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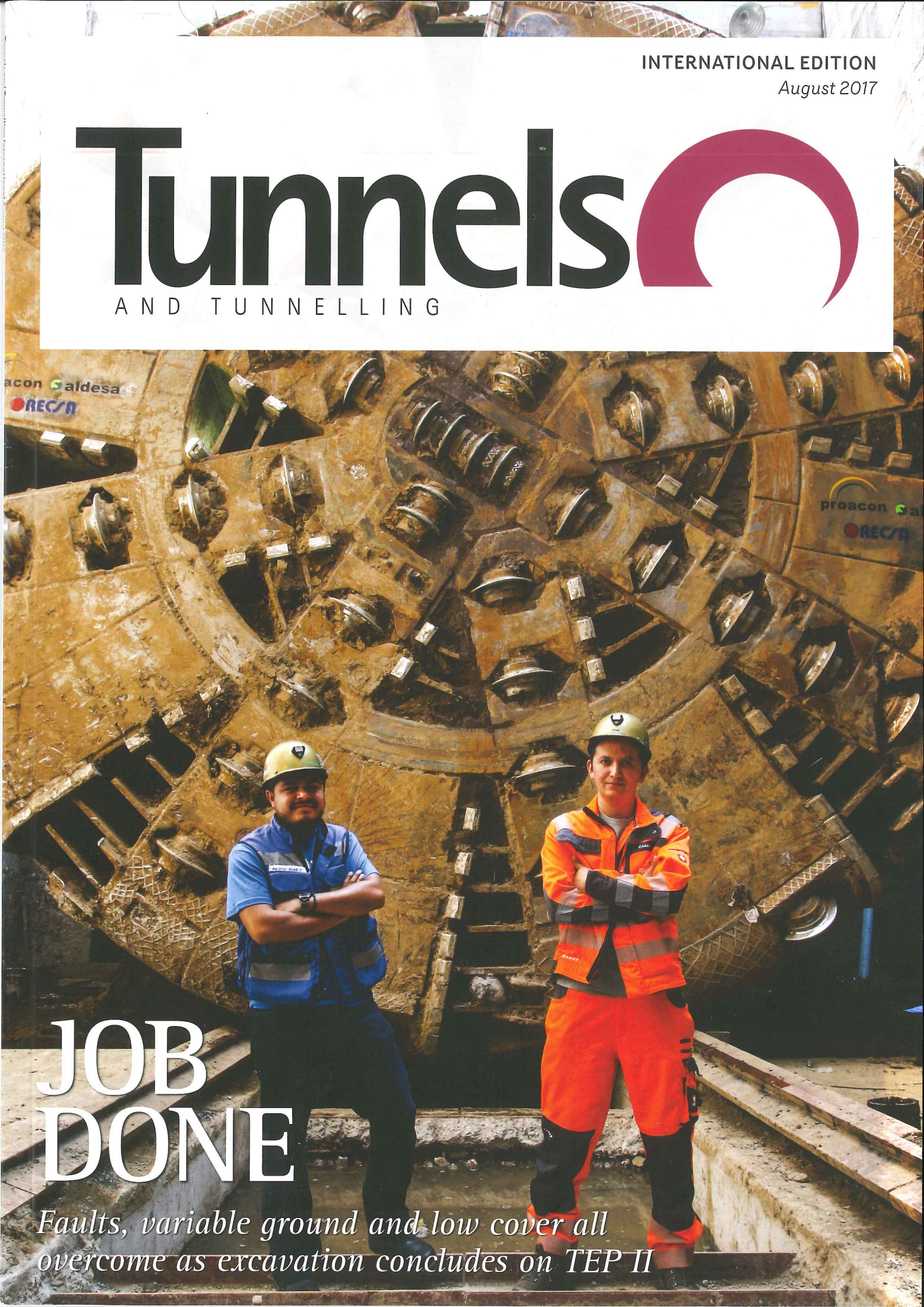
Tunnels AND TUNNELLING



JOB DONE

Faults, variable ground and low cover all overcome as excavation concludes on TEP II

GIVE THE DEVIL HIS DUE

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

Tunnelling unnerves a lot of people. Whether it's something about the thought of a large hole being dug beneath the foundations of their property, the disruption of a few years of construction work, or the general idea of infrastructure being driven through a pleasant environment, it worries people. Especially environmental pressure groups.

Tunnellers should, then, welcome as a victory the news from the UK's National Trust that as a result of a major road tunnel project, a site has become one of the top wildlife havens in this part of the country.

It is now six years since the Hindhead Tunnel opened in the south east of England. The 6.5km twin tunnel facilitated the undergrounding of the A3, which at the time separated 'the Devil's Punch Bowl' and Hindhead Common. But with these historic habitats reconnected, the project has, according to a body of scientists called Natural England, been declared as having met all of its nature conservation objectives.

Significantly, at 300m above sea level, this location is one of the highest places in low-lying southern England, bringing together an unusual combination of flora and fauna, and is therefore a Site of Special Scientific Interest (SSSI). The mosaic of habitats found on site include upland and lowland heath, bog, streams, ancient woodland, and free draining sandy soil.

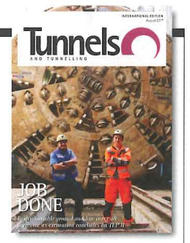
Matt Cusack, lead ranger said: "The removal of the A3 in July 2011 was a major milestone, enabling us to thin trees and transform the site into a swathe of heathland."

For interested readers, significant naturalistic coups include the arrival of the scarce heath tiger beetle, the Dartford warbler, the woodlark and the nightjar, as well as conditions favourable for the return of the silver studded blue butterfly. New paths have been created by the rangers, and visitor numbers are up to 700,000 per year.

Henry Penner, senior environmental advisor with Highways England said: "The tunnel is a ground breaking piece of engineering and shows how, by working together, we can deliver a road network fit for the 21st century in a way that not only protects but enhances the environment.

"The old A3 around the Devil's Punch Bowl was filled in using sandstone excavated from the tunnel and a mix of seeds to match the surrounding environment. I am delighted that six years on it has been recognised for playing its part in the wildlife success of the Devil's Punch Bowl SSSI, and recognise the excellent work that Natural England and the National Trust have done to protect and enhance this special place for the country."

Cover
This month the front cover shows the aftermath of breakthrough on the TEP II project in Mexico.



Next issue
In the next issue of *Tunnels and Tunnelling International* we have a technical note from Barry New regarding his recent work to form a relationship between the settlements due to a shaft's construction with the diameter of the shaft in question.

This month...

20 YEARS AGO

Contractors to Union Railways have started necessary advance works in preparation for the main construction on the GBP 3bn Channel Tunnel Rail Link. The works include diversion of 132kV power cables under the A2 trunk highway, involving construction of four 4.5m diameter shafts with 125m of connecting tunnels. They are driven with a hand excavation shield through chalk. First bids for the main tunnelling work were received at the beginning of June. These were for the longest contract: the 1km-long Stratford Station box in east London, together with the 10km long twin tunnels from Islington to Barking.
Tunnels and Tunnelling, August 1997, page 6

40 YEARS AGO

A federal grant of USD 606,000 to begin planning the first line of the Los Angeles rail transit system has been awarded to the Southern California Rapid Transit District (SCRTD) by the Urban Mass Transportation Administration. It is estimated that this ine would be about 27km long, of which 11km would be in tunnel through the central business district and cost about USD 1.6bn. The grant is the first instalment of a USD 1.6M federally sponsored study of the project with the remaining sum expected in October. Since 1954, about USD 8M has been spent on rapid transit studies for the Los Angeles area.
Tunnels and Tunnelling, July/August 1977, page 25

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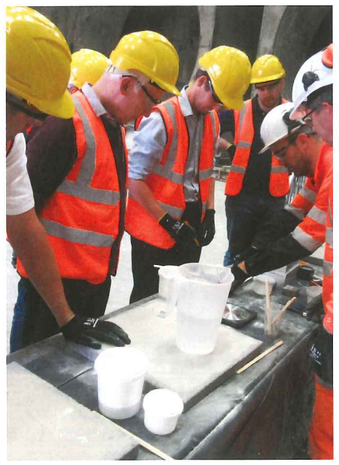

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Above: Artist's concepts of station design in the previous version of the Cross River Rail project

QUEENSLAND FULLY BACKS CROSS RIVER RAIL

AUSTRALIA — The on-again, off-again Cross River Rail project will go ahead with or without federal support according to the Premier of Queensland, Annastacia Palaszczuk. In a budget pledge last month, the State of Queensland committed the full AUD 5.41bn (USD 4.12bn) required to deliver the project after failing to receive an immediate pledge from the federal government.

The current project design for Cross River Rail involves a 10.2km rail link from Dutton Park to Bowen Hills in Brisbane, with 5.9km of tunnel under the Brisbane River and central business district. The project forms a direly needed second crossing of the Brisbane River, a transport bottleneck in the region.

A spokesperson for the Queensland Government added, "The Cross River Rail Delivery Authority will now move to undertake the early works necessary and conduct market engagement to confirm the procurement and delivery strategy for major project elements.

"While this commitment delivers certainty of funding, it is expected that the cost to the State will be reduced through future Australian Government contributions and the proceeds of commercial funding sources, such as the development of government land around stations. The Queensland Government will continue to work with the Australian Government to secure a contribution that properly reflects the strategic importance of this project and its contribution to the nation."

Previous visions for the project saw four TBMs with a 7m bored diameter, with underground stations to be constructed with various techniques including roadheader, cut and cover, piles walls and rock cuttings.

Studies of the previously planned corridor revealed geology consisting of Neran-Fernvale Beds, Aspley Formation, mudstone, sandstone, Brisbane Tuff and alluvium. A particular challenge identified was uncertainty over the precise depth of the river.

HS2 Phase One Stage One winners announced

GREAT BRITAIN — High Speed Two (HS2) has announced the victorious bidding consortia that will construct the first stage of the first phase of the project, which has been split into three geographical 'Areas', each broken out into sections.

