BTSYM) group has also begun hosting its own events.

AGM followed by presentation on Singapore's Thomson Line
19 May 2016
Singapore's 30km all-underground Thomson Line (TSL) involves the operation of 30 TBMs to complete the twin running tunnels and the construction of 22 underground stations including 6 interchange stations. This involves a number of challenges in complex urban areas and partially reclaimed land. The presentation will concentrate on TSL-A and TSL-D with project features such as varying geotechnical conditions, SFRC and RC segment design, design of bored tunnels in consolidating marine clay, under- and overcrossing of existing railway lines, tunnelling beneath operational stations, as well as three-way Interchange Stations.
Speakers: Andreas Raedle, Leo Suhaendi and Rob Harding of Arup, and a yet to be confirmed representative of the LTA

Developments in the jacked-concept for urban shallow tunnels
16 June 2016
The use of jacked installation for tunnels and structures has been greatly extended in capability and application in the last 50 years. This presentation reviews the past developments and focuses on the recent innovations and applications to large non-circular underground structures including underpasses below rail and road, subways, shallow tunnels and green tunnels. This will be put in the context of future projects, such as High Speed Two for putting rail underground, Hammersmith Flyunder and many others. Innovative concepts for creating large underground structures and caverns in soft soil – which could find extensive use will also be presented.
Speakers: Andrew Robinson, Christopher Howe, and James Thomson, all of Jacked Structures

The Emscher Interceptor
22 September 2016
Klaus Rieker of Wayss & Freytag will give a presentation on the construction of the Emscher wastewater tunnel over no less than 35 km from Dortmund to Bottrop. The contract was awarded to Wayss & Freytag Ingenieurbau in January 2012 and includes 47km of pipe jacking and the construction of over 100 shafts. The River Emscher in the German Ruhr District has been used for disposing of wastewater. In the early 1990s, it was decided to replace the existing open wastewater system with a sewer system and to restore the River Emscher to its natural state. The project is divided up into a number of individual contracts. Pipe jacking ranged from 1.6 to 2.8m internal diameter with interlinking conduit sections in excess of 1,100m in length.
Speaker: Klaus Rieker, Wayss & Freytag

Harding Memorial Lecture
20 October 2016
The Harding Lecture is named after the founder Chairman of the Society, Sir Harold Harding and is given every second year. The lecture is given by an eminent speaker who presents a lecture on their specialist, tunnelling related subject.
The speaker has yet to be confirmed

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
Paul Perry: paul.perry@ch2m.com

Contact us

Editorial


Alex Conacher

Editor
Alex Conacher
Tel: +44 7429 156 753
alex.conacher@tunnelsandtunnelling.com


Nicole Robinson

North America Editor
Nicole Robinson
Tel: +1 612 940 2780
nicole.robinson@tunnelsandtunnelling.com

Contributing Editor
Sally Spencer
sspencer@progressivemediagroup.com


Sally Spencer

Contributing Editor
Keren Fallwell
kfallwell@progressivemediagroup.com

Associate Publisher
Jon Young
Tel: +44 20 7406 6622
jon.young@worldmarketintelligence.com


Keren Fallwell

Sales & Production

Group Sales Manager
Tom Willard
Tel: +44 20 3096 2608
twillard@tunnelsonline.info


Tom Willard

Classified Sales
Tanvir Sarker
Tel: +44 20 3096 2609
tanvir.sarker@tunnelsandtunnelling.com

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

North American Sales
Clive Bullard
Tel: +1 845 231 0846 Mob: +1 845 309 0892
cbullard@cs.com

Italian Sales
Davide Ferrati
Tel: +39 331 521 8050
d.ferrati@ad-communication.it

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

Head Office

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

Tel: +44 20 7406 6622
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editor@tunnelsonline.info

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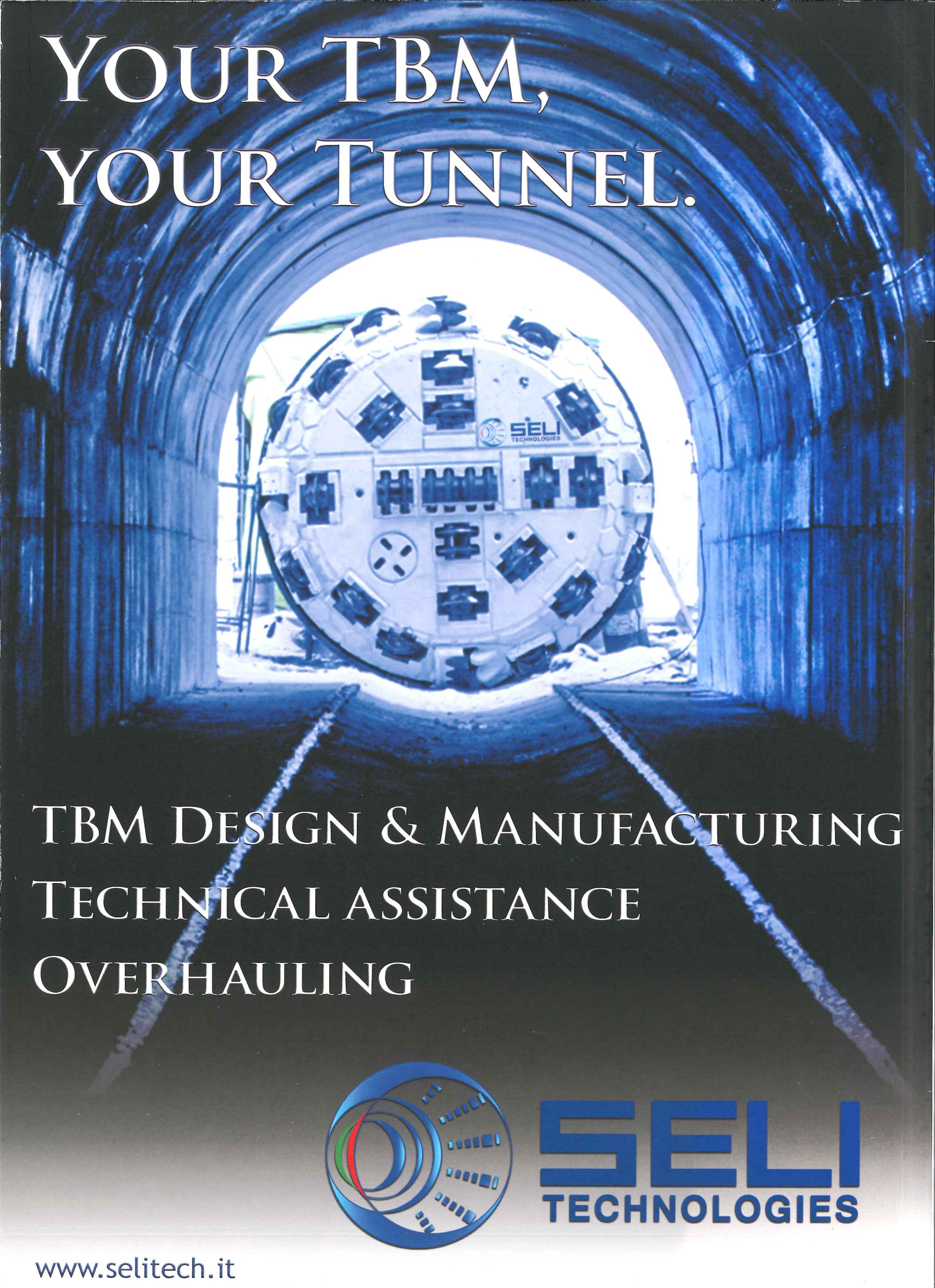
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