The expected total value of these contracts including both Stage 1 and Stage 2 (the full construction phase) is estimated to be worth GBP 6.6bn (USD 8.67bn). The winning consortia are:

Area South
- S1: Euston Tunnels and Approaches – SCS JV (Skanska Construction UK, Costain, Strabag)
- S2: Northolt Tunnels – SCS JV (Skanska Construction UK, Costain, Strabag)

Area Central
- C1: Chiltern Tunnels and Colne Valley Viaduct – Align JV (Bouygues Travaux Publics, VolkerFitzpatrick, Sir Robert McAlpine)
- C2: North Portal Chiltern Tunnels to Brackley – CEK JV (Carillion Construction, Eiffage Genie Civil, Kier Infrastructure and Overseas)
- C3: Brackley to South Portal of Long Itchington Wood Green Tunnel – CEK JV (Carillion Construction Ltd, Eiffage Genie Civil, Kier Infrastructure and Overseas)

Area North
- N1: Long Itchington Wood Green Tunnel to Delta Junction and Birmingham Spur – BBV JV (Balfour Beatty Group, Vinci Construction Grands Projets, Vinci Construction UK, Vinci Construction Terrassement)
- N2: Delta Junction to WCML Tie-In – BBV JV (Balfour Beatty Group, Vinci Construction Grands Projets, Vinci Construction UK, Vinci Construction Terrassement).

This tranche of works covers the main civil engineering work on the first phase of HS2 between London and Birmingham – including construction of tunnels, bridges, embankments and viaducts. Transport Secretary Chris Grayling announced the decision to award contracts today, 17 July.

Grayling said of the occasion: "This is a hugely important step in the construction of Britain's new railway and underlines this government's determination to deliver an economy that works for all. HS2 will deliver vital links between some of our country's biggest cities, helping to drive economic growth and productivity in the north and midlands.

"As well as providing desperately needed new seats and better connecting our major cities, HS2 will help rebalance our economy."

David Higgins, chairman of HS2, said: "This is a huge day for the HS2 project and for the country. These contracts will support 16,000 jobs here in Britain and will create opportunities for thousands of small and medium-sized enterprises.

"HS2 was always designed to be much more than just a high speed railway and today we can see the opportunities it brings right around the country – spreading prosperity, acting as a catalyst for investment and rebalancing our economy 10 years before the railway even opens."

CSA tunnel safety committee appoints new chair

CANADA — During the Annual CSA Conference in Halifax, Nova Scotia, ASI Marine's group manager, Scott Black was voted in and appointed as the new chair of the CSA Z275.3 'Occupational Safety Code for Work in Pressurized Air Environments'.

The Z275.3 standard is part of the CSA Z275 series of standards covering a wide range of related competencies, training and operational safety codes for Commercial Diving, Remotely Operated Vehicles and Hyperbaric facilities.

The established Z275.3 committee will work together with the support of the Z275 Technical Committee to achieve its goal of updating the standard and closing the identified subject gaps between the current published 2009 version of the Z275.3 Standard.

ASI said it continues to be an industry leader contributing to regulatory standards that protect the health and safety of both employees and clients alike.

AASHTO publishes LRFD tunnel design and construction guide

USA — New guide specifications on load and resistance factor design (LRFD) and construction of road tunnels have been published by the American Association of State Highway Transportation Officials (AASHTO).

The LRFD Tunnel Design and Construction Guide Specifications, available on the AASHTO website, is the result of a five-year research effort by WSP USA performed under a task order from the National Cooperative Highway Research Program (NCHRP).

The specifications are intended for the design, evaluation, and rehabilitation of road tunnels constructed using cut-and-cover, bored, mined, and immersed tunnel construction methodologies. In developing these specifications, consideration was given to safety and operations, maintenance, and inspection of tunnel systems. The publication, the first national design and construction specifications for road tunnels, represents groundbreaking work to advance and support the professional practice in tunnel and underground engineering in the United States.

The recommended LRFD-based tunnel design methodology used to develop the Guide is presented in the final NCHRP research report. A literature search was performed to review existing design codes and standards, project-specific design criteria, reports, and technical publications.

Limited calibration of the load factors was performed based on results from the analysis of a circular bored tunnel.

A summary of the calibration procedure is presented in the report.

Walter Burke joins Mott MacDonald

USA — Walter Burke has joined the Environment Practice of Mott MacDonald as a Vice President for Geotechnical Services. He is based at Mott MacDonald's headquarters in Iselin, NJ.

Walter Burke's expertise encompasses geotechnical/foundation engineering studies, shallow and deep foundation systems, slope stability, ground improvement measures, solid waste disposal facilities, landfill closure, and environmental engineering.

"Walter Burke brings us 40 years of professional experience in the fields of geotechnical and geo-environmental engineering," said Nick DeNichilo, President and CEO of Mott MacDonald in North America.

"He offers skills that will add to our strength of our offerings not only in the Environment Practice but across all the sectors we serve, from aviation and tunnelling to railways and bridges."

Walter Burke has authored and/or presented technical articles, case studies, and publications to numerous professional organisations, including the Deep Foundations Institute.

MELBOURNE METRO TUNNEL DESIGN BUILD CONTRACTOR CHOSEN

AUSTRALIA — A consortium of Lendlease, John Holland, Bouygues and Capella Capital will construct the AUD 6bn (USD 4.75bn) Melbourne Metro Tunnel Project. The contract covers main tunnelling works, five underground stations, station fit-out, mechanical and electrical systems and specific maintenance services for the infrastructure delivered by the package and commercial opportunities at the new stations.

The twin 7m o.d., 9km-long tunnels will be constructed by TBM at a depth of up to 42m through a range of ground conditions, as ascertained by 270 boreholes to a 50m depth, ranging rock to sands, clays and silt. The TBMs will also underpass two waterways: the Yarra River and Moonee Ponds Creek.

The two stations in the central business district will be built as trinocular caverns. Three overlapping tunnels will be mined by road headers to create a wide open space that allows the concourse and platforms to be integrated on a single level. The result is a spacious station cavern with vaulted ceilings, rather than two separate tunnels separated by a cross passage. The total platform width at the CBD stations will be around 19m. Other stations will be constructed by cut and cover.

On muck removal, a spokesperson for the client said: "Around 1.8 million cubic metres of excavated soil and rock will be produced during the construction of the Metro Tunnel. Given the importance of roads to local communities, effective traffic management plans will manage truck movements.

"The predicted daily truck movements for Metro Tunnel will not create substantial increases in daily traffic volumes on the arterial roads that are to be used.

"As the bulk of works are underground, there will be limited opportunities to re-use excavated clean fill as part of Metro Tunnel's construction. As such, it will need to be removed from construction work sites and potentially re-used at other locations. Materials that cannot be re-used due to contamination will be disposed of in line with Environment Protection Authority (EPA) Victoria and WorkSafe Victoria guidelines."

Premier of Victoria, Daniel Andrews said: "We're building the turn-up and go train system Victoria has been waiting for. We've chosen the design, we've chosen the builders and we're getting on with it. "We don't just talk about it – we're building the train network Victoria needs and creating thousands of local jobs."

Stone joins HNTB

USA — Charles Stone joined HNTB Corporation as principal tunnel engineer on May 30. Stone is based in the firm's New York City office and works with clients nationwide.

Stone has more than 25 years of experience on tunnelling, shaft and mining construction projects. His experience includes construction and design of highway, rail, transit, water/wastewater tunnels and deep mine shafts. His area of specialisation is the construction of underground structures in rock, ranging from large drill and blast underground subway caverns to TBM-driven tunnels.

"Charles is a seasoned tunnelling professional bringing an incredibly diverse array of practical tunnelling design and construction experience to HNTB's growing infrastructure team," said Sanja Zlatanic, HNTB tunnel services practice chair and senior vice president. "As the firm continues to deliver the world's most complex tunnelling and underground projects, his expertise will serve as a key component of our clients' success."

At HNTB, Stone's responsibilities include investigating complex technical problems and serving as a senior technical specialist on major underground projects. He also will provide independent analysis and quality control of underground work performed by other professionals.

Prior to joining HNTB, Stone served another consulting firm where he worked on the Ohio River Bridges (Louisville, Kentucky), Hamilton Interceptor Improvement Project (Hamilton, Ohio), Central Bayside System Improvement Project (San Francisco), and East Side Access West Bound Bypass Structure (New York). He is a registered professional engineer in New York, Indiana and Kentucky.

Stone earned a doctorate in mining engineering/rock mechanics from Michigan Technological University; a Master of Business Administration, executive management, from Ashland University; a master's degree in mining engineering/mineral processing and a bachelor's degree in mining engineering from the University of Kentucky.

Stone's addition expands HNTB's tunnel technical bench and brings an additional array of in-depth experiences in providing innovative solutions and managing risks on tunnelling projects in the highway, transit, rail, aviation and water resources markets. The firm's tunnel projects range from small-diameter excavations to the largest machine-bored tunnel in the world. Some of the nation's most complex underground projects have benefited from HNTB's award-winning planning, design and support services, including the Crenshaw/LAX transit corridor in Los Angeles; Presidio Parkway in San Francisco; Devil's Slide Tunnel in San Mateo, Calif.; the Washington Dulles International Airport tunnels; and the SR 99 Alaskan Way Viaduct and Seawall Replacement project in Seattle.

Four Terratec TBMs ordered for Istanbul Metro

TURKEY — Australia-based TBM manufacturer, Terratec, has secured an order to supply four new 6.56m diameter EPBMs for Istanbul's Ümraniye-Atasehir-Göztepe Metro Line from the Turkish tunnelling Joint Venture of Gulermak, Nurol and Makyol. This will see a total of seven Terratec EPBMs working simultaneously on the Istanbul Metro by the middle of 2018.

The new TBMs will be used by the Gulermak, Nurol & Makyol JV on the €600 million Ümraniye-Atasehir-Göztepe Metro contract, awarded in April 2017. The 13km-long line, along with 11 new stations will form a second north to south rail corridor under the densely-populated Anatolian side of the city. The TBMs will undergo factory acceptance and testing at the end of 2017.

NEBT CONTRACT AWARDED TO SALINI IMPREGILO-LANE JV

USA — Salini Impregilo and the Lane Construction Corporation announced July 7 they have won a USD 580M contract to build the Northeast Boundary Tunnel (NEBT) project in Washington, D.C.

The NEBT will be a large, deep sewer tunnel that will increase the capacity of the District's sewer system, significantly mitigating the frequency, magnitude and duration of sewer flooding and improving the water quality of the Anacostia River.

As joint-venture partners, Salini Impregilo and Lane's S.A. Healy won the contract from the District of Columbia Water and Sewer Authority (DC Water). Salini Impregilo has a 30 per cent stake in the joint-venture and Lane the other 70 per cent.

The tunnel, the largest component of DC Water's Clean Rivers Project, will be excavated by EPBM and will have a 26ft (7.9m) excavated and a 23ft (7m) internal diameter. It will lie 50-160ft (15.24-48.7m) below ground and run 27,000ft (8229.6m). It will be aligned to intersect existing chronic flood areas, aside from this the gradient has been modified slightly to avoid bedrock.

Geology along the route is expected to be PA formation (stiff clay) for one third of the drive and PTX formation (sandy clay) for the remainder.

The lining will be a 7,000psi (48.3MPa) steel fibre reinforced universal ring for the entire tunnel, apart from adit connections where it will be conventionally reinforced. The design of the segmental lining is in progress, but Lane is proposing an anchored gasket system; Datwyler Portland 26mm or similar.

Jet grouting and freezing will be performed in correspondence of the connection between the NEBT main tunnel and the adits. Jet grouting, permeation grouting and dewatering will be performed at the shaft bottom where required. In times of flooding, the tunnel will receive flows from the sewer system captured by diversion facilities and convey them to DC Water's Blue Plains Advanced Wastewater Treatment Plant. The NEBT project will also include the construction of ventilation control facilities, storm water inlets, and green infrastructure.

Once it is connected to the other Clean Rivers Project tunnels, the NEBT will help reduce combined sewer overflows to the Anacostia River by 98 per cent and the chance of flooding in the areas it serves from about 50 percent to seven percent in any given year.

Work is expected to begin in September and be completed in 2023 - two years ahead of the Consent Decree schedule. Lane's S.A. Healy and Salini Impregilo are also working on the Anacostia River Tunnel, another component of the Clean Rivers Project.

Atlas Copco takes share of Swedish software company...

SWEDEN — Atlas Copco has taken a 34 per cent stake of Mobilaris MCE, a Swedish software company that 'optimises underground mining operations' The company, based in Luleå, produces software that gives situational awareness in mines, real-time positioning and vehicle status information, as well as details on personnel and equipment on a 3D user interface.

The software has applications in mining, tunnelling and other civil engineering works according to a spokesperson for Atlas Copco, who added: "The acquisition is expected to be completed in the beginning of the third quarter 2017. The purchase price is not material relative to Atlas Copco's market capitalization and is not disclosed. Mobilaris MCE will operate as a separate company partly owned by Atlas Copco."

Mobilaris has about 20 employees and revenues of about SEK 30M (USD 3.5M).

Helena Hedblom, President of Atlas Copco's Mining and Rock Excavation Technique business area said: "This is the future of mining."

....and opens South Carolina facility

USA — Atlas Copco announced May 23 the grand opening of its new production facility in Rock Hill, South Carolina, following a ribbon-cutting ceremony on May 17.

Atlas Copco said it built the USD 25M facility to enhance its support for the North American construction market. The 18,300sq.m, LEED-certified plant serves as the production and assembly facility for Atlas Copco's North American Construction Technique division. Generators and portable compressors and other equipment are produced at the plant, which officially opened in February.

The May 17 event featured a VIP tour, ribbon-cutting and presentations by: Mats Rahmstrom, President and CEO of Atlas Copco AB; Peter Lauwers, President of the Atlas Copco Portable Energy division; and Andrew Walker, President of the Atlas Copco Construction Technique Business Area. Approximately 400 employees and guests attended.

"This is a landmark day for Atlas Copco in the U.S.," said Scott Carnell, Atlas Copco U.S. president. "The new facility strengthens our commitment to producing superior equipment and customer support — and it aligns perfectly with our mission of sustainable productivity."

The new Atlas Copco building is in one of Rock Hill's newest mixed-use developments, Riverwalk Business Park, and replaced the company's original facility in Rock Hill.

Feasibility award for trans-Andean project

PERU — A feasibility study for a link between Huancayo and Lima has been awarded to a joint venture of Dohwa Engineering, Geodata and Italferr.

The study length is two years. The project will consist of three tunnels: a main 25km drive, a 13km and a 5km. The project will cost approximately USD 2bn.

VDMA RELEASES CORE-DRILLING SAFETY BROCHURE

GERMANY — The core-drilling equipment working group of the German Engineering Federation (VDMA) has produced a document describing how to safely fasten core-drilling equipment. The work was carried out in cooperation with Detlev Borstell of the University of Koblenz.

A spokesperson for VDMA said that only qualified personnel should be put in charge of the process, despite the document.

"The relationship between the influencing variables 'machine' and 'site conditions' for core-drilling work is rather complex. Taking advantage of the information provided in the brochure requires in-depth knowledge in the field of applied machine and fastening technologies.

"The fact that the materials making up the ground are not homogenous leads to varying strength characteristics. For this reason users cannot be provided with a universal recipe.

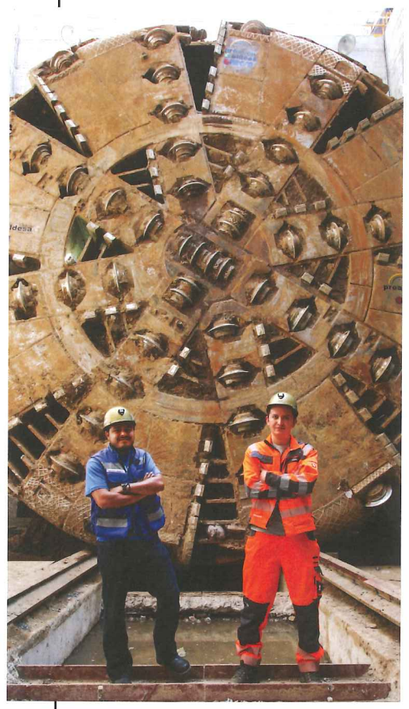
"As dowel manufacturers cannot provide universal data regarding the dowel extraction force, it is necessary to study and to contact all possible sources and know-how providers when it comes to selecting the most suitable fastening system.

"[We] therefore advise users to have all decisions regarding the method of fastening the equipment on the construction site taken only by adequately trained and instructed personnel."

The document is available from the VDMA website, www.vdma.org

Above: ***Core-drilling operation*** *©VDMA*

TEP II PROJECT MAKES FINAL BREAKTHROUGH



MEXICO — The TBM working on Mexico City's Túnel Emisor Poniente (TEP) II sewer tunnel has made its final breakthrough, manufacturer Robbins announced on 6 July.

On 8 June a select group of project officials, including Mexico's President Enrique Peña Nieto, celebrated the milestone. Robbins said the 8.7m diameter Crossover TBM is the first such hybrid machine to operate in North America. The TBM, known an XRE—a Crossover (X) between Rock (R) and EPB (E) TBMs—navigated fault zones, variable ground, low cover, and more to achieve a national record of 57m in one day as well as maximum rates of 231m in one week and 702m in one month.

"The XRE has a great advantage as it is designed to work in open and/or closed mode (EPB); allowing it to excavate the tunnel either in soil or in rock. We've verified that its performance was very efficient," said Juan Alberto Herrera Moro y Castillo, TEP II section chief for owner Conagua, Mexico's national water commission.

The machine and its continuous conveyor system were built on location, and designed for a contractor consortium of Aldesem, Proacon, and Recsa.

The machine was launched in August 2015 to bore the 5.8km-long wastewater tunnel. The machine was set up in a hard rock configuration and mounted with 20-inch diameter disc cutters. Early in 2016 the TBM hit the first of several contact zones, a 30m wide fault of fractured and blocky rock. While the excavation through the contact zone was slow going, progress picked up again in the more competent andesite rock. After an intermediate breakthrough in March 2016 into an 80m deep shaft followed by inspection and maintenance, the TBM continued on.

While boring in fractured andesite rock in autumn 2016, the TBM encountered a naturally occurring cavern believed to be the result of either a rock fall in a transition zone, or an old, underground lake body that had eroded the rock away. The cavern was estimated at 90 cubic meters in size, including about 57 cubic meters of unstable floor area. The TBM was stopped and immediate measures were taken to stabilise the ground in front of the machine with polyurethane foam before filling the cavern with a mixture of pea gravel and grout.

By the end of October 2016, the TBM had reached a final 900m-long section of soft ground, where it was converted to EPB mode. In this final reach of tunnel with low cover, the distance from the top of the tunnel to residential home foundations was as low as 4m, and the ground had the consistency of reconsolidated soil.

In order to stabilise the soft soils and minimise the risk of settlement below the residential area, the tunnelling crew drilled from the surface and installed 890 micro-piles at 1m intervals.

"We were able to do this without causing damage to property owned by neighbours in the zone bordering the path of TEP II, or to the road or the urban infrastructure installed in that area," explained Francisco Miguel Lopez, jobsite manager TEP II for contractor Aldesa.

Now that tunnelling is complete, the tunnel will receive a secondary concrete lining of 350mm thickness before going into service. The wastewater tunnel will overhaul the current system in western areas outside of Mexico City and serve to prevent recurrent flooding in Valle Dorado. In particular, the tunnel will benefit the cities of Cuautital Izcalli, Tlalnepantla, and Atizapan de Zaragoza, which altogether are home to 2.1 million inhabitants.

Top: Personnel from the manufacturer pose after breakthrough
Above: After celebrations, the contractor will construct the secondary lining

Ghagoo, Botswana

BELCHEN BREAKTHROUGH

Top: Excavation began in early 2016
Centre: Handover in September 2015
Above: Breakthrough in June

SWITZERLAND — Breakthrough on the Belchen Tunnel was achieved on 21 June. The road tunnel, which runs for 3.2km and has a cut diameter of nearly 14m, passes through the Jura Mountains between Basel and Lucerne and has been constructed to facilitate traffic flow while renovation work is carried out on two existing tunnels.

The original tunnels, which date from 1970, cross the Juragebirge, a ridge that is interspersed with large amounts of gypsum. Ground swelling resulting from the geology has damaged the tunnel support structure, causing safety concerns for the 50-year-old tubes.

Contractor Marti Tunnelbau carried out excavation on behalf of the client, the Swiss Federal Roads Office, from February 2016 and finished three months early. The TBM chosen was a Herrenknecht single shield

The new tunnel was excavated between 40-116m from the existing tunnels and faced overburdens up to 360m. Geology encountered was soft layers of rock alternated with up to 225 MPa hard layers, in places with karstified and water-bearing transition zones. In addition, long sections of squeezing opalinus clay and swelling gypsum keuper had to be passed through.

Site manager Sergio Massignani said of the breakthrough: "Thanks to the comprehensive knowledge of the ground conditions from the two existing tunnel tubes, coupled with our experience and Herrenknecht's know-how, the machine was optimally designed for the demanding requirements of the alignment of the Belchen rehabilitation tunnel."

After completion of the final works inside the tunnel and its commissioning in 2021, the two existing tubes dating from the 1970s will be renovated one after the other so that, as before, two lanes will be available in each direction, north and south, and the traffic can flow unimpeded.

PROJECT DETAILS
Contractor: Marti Tunnelbau
TBM: Herrenknecht single shield
Shield diameter: 13.91m
Drive power: 3,500kW
Tunnel length: 3,200m
Geology: Gypsum, clay, lime, dolomites, marl
Client: Swiss Federal Roads Office

Left: On 21 June miners celebrated breakthrough at the Belchen rehabilitation tunnel. The 3.2km tunnel was completed in only 16 months. *See news, page 16*

WTC BERGEN

The World Tunnel Congress was held at the northern extreme of Europe this year as the Norwegian Tunnelling Society (NFF) welcomed 1,550 delegates to the colourful coastal town of Bergen

TUNNELLING IS CULTURALLY PROMINENT in Norway, and it needs to be. The country is topographically dramatic, with sharp changes in elevation and deep fjords that have separated communities for most of Norway's history, until tunnelling linked (and continues to unite) isolated communities. Crown Prince Haakon opened the event in June and referred to this social and geographical coming together that came with the building of tunnels (and bridges) as "the great transformation".

As a special mention, Haakon picked out the 1909 opening of a railway between Oslo and Bergen, which connected eastern Norway with the west coast for the first time, through 182 tunnels. Today the country has more than 1,100 road tunnels; more than 1,000km bringing the people together across mountains and fjords.

Frode Nilsen, the chair of the NFF said that Norway boasts more cubic metres of material excavated than anywhere in Western Europe. The country also has the longest road tunnel, the deepest subsea tunnel and the largest rock cavern. For the country's population, the amount of tunnelling is very impressive, Nilsen points out that taking the length divided by the number of people, each Norwegian citizen is the 'owner' of 1.3m of tunnel.

HIGHLIGHTS FROM 2017

Tunnel market survey

The ITA released its Tunnel Market Survey 2016, which gives a statistical view of industry growth. The survey will be repeated every three years. For an extended look at some of the numbers, see the *Tunnels and Tunnelling International* July 2017 Editor's Comment, but the headline is 7% annual growth averaged across the global underground construction industry, which the ITA sees continuing into the near future.

ITA president Tarcisio Celestino said, "This is even better than expected. There has been really significant growth in underground construction, twice that of the general construction market. We are at a good moment right now, despite the global economic situation."

The survey is a bit of a revelation for the ITA, which has historically not had an accurate handle on the size of the industry. The survey's future predictive accuracy is conservative for countries such as China, which plan, construct and commission far more swiftly than western nations, so a given study period into the future is likely to have more activity than expected.

New BIM Working Group

This year the ITA launched a new Working Group (WG 22) for building information modelling (BIM). The animateur is Jurij Karlovsek, the vice-animateur is Paolo Cucino and the tutor is Lars Babenderede. Celestino hailed this as another one of his highlights of the 2017 congress "having the Working Group will make a huge impact, what with the growing importance of BIM to the industry. In Norway for example, BIM is now a requirement of the roads authority."

An attendee of the initial BIM WG meetings told *Tunnels and Tunnelling:* "The new WG 22 meetings were interesting, and there is a good deal of enthusiasm within the group. The group has a number of ambitions in terms of pushing forward IFC standards for underground works and publishing various guidance documents. However, the first phase must be the gathering of information to ensure that we are working alongside (and not against) any other initiatives. This will take a few months."

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

Nigeria joins the ITA

In Bergen, Nigeria became the newest ITA Member Nation. The African nation, currently in seventh place, is set to become the world's third most populous nation within the next few decades. This population growth, and the urgent need to create the infrastructure to deal with it, is the main reason to join the ITA and "come on board" according to Tunnelling Association of Nigeria president Abidemi Agwor.

The Nigerian economy, worth approximately USD 500bn, is the largest in Africa and has recently emerged from a bad recession. It still faces the challenge of being overly reliant on oil, but the government has apparently recognised the need to invest in infrastructure. It is possible that the new Nigerian society will spark more engagement in tunnelling locally. According to Agwor, promoting United Nations sustainable development goals and the education of government and populace as to the benefits of underground construction will be among the initiatives put forward by the group.

Agwor also made special mention of the help given to the fledgling society by Roger Bridge on behalf of the BTS.

ITA STRATEGIC PLAN 2017-2020

ITA Goals:

- Encourage Member Nations to develop activities, share knowledge and promote underground space
- Optimise the contribution of working groups and committees
- Enhance interaction with industry
- Encourage further knowledge sharing through education and training
- Enhance tunnelling and underground space awareness
- Improve communication with Member Nations, industry and the general public

As for the prospects of the organisation, ITA identified the following:

- **Strengths:** Global network covering all categories of tunnel work; a recognised platform for knowledge development and knowledge sharing; established relationship with other global organisations (PIARC, ISOCARP, UN); recognised as bringing a strong international and unbiased voice; excellent networking platform; strong brand; involvement of young professionals; financial standing allows new initiatives; ability to pioneer new approaches in tunnelling e.g. risk management
- **Weaknesses:** Insufficient involvement of some Member Nations; limited knowledge sharing in some areas (e.g. financing and technology); communication channels with Member Nations and other stakeholders not sufficiently established; limited representation of contractors; limited representation of public agencies; limited contact with private investors and owners; known inside industry but not sufficiently outside; activities rely mostly on volunteer work; cost of participation in ITA activities
- **Opportunities:** Growth of urban development will require increased use of underground space; increasing share of underground mining; increasing demand for education and professional training; availability of new technologies for use in the tunnelling industry; increasing private investment in underground projects; increasing awareness of sustainability requirements and the contribution that underground can bring
- **Threats:** Financial constraints may cause a reduction in membership and sponsorship; other organisations trying to attract members from the same pool of professionals as ITA, plus numerous competing conferences; media focus on negative projects rather than successes; European domination of the industry; the recent global economic downturn reducing available investment; insufficient use of best contractual/procurement practices

ROOM FOR IMPROVEMENT

In terms of how the industry can assist ITA, at the general assembly it was noted that some of the working groups have had issues with poor attendance and inactivity. Romania proposed that such groups should be divided up or suspended if they cannot improve. Any help from industry experts is appreciated. A list of active member groups and their contact details can be found on the ITA website (ita-aites.org).

It was also noted that over half of the Member Nation websites are totally inactive. This is not directly ITA business and is down to local engineers to engage with their national societies. The websites often being a useful first point of contact with these societies.

***Both:** The substantial Follo Line project has seen Norway make a rare use of TBM technology*

GIULIA VIGGIANI

Paola De Pascali interviewed Giulia Viggiani, the new professor of infrastructure geotechnics at Cambridge University as she enters the UK tunnelling industry. She joins the university as Robert Mair becomes president of the Institution of Civil Engineers

Paola De Pascali
Paola joined the *Tunnels and Tunnelling* team in 2016 as a contributing editor

"SOMETIMES I ASK MYSELF if my passion for engineering is just the result of an Electra complex, because my father is a geotechnical engineer and I always dreamed of following his footsteps," says Giulia Viggiani, newly-appointed professor of infrastructure geotechnics at Cambridge University. "Of course my enthusiasm for scientific studies helped me to pursue my career in this field."

Viggiani has worked as professor of geotechnics at Tor Vergata University in Rome for 10 years, where, together with colleagues in structural engineering, she has helped establish the 'Tunnelling Engineering Research Centre' to address and coordinate the many departmental research activities on tunnelling connected to geotechnics, structures, transport and environmental engineering.

She has recently moved to Cambridge to join the geotechnical group currently headed by Robert Mair who retires next year.

"Professor Mair spent his life in the tunnelling industry. I'm honoured to take over from him at Cambridge University, which is a very interesting place to be," Viggiani says. "Cambridge University offers several centres and networks to work with. For example, the Centre for Smart Infrastructure and Construction (CSIC), an international centre for excellence providing organisation operating in the infrastructure and construction sectors with tools and information necessary to take advantage of the latest technical developments in asset management and sensor technology, or the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC)."

"Moving to Cambridge is important not just because the British tunnelling industry is so active, but also because the themes and goals of my research are very well-matched with the current activities of the geotechnical research group here. I hope that I may contribute positively to maintain and further develop the world leading role of Cambridge's group in producing high quality, innovative, and industry-relevant research in geotechnical engineering.

"At the same time, I also believe that my research will benefit from the huge potential offered by the innovative sensing and monitoring systems available at CSIC and by the availability of excellent laboratory facilities, including the Turner Beam Geotechnical Centrifuge of the Schofield Centre and the planned National Research Facility for Infrastructure Sensing on the West Cambridge Site."

***Below:** Professor Viggiani working at Municipio Station of Napoli Underground, checking progress on one of two cross passages excavated under the Protection of artificial ground freezing*

BACKGROUND

Viggiani graduated in Civil Engineering at Università di Napoli Federico II, Italy in 1989. While completing her PhD in geotechnical engineering at the City University in London, under the supervision of her professor, John Atkinson, she had an opportunity to help another professor, John Burland of Imperial College, on a project on the stabilisation of the Leaning Tower of Pisa.

"He had been appointed member of the International Committee to Safeguard

the Leaning Tower of Pisa, and had received a huge amount of technical paperwork in Italian, so I helped him with translation and interpretation, which was an amazing great experience for a young geotechnical engineer."

"After a few years professor Burland invited me back to London to participate to the CIRIA-LINK team on Monitoring Building Response to Tunnelling, in connection with the construction of the Jubilee Line Extension. I joined the monitoring group at Imperial College at the very beginning of 1996 and worked there for nearly two years. It was a great experience, which enriched my scientific and technical skills. Before that, my research had mainly been focused on laboratory work on fundamental aspects of the mechanical behaviour of soils. Joining the IC group gave me the opportunity to get involved in more engineering oriented research and also put me in touch with many people in the in underground construction and tunnelling sector. I guess it is not by chance that, towards the end of 1996, I became one of the two Italian representatives on the then Technical Committee TC28 of the ISSMGE on Tunnelling in Soft Ground."

CURRENT AND FUTURE RESEARCH

Viggiani's research interests and areas of expertise span from soil mechanics to geotechnical engineering. "I regard the technical challenges stemming from geotechnical engineering as opportunities to advance fundamental understanding in soil mechanics, and in turn, have always tried to transfer any fundamental developments back to the engineering practice, in the belief that they can provide powerful tools to optimise design and control construction processes," Viggiani says.

"The main thrust of my current research is on the applications of soil mechanics to geotechnical engineering, and deals mainly with underground construction, foundation engineering and earthquake geotechnical engineering. I have been involved in some of the most important current infrastructural projects in Italy, including the design and construction of Lines 1 and 6 of Napoli Underground and of Line C of Roma Underground, and the design of the foundations, anchor blocks and terminal structures of the Strait of Messina Bridge."

The participation in these projects gave her the opportunity to carry out research on tunnelling and construction processes, tunnelling induced damage assessment and connected mitigation and remedial measures, and performance-based design of geotechnical structures under seismic actions, using a combination of field monitoring and laboratory observations, theoretical analyses, and physical and numerical modelling.

Viggiani is currently working on a number of interconnected themes including the development of advanced numerical modelling of mechanised tunnelling, the study of the impact of tunnelling on structures and of construction processes involving coupled phenomena in soils, such as artificial fround freezing, and the evaluation of the effectiveness of mitigation measures.

"Together with researchers of National Technical University of Athens, I am currently contributing to the development of 3D FE procedures to model TBM tunnelling," she says. "These include the realistic simulation of the main physical phenomena occurring during EPB shield tunnelling, such as the application of a variable support pressure at the face, the presence of a physical gap between the excavation boundary and the permanent lining - due to over-cut at the cutter-head, shield tapering, and installation of the segmental lining within the shield - and the execution of tail void grouting.

"We are simulating the contact between the shield and the ground introducing appropriate normal and tangential contact laws, while tail void grouting is modelled using a time-dependent setting law for the grout and an initial stress state in the grout elements to represent the injection pressure. Since a significant proportion of ground deformation due to tunnelling in fine grained soils is associated with consolidation settlements, fully coupled consolidation analyses are carried out with realistic rates of advancement of the shield.

"Although numerical results are very promising at this stage, the comparison with real field data is crucial for the ultimate validation of the proposed methods. We plan to apply these numerical techniques to full scale class A predictions of the ground and monument response to construction of the tunnels of Line C of Roma Underground."

Viggiani has been leading one of the work packages of a EUR 10M (USD 11.7M) Large European Collaborative Project involving 22 partners across nine countries, including universities, R&D laboratories, large companies and SME. This project addressed key scientific and technical challenges on the theme of mechanised tunnelling such as the development of an advanced multi-sensor ground prediction system for TBMs, of a suite of systems for modelling and thus controlling the impact of tunnelling on surrounding structures, and the creation of a decision support system for tunnel maintenance management.

A large experimental campaign has been undertaken at ENTPE Lyon to investigate the impact of tunnelling on reduced scale models of piled structures, using a small scale EPB shield advancing inside a large tank filled with sand, in which instrumented piles or small pile groups are pre-installed at different locations around the tunnel. The response of the piles in terms of settlement, axial load, longitudinal, and transverse bending moment, was monitored during advancement of the TBM. The results obtained so far show non-negligible effects in terms of displacements and bending moments associated to the changes of stress in the direction of TBM advance.

PROJECTS

"I have recently contributed to activities connected to the design and construction of Napoli Underground, and I am a member of the Geotechnical Working Group of the International Technical and Scientific Committee set up to assist the designers of Line C of Roma Underground, in close co-operation with the general contractor, Metro C SpA," Viggiani says.

At present, Napoli Underground includes six underground

***Above:** One of the new Line C stations in Rome*

rapid transit railway lines, a commuter rail network, and four funicular lines, with planned upgrading and expansion work underway.

"The idea of a fully integrated urban rail network was proposed in the 1950s as part of the post-war regeneration effort; plans were first formulated in the 1960s, but funding, planning, and development problems all caused long delays," Viggiani says. "Construction began in 1976 and the first 4km-long rapid transit line opened in 1993, running between Colli Aminei and Vanvitelli Stations; two years later, the line was extended to reach Piscinola, for an overall track length of 13km."

The City Transport Plan, approved by the Municipality in 1997, included three main phases of re-development. Phase 1 consisted of an expansion to five lines, to take the network up to 53km of track, with 68 stations (23 newly built), and 12 interchange nodes, and was completed by 2002. Phase 2 was designed to increase the network to seven lines, with 84 stations, and 16 interchange nodes, and is currently under way. Phase 3 will see the network expanded to 10 rail lines with 93km of track, and a further 30km of new light rail linking 114 stations, with 21 interchanges.

Once completed, Line 1 of Napoli Underground will form a closed ring connecting the northern outskirts of the city, the area of the hills, the historical centre, the administrative district, and the airport, for a total length of about 40km and 25 stations. The first 22km of the line, between Piscinola and Dante Stations, were completed relatively quickly and were fully operating by 2002. The next 6km, between Dante and Garibaldi Stations, proved to be much more problematic. This is because all five stations included in this work had to be excavated through loose granular deposits, well below the water table, and in an extremely densely built urban environment.

At present, four out of five stations are open to the public, bringing the number of operating stations on Line 1 to a total of 18, while it is expected that the last station on this stretch of the line, at Duomo, will be completed in 2020.

The preliminary design of the line between Duomo and Garibaldi consisted of shallow tunnels constructed by cut-and-cover. At a later stage, it was decided to bore the tunnels within the Yellow Tuff formation, because this would both minimise direct interferences with the archaeological layer and reduce limitations to the surface traffic during construction. The good mechanical properties of the tuff also reduced the risk of settlements and hence potential damage to nearby structures. The main drawback associated with this design is that the line is quite deep and for a long stretch it is well below the groundwater table, with hydraulic heads between 25 and 30m. The very high pore pressures, together with the random occurrence of fractures in the tuff, made it necessary to bore the running tunnels with closed-shield EPBMs.

The station tunnels and passageways were enlarged by conventional mining and had to be constructed with the aid of a variety of ground improvement methods, including chemical injections, cement grouting, and the extensive use of artificial ground freezing (AGF).

"The works on Napoli underground brought about international co-operative research bringing together constitutive modelling, laboratory tests and field data involving Universitat Politécnica de Catalunya Barcelona, Università di Roma Tor Vergata, and Seconda Università di Napoli," Viggiani says. "The participation of technical personnel and engineers involved in the design and construction of Napoli underground permitted to collect all monitoring data on the applications of AGF.

"The predictive capabilities of an existing fully coupled thermo-hydro-

mechanical model of the behaviour of frozen ground were tested against the experimental results of a number of triaxial tests carried out at different temperatures and confining stress. The predictions of the model compared very favourably with the experimental observation and the softening behaviour of the material on thawing was remarkably well reproduced by the numerical simulations.

The constitutive relations are implemented in a visco-plastic form, mainly to regularise integration of the material law on softening; this feature of the formulation may be enhanced to model the time-dependent behaviour of frozen soils, and it is envisaged that the role played by temperature may be accounted for by introducing the dependency of fluidity on suction.

"The triaxial tests for Napoli Underground were carried out in a double-walled triaxial cell working under temperature-controlled conditions developed by Tecno-in SpA, which, in its present configuration, has several limitations. For instance, due to water freezing in the drainage lines, it is not possible to measure volume changes using external volume gauges and, contrary to conditions on site, freezing proceeds from the outer boundary of the sample towards its centre.

"Building on this experience and to overcome these limitations, funding has been secured to design, build, and set-up a prototype stress-path-controlled triaxial system for frozen soils at Tor Vergata University."

Line C of Roma Underground, whose preliminary design was approved by the municipality in October 2002, is currently under construction. To date, the existing network consists of only two lines, Line A and Line B, intersecting at Termini Central Railway Station. Line B was built in the 1930s by cut-and-cover whereas the bored tunnels of Line A date back only a few decades.

The new Line C runs north-west to south-east of the city, for a total length of more than 25km and 33 stations. The project is divided into seven contracts; its easternmost stretch, between Monte Compatri-Pantano and Giardinetti Stations (contract T7), is on surface, while the remaining part of the line is excavated using two EPB shields of a diameter of 6.7 m. The stretch between Giardinetti and Parco di Centocelle was completed in November 2014, while the following six stations, from Mirti to Lodi, were opened to the public in June 2015, thus completing contracts T6 to T4. The part of the line between San Giovanni and Fori Imperiali (contract T3) is currently under construction, at different stages of advancement: San Giovanni station was opened to the public at the end of 2016, while it is expected that the stretch between San Giovanni and Fori Imperiali will take another five years to be finished.

"Construction of contracts T3 and T2 is very problematic because the running tunnels and the stations will have to be built in the historical centre of the city, with significant problems connected to buried archaeological remnants, the geotechnical characteristics of the soil, consisting of alluvia from the Tiber River, construction below the water table, and the necessity of minimising the effects at the surface on the historical and monumental heritage," says Viggiani. "Contract T3 interacts mainly with monuments of Roman Age, including some of the most famous archaeological landmarks in Roma, such as the Coliseum, the Basilica di Massenzio, and the Foro di Cesare, while contract T2 underpasses the historical centre of the City, potentially affecting a large number of ancient masonry buildings of historic and artistic value built between the XV and the XIX century."

Because of the exceptional archaeological and historical value of the structures potentially affected by the construction of the line, the design had to include a detailed study of the interaction between the construction activities and the monuments. As prescribed by the grantor of the project (Roma Metropolitane), the general contractor (Metro C) set up an international, multidisciplinary steering technical committee with the assignment of implementing all necessary procedures to safeguard the historical buildings.

The main tasks of the steering committee were to evaluate the influence of the construction of Line C on the existing monuments and historical buildings, suggest, where necessary, appropriate mitigation measures of geotechnical and structural nature, develop a comprehensive and redundant monitoring scheme to follow in real time the response of the buildings to construction, and assist the general contractor in the evaluation of the monitoring data to optimise construction sequences and procedures. To accomplish these tasks, five working groups were set up, whose activities were coordinated by the steering committee, including experts in preservation and restoration of monuments, tunnelling, geology, structural and geotechnical engineering, geomatics and monitoring.

"The geotechnical engineering working group, of which I was a member, was charged with the tasks of the mechanical characterisation of the deposits and the definition of the relevant soil parameters, the prediction of the displacement field affecting the different buildings during and after construction, the evaluation of the feasibility of different mitigation measures to be implemented when the soil-structure analyses yielded unacceptable displacement fields, and the development of a geotechnical monitoring scheme," Viggiani says.

"In close co-operation with the structural engineering group, the geotechnical engineering group was also required to develop a consistent and scientifically sound methodological approach to be followed to evaluate how the construction of the line would affect the existing historical buildings, thus assessing the expected damage category."

In the subject of mitigation measures, Viggiani is carrying out field trials, including both compensation grouting and barriers, along a dedicated stretch of Contract T3 of Line C.

"Properly conducted field trials prior to tunnelling are therefore vital to prove the feasibility of compensation grouting and its efficiency in the long term, but also to evaluate the effects of the grout sleeve tubes and the proposed grout mixes, and to validate assumptions regarding grout spread," Viggiani says. "The proposed field trial of compensation grouting will include a dummy foundation and a monitoring system of surface and subsurface displacements. The circular shaft from which the grout sleeve tubes will be inserted has already been constructed in Largo dell'Amba-Aradam, where very similar soil conditions exist as for the nearby Mura Aureliane at Porta Metronia, which we intend to protect from settlements using this technique.

"The other mitigation measure under examination is the installation of barriers between the tunnel and the building, by introducing alignments of piles, jet-grouted columns, discrete micro-piles, or plastic (bentonite) diaphragm walls. The results of centrifuge and numerical studies show that barriers can be very effective in reducing tunnelling induced ground movements. However, these are often implemented in practice on the basis of empirical knowledge more than as a result of a rational design process."

The effectiveness of a barrier consisting of 48 concrete piles with a diameter of 600mm, a length of 34.5m and a spacing of 900mm, will be tested in an instrumented dedicated section, located at the beginning of Contract T3. Parallel to the site work, small scale physical modelling and numerical modelling of barriers are also being carried out at ENTPE Lyon and at Tor Vergata. The effects of the distance of the barrier from the tunnel axis, its length, stiffness and nature of the soil-barrier interface (rough or smooth) were examined numerically to orient design of the field trial and extend the parametric study carried out by physical modelling.

ACHIEVEMENTS

Viggiani's role as a recognised expert in the field of geotechnical engineering for infrastructure has been acknowledged both at national and international level. She has prepared general reports for several international conferences on infrastructure geotechnics, and has been invited to deliver lectures in many countries. The research she carried out in cooperation with Gopal Madabhushi of Cambridge University and Riccardo Conti of Tor Vergata, on the behaviour of flexible retaining structures under seismic actions, received the 2012 ICE TK Hsieh Award.

Viggiani delivered a keynote lecture at the XVI European Conference on Soil Mechanics and Geotechnical Engineering, which took place in Edinburgh in September 2015.

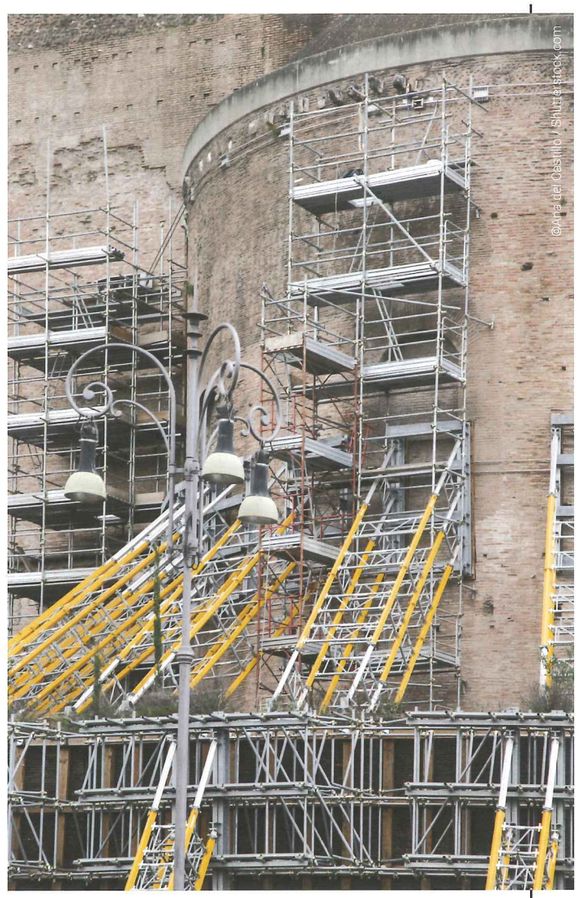
"I talked about applications of artificial ground freezing in tunnelling related to Naples underground," she says. "I was honoured to be one of the three keynote lecturers at this prominent international event. I consider it one of the highest points of my career, although, of course, there are other things I take great pride about.

"Because of my commitment to the activities of the technical committee, I was gratified to have been awarded the prize for the best presented paper at the 5th TC28 IS on 'Geotechnical Aspects of Underground Constructions in Soft Ground' in 2005 in Amsterdam, and am still very proud of having organised its 7th edition in Roma in 2011."

TUNNELLING INDUSTRIES

"Italy still has serious infrastructural deficiencies; in particular, in the field of transport infrastructure, there are significant faults in the congestion of major metropolitan urban areas and low quality of the regional public transport," Viggiani says.

In 2015, the Italian Strategic Infrastructure Programme identified 25 priority projects, for a total cost of EUR 70.9bn (USD 80.55bn) and financial hedges amounting to EUR 48bn (USD 54.53bn). In this context, the amount of resources allocated to the extension of metropolitan underground lines was very significant; for the underground lines of Napoli, Bologna, Milan, Turin, Palermo, and Florence these amounted to approximately EUR 9.5bn (USD 11.12bn), while the total cost of the sole Line C of Rome Underground was estimated at EUR 2.7bn (USD3.16bn).



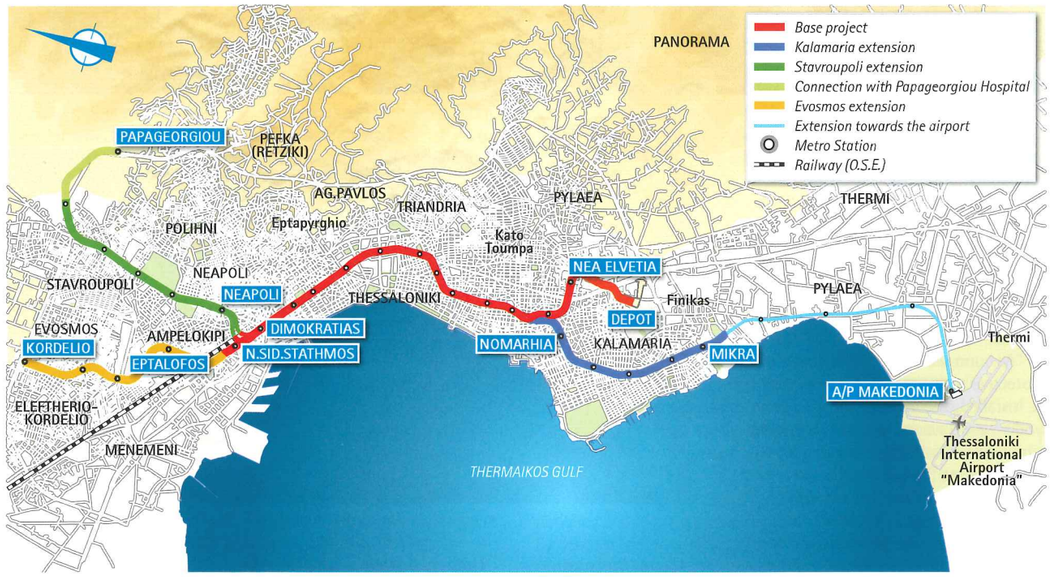
***Above:** Photo of support works during Rome Metro Line C*

"I believe that Italian companies have established expertise in tunnelling and excavation works; for example, in ground treatment and artificial ground freezing, we have world leading companies that are currently involved in tunnelling projects all around the world. I believe that the expertise of Italian industry in this market should be maintained and, if possible, expanded as it can play a role in the national economy.

"To carry out big construction projects in Italy, the main problems are often the political management and bureaucracy that can slow down or even put on hold public works. Instead it seems to me that in the UK there is a custom of virtuous interaction between governmental action, research and the construction industry, tunnelling included."

BALANCING THE OLD WITH THE NEW

Creating Thessaloniki's first ever metro system means striking a balance between preserving historic artefacts and delivering a state of the art public transport system



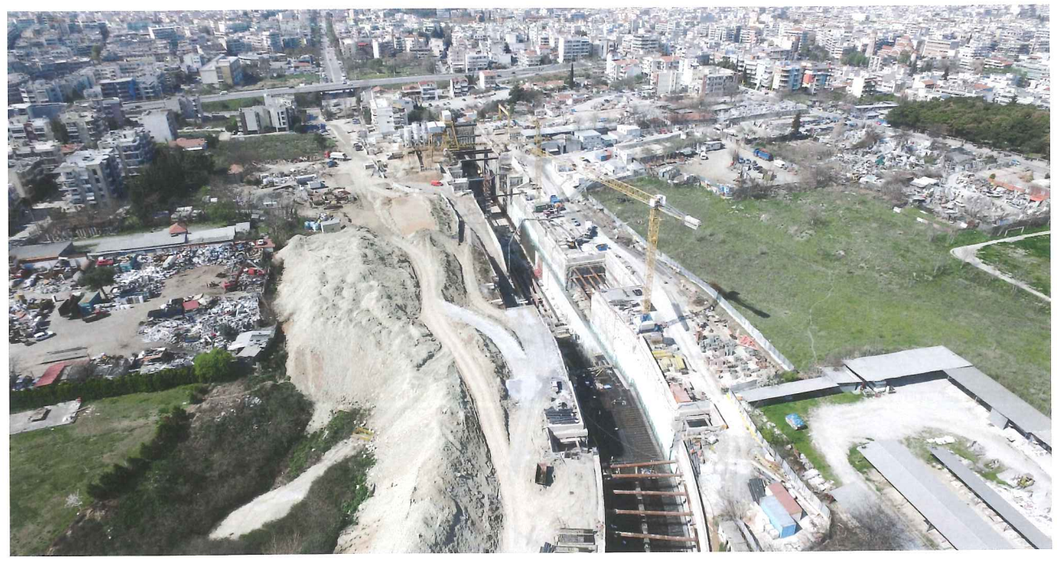
Bernadette Ballantyne
Bernadette is an engineer and freelance technical journalist

Above: *The Thessaloniki Metro alignment*

CONSTRUCTING METRO SYSTEMS IS never easy, but in the Greek coastal city of Thessaloniki contractors have faced a range of challenges that have not only delayed work, but caused redesigns and major cost increases. The 9.6km twin tunnel, which runs at a 20-25m depth below the city, is deep enough to avoid harming the historic artefacts. However the station boxes, which are constructed top down from the surface to the base encountered a raft of ancient treasures from the Roman, Byzantine and Ottoman eras which must be preserved.

TBM and station excavation work rates are usually measured in meters per day. These statistics are compared to the forecasts, the actual ground conditions, the machine wear rates and of course the overall programme. Contractors and their clients are of course seeking to maximise progress and set up their machines and site processes to ensure that the schedule is met.

Archaeologists take a very different approach. "The archeological research works were proceeding in parallel with the normal excavation," explains Rainer Dell'Onze, project engineer for contractor Salini Impregilo which is responsible for around 42.50 per cent of the civil works



on the project. Excavations would always commence under the supervision of an archeologist and as soon any findings were discovered, the archeological services would take over the continuation of the excavation with the support of the contractor. The rate of archeological excavation was of about 300mm per month.

"As soon we reached the depth where protective measures were foreseen to be installed, the archeological research works were suspended and the findings temporary covered to allow the access of equipment for the installation of shotcrete, anchors, pre-stressed anchors, struts, etc. Only after the protective measures were completed the archeological research works could be resumed," says Dell'Onze.

Removing the findings once discovered was also very time consuming. So, it is not surprising then that the project timescale has slipped a rather long way. Commencing in May 2006, the new metro line was originally scheduled for completion by the end of 2012. The forecast budget at this time was EUR 798M (USD 930.8M) with an additional EUR 15M (USD 17.5M) for archeological excavation and research works.

But this turned out to be quite an underestimate. As of May, the actual budget was EUR 1.3bn (USD 1.52bn) with EUR 115M (USD 134.24M) for archaeological and research works and the final completion date is 2020 except for two stations where significant archaeological excavation is currently in progress.

***Above:** Cut and cover and shaft works showing differing levels of disruption*

These two stations are Venizelou and Aghia Sofia which sit at the western end of the first phase of the metro project (see map, page 29).

The stations are two of 13 which fall under the scope of the first phase of the works, which also includes the excavation shafts, the 9.6km twin tunnel railway lines, one forestation, two underground crossovers for future extensions, one depot covering a surface of approximately 540,000sqf (approximately 50,000 square meters) with the operation control centre and the administration building, as well as all the electromechanical and railway systems including rolling stock formed of 18 ultra-automatic and state-of-the-art, fully air-conditioned trains.

The new line will be completely automated with a transport capacity of 18,000 passengers per hour in each direction and a frequency of 90 seconds at peak times.

Construction is being undertaken by the AIASA joint venture consisting of Greek firms Aegek/Aktor (28.78 per cent), Italy's Salini Impregilo (26.71 per cent), Italy's Seli (7.19 per cent), Italy's Ansaldo STS (25.84 per cent) and Hitachi Rail Italy (11.49 per cent, formerly Ansaldo Breda). Works have been separated into two packages.

Group A which is Aegek-Aktor, Salini Impregilo and Seli is undertaking the civil works, track works and auxiliary electromechanical works. Group B consisting of the remaining partners is responsible for design and detailed design, supply, testing and commissioning, training, operation and maintenance organisation of the main electrical and mechanical systems and rolling stock.

Monitoring

Project engineer for Salini Impregilo, Rainer Dell'Onze, explains the geo-mechanical and structural monitoring being used on the Thessaloniki project

In the JV organization, a special geo-mechanical and structural monitoring (GSM) department was created at the start of the project to face all the challenges expected within the contract, the design and the construction.

At the beginning the GSM department carried out supplementary geotechnical work such as drilling boreholes and undertaking laboratory tests, as well as further geological and hydrogeological design. This alongside the earlier data at disposal of the client Attiko Metro, allowed us to determine the geological and hydrogeological conditions, prepare reports, maps and longitudinal sections and asses finally the design.

In addition concerning the buildings and the monuments, we needed a risk analysis, alert and alarms limits, to guarantee that the effects on the project are within the specified limits. The objective of the risk analysis is to reduce and control the risk of a building against structural damage in normal buildings and aesthetical and/or functional damage to important buildings. In other words, to minimize the potential impact caused by the excavations and particularly by the tunnel excavation. Our approach to this was in six stages:

1. **Design phase:** Identify the building vulnerability to settlements, eventual optimization of TBMs advance mode, design mitigation measures (preventive measures) and controls (monitoring) for building at risk
2. **Building survey:** Determine the actual conditions of buildings in the tunnels' influence zone
3. **Project data input:** Alignment, geotechnical and geo-mechanical characteristics of ground and eventual settlement forecasts from the design and from numerical analysis.
4. **Method of analysis and phases of the process:** Type of damage, definition of control parameters, classification of risk damages, identification of the buildings potentially at risk, evaluation of control parameters for affected buildings, determination of damage risk for affected buildings and the definition of measures to be adopted
5. **Types of damage:** Aesthetic - minor cracking or minor movement of finishing which is easily reparable. Functional - loss of functionality of part of the structure, without danger for collapse. Structural - intense cracking (concrete structures) or excessive deformations (structures with load bearing walls) of structural elements which could lead to partial or total collapse.
6. **Control parameters:** The control parameters permit the correlation of settlements affected by tunnel excavation with potential damages to buildings. For each building the control parameters are calculated at foundation level and the identity value (IV) of the building is identified. Knowing the control parameters, the IV index and the correct risk classification, allows to define the risk category of a building. For various risk categories, there are different corresponding preventive measures:

- **Aesthetic:** Monitoring of building. Does not require preventive measures
- **Functional and structural:** Preventive measures to be taken prior to tunnel excavation (consolidation of ground of building) and monitoring of building to check the effectiveness of the preventive measures. Preventive measures could be protection of the structure through vertical or crossed micro-piles; ground condition improvement through consolidation grouting; reinforcing the structures (struts or ties); additional foundation treatment and compensation of settlements using compensation grouting.

Trigger limits for an alert are 80 per cent of the predicted value and the alarm limit is 100-120 per cent of the predicted value. The maximum settlements allowed by the contract are 15-24mm and depend on the importance of the buildings above.

Monitoring of the ground and buildings is required to measure, analyse and assess the data. This includes verification of the design input data, for the verification of the provisions made at the time of design, for control of the advance of the tunnel excavation and control of the effect of the tunnel excavations on the buildings. We were monitoring the TBM, the tunnel lining and the buildings and all this data was stored on a database.

In terms of instrumentation this meant that piezometers were installed to measure the water table and the variation of hydrostatic pressure and pore pressure. Inclinometers were used for monitoring lateral movement parallel and perpendicular to the tunnel's axis. Extensometers were used to measure vertical movement at selected depths and sliding micrometers were used to measure vertical movement in the area around the project. Pressure cells and load cells measured loads and stresses. Strain meters monitored the concrete and crack meters measured cracks on the buildings and structures.

The data acquisition system and GSM Kronos Software was designed and adapted exclusively for the Thessaloniki metro project by Geodata Loeben of Austria. This Software solution allows the contractor to follow all the phases of the project from the design through to its operation. In addition, the software can produce diagrams of how parameters change over time.

PRESERVATION STATION

The ongoing construction of Venizelou station highlights the challenging nature of this project. Here as the team worked down through the layers of ground, they moved through almost two thousand years of Greek history.

In the first couple of metres were the remains of the city's commercial centre, which had been buried following the great Thessaloniki fire in 1917. "As soon as the first 2m were excavated, we started to find the remains from the 19th century. This was the commercial centre of the Jewish population at this time.

"Then digging further down, we start to find relics from the Ottoman period," explains Dell'Onze.

Under the Ottoman Empire which took control of Thessaloniki in 1430, the city had a central role as main harbour of the Balkans, building on its heritage as the Co-Capital of the Byzantine Empire when it was considered to be second only to Constantinople.

Not only did the team find Byzantine relics but it also found the Roman remains that preceded this.

Roman planners made their towns

rectangular with two through roads, the Decumanus Maximus running east to west, and the Cardo Maximus running north to south.

"At Venizelou we found exactly these two roads and the same thing at Aghia Sofia. We also found the drainage system, the water supply system in this period."

So well preserved are the remains that wheel tracks are visible in the marble that constituted the Byzantine roads. The question now is how to build the station as the usual top down method, where soil is excavated above the new roof slab, would no longer be acceptable.

"Last week we received the final decision of the archaeological council for the municipality of culture who took the decision to maintain the findings so now we are trying to find a technical solution that enables us to keep the archaeological findings in situ and enable the excavation of the station," explains Christos Panou project manager of Salini-Impregilo.

The most likely methodology will see completion of the archeological research works followed by careful construction of a wall around the findings that then enables the station roof slab to be cast above. The eastern and western ventilation shafts will then be excavated and from here (the shaft bottom) the team will be able to excavate the 80m x 20m station box in many phases.

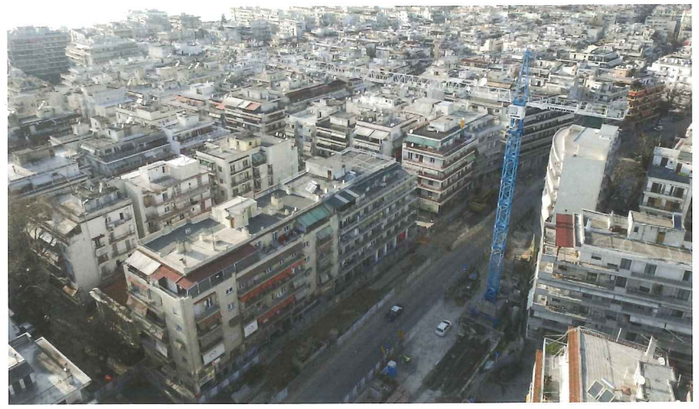
For temporary support of the shafts, 300mm diameter concrete micropiles will be concreted (or constructed) into place and metal struts will be placed to support the micropiles. Pipe jacking will then be used to create the tunnels (many phases). This process is expected to take around three years.

MOVING FORWARD

Today 80 per cent of the civil works for the project are finished, but much remains to be done with over half of the total project work still to be completed. "The TBM tunnel excavation is complete," says Dell'Onze, "as well as the excavation works on 11 of the stations. Remaining excavation work is underway in the two stations in parallel with the archeological research works."

"Concrete works are completed in all the excavated stations and finishing works such as masonry, plastering and painting works escalators and doors installation have started already in these stations as well as in the depot," explains Dell'Onze.

Ground conditions along the route have been as expected in soil comprised of formations of red clay, sandstone–marl and quaternary deposits with sensible variation in the soil permeability.



***Both:** Aerial view of lifting operations at two of the worksites*

The original time schedule had planned that the 6m diameter Herrenknecht EPB machines passed through five stations before their excavation was completed, and eight already excavated stations. Instead, due to delay in the expropriation of the area of some stations, some changes in design and delay in the works due to the unexpected huge amount of archeological excavation, the TBMs only broke though into two completed stations during their journey.

The archaeological findings have not been the only challenge for the project. Some station sites were handed over late due to issues around expropriation of land.

"We had two major problems. One was the Archeological findings which were beyond all the provisions of the time and the second was the expropriation of the areas which was not on time from the client.

"For these reasons the project was stopped for a long period to find a new solution and to cover the expenses," explains Panou.

Work was put on hold following an arbitration process between the contractor consortium and its client Attiko Metro which ran from 2014 and 2015. Once resolved the project restarted again on 1 January 2016.

"The positive decision of the arbitration allowed us to cover most of expenses we were suffering," explains Panou.

The revised budget will now see the first phase of the project through to partial opening in 2020 with the outstanding work at Venizelou and Aghia Sofia following on 2022.

TUCA PART TWO

Part of Crossrail's legacy is the training academy it set up in 2011 to address the skills shortage. **Sally Spencer** reports

Sally Spencer
Sally joined the *Tunnels and Tunnelling* team as a contributing editor in 2015

***Above:** TUCA opened in September 2011*

THE TUNNELLING AND UNDERGROUND Construction Academy (TUCA) was set up by Crossrail Limited to bridge the skills gaps it knew it would encounter along the way. But while the Crossrail project itself is nearing its conclusion, there is still plenty of life in its training academy.

The GBP 13M (USD 16.9M) academy in Ilford, east London, was part-funded by a GBP 5M (USD 6.5M) grant from the Skills Funding Agency and by sponsorship from major contractors and opened its doors in September 2011. This first incarnation followed Crossrail's in-depth skills forecasting exercise, which looked at both the demand for and the availability of the expertise required to deliver the whole project. The forecast flagged up some skills gaps in the first phase of the project – the tunnel construction itself.

The study looked at what other skills providers were already offering and at the number of people working in the industry. The conclusion was that while Crossrail would require around 2,000 tunnellers, only 500 were working in the UK at that time. Many of this workforce were also "at the higher end of the age

A Centre of Excellence

TUCA is one of a network of three national Centres of Excellence identified in the Transport Infrastructure Skills Strategy written by Crossrail chairman Sir Terry Morgan and published by the Department of Transport in January 2016.

The strategy contains recommendations for both government and industry to act on. It outlines the skills needed to deliver £61 billion in transport investment up to 2020. The recommendations include:

- Delivering on the UK government's ambition for 30,000 new apprenticeships over five years to 2020, reflecting its overall apprenticeship target and funding from the proposed apprenticeship levy
- Ensuring the right mix of apprenticeships are on offer for the transport sector, including many at higher levels
- Meet the challenge of new technologies by upskilling the existing workforce
- Encouraging greater diversity in the workforce
- Promoting transport and engineering as a career of choice for the brightest and best, leading to using 2018 as a year to celebrate engineering

bracket", leading to fears that the combination of an ageing workforce and the lack of a formal pipeline for people to come into the industry could result in a loss of existing skills and expertise.

The forecasting dug deeper and scrutinised specific job roles and functions – plant operations, shuttering and form work and so on. It predicted some issues around particular types of plant but deemed that these could be covered by existing training provision. However, the skills gap that caused the most concern was in sprayed concrete lining (SCL).

"Crossrail had looked at how the wider tunnelling industry was meeting its skills needs, including at the Hagerbach training centre in Switzerland," said Georgina Bigam, strategy and commercial manager for TfL at TUCA.

"But Hagerbach specialises in hard rock tunnelling – very different to the type of tunnelling Crossrail needed, which was going through soft rock and using a combination of TBMs and sprayed concrete.

"Another thing Crossrail found was that there wasn't an existing qualification and skills structure for SCL. What had been happening was 'informal apprenticeships' where someone had taken a friend or relative down into the tunnel and taught them the job as they went along."

There's no doubt that a wealth of information and experience was being passed down in this way, but it wasn't necessarily standardised, added Bigam.

So, the rationale behind setting up a training academy was pretty compelling and TUCA, which is the only soft-ground tunnelling training facility in Europe, was established. Since then more than 17,500 people have received skills and safety training designed and delivered by industry experts.

The facility includes workshops with specially designed tunnel openings for practical training in SCL, a UKAS-certified materials testing laboratory (primarily for concrete testing), a tunnel mock-up, complete with railtrack and locomotives, in which to put health and safety learning into practice and seven classrooms.

For the first five years the training was managed by the Construction Industries Training Board (CITB) but in January this year there was a changing of the guard. Crossrail handed over the TUCA reins to Transport for London (TfL) and TfL, in turn, has appointed Prospects College of Advanced Technology (PROCAT) to deliver the training.

PROCAT is a specialist technical training college established to meet the workforce development needs of businesses that operate in sectors that are critical to the UK economy. This includes advanced apprenticeships to secure a pipeline of new talent and higher and degree apprenticeships, which follow the STEM model, leading the way in Science, Technology, Engineering and Mathematics.

Speaking at the time of the transfer, London's Transport Commissioner, Mike Brown said TUCA had played a leading role in the Crossrail project and would leave "a lasting legacy".

"It is essential we continue to develop the skills this country needs to deliver major infrastructure projects," he said.

"I think there was always an expectation that TUCA would continue to provide tunnelling and underground construction training [after Crossrail]," said Bigam. "There was always an eye on HS2, Thames Tideway, Crossrail 2 and, obviously, all the work TfL undertakes, all of which is in soft ground."

She added that the opportunity had then arisen for TfL, which is responsible for delivering, operating and maintaining the central section of the Elizabeth line, to provide additional training facilities at the academy.

TUCA will also be home to the Elizabeth line maintenance and station staff training centre. Facilities will include a mock-up station to train staff in customer service. More than 130 PROCAT railway engineering apprentices will start training at TUCA from September.

These new training facilities will add to TUCA's offering and will not dilute or detract from its focus on tunnelling and underground construction in any way. The mock-up evacuation tunnel will be relocated to a new covered area just outside the building and will have "some extra facilities bolted on so it will be even better". The space it currently occupies will be converted to accommodate the railway facilities and extra classrooms will

Right: There are currently seven classrooms and more will be added when TUCA becomes home to the Elizabeth line maintenance and station staff training centre

be built on a new mezzanine level alongside a comprehensive railway maintenance training facility.

Meanwhile, TUCA's tunnelling skills training curriculum continues to be driven by the needs of industry and it is evolving as those demands become clearer.

For example, the workshop where the practical SCL training takes place is currently underused simply because the Crossrail project is already well beyond that stage of construction.

That's not to say that there has been no workshop activity, however. For example in June, TUCA hosted a workshop run by BASF Underground Construction and partners, Atlas Copco, CK-Tech and CPI Euromix.

"TfL has been very upfront with regard to innovation and new approaches to technical solutions and to this end we were asked to put together a workshop to cover latest developments in sprayed concrete, in association with water management," said Richard Foord, BASF project manager, Underground Construction UK and Ireland.

"The delegates were 50 engineers and inspectors from all shifts in TfL teams, split over two separate days to capture shift pattern," he added. "The structure of the day had a real emphasis on practical demonstration and delegate engagement."

The use of the TUCA facility was maximised by group presentations to set the scene and cover design and theoretical matters with a taste of the innovation that followed. The whole group was then divided into three smaller teams who visited three separate, but technically related work stations throughout the day. These were:

- Sprayed concrete – concrete mix, production from silo, equipment and a spray demo and testing with assistance from specialist applicator Shotcrete Services;
- Water proofing – spray applied membrane, equipment, preparation, application and testing, interface with sheet membrane, all with practical input from Gunform Ltd;
- Injection – ground engineering, soil stabilisation, water stopping, sealing, re-injectible hoses, void filling using equipment and assistance from CK – Tech.

"The level of attention, the hands-on involvement and the quality of the questions was a reflection of the delegates' knowledge of their roles and environment and keenness to learn more on new technology," said Foord.

"The ability to provide a cohesive and stimulating workshop stems from the organiser's fundamental knowledge of their business and a passion to share the information to a receptive audience," he continued.

"The workshop was part of a long line of contact between the parties in various arenas and formats over many years, (for which we are very grateful), and it is hoped that similar events can be held in the future to the mutual benefit of all," said Foord.

Left: TUCA trained 120 people in SCL for Crossrail

Above: TUCA's tunnel mock-up enables health and safety training to be put into practice

More recently, TUCA hosted a five-day pilot TunnelSkills workshop. The Tunnel Surveying Skills Course ran from 31 July – 4 August and covered subjects such as handwork, pipe jacking and micro-tunnelling, TBM tunnelling, SCL tunnelling, equipment and project costs and laser scanning outputs and applications.

"We are now talking to industry to find out what we can develop and how we can put new courses together," said Dave Watson, PROCAT project manager. "We are working with the TunnelSkills national specialist training forum, which meets at TUCA bi-monthly and with TUCA's Industry Advisory Panel, which includes major clients and contractors from the underground construction sector.

"Wherever there is a demand for training, whether it's in practical skills or in health and safety, we can develop that with the sector experts and put a package together."

"We're already working with Thames Tideway, which is about to start, but we have also engaged with HS2 as well as the national colleges for high speed rail," added Bigam. "That's for the longer term but starting those conversations now means we will be able to meet their needs in the future."

There are two prongs to the training being offered – apprenticeship training and workforce development training, although Watson stresses that the emphasis is on the latter in respect of the

underground construction offer.

"This September there will be 2,000 learners doing one- to five-day courses and of that around 250 will be apprentices," he said.

He added that TUCA has the ability to run on extended hours. "We have the ability to work 24/7, so if there is demand for training on a Saturday, that's what we will provide. We really want the facility working to its capacity."

In the workforce development camp, CPD courses ready to roll are the Tunnel Safety Training Scheme, a one-day classroom-based course, and Tunnel Entry and Emergency Procedures. This one-day course is split between classroom tuition and a spell in the mock-up tunnel where students are able to put theory into practice and is accredited by City & Guilds but is exclusive to TUCA.

New apprenticeship courses will be on offer later this year including – Tunnelling Operations (Level 2), Lab Technician (L2), Surveying technician (L3), Building Services technician (L4), Rail Operative (L2), Rail technician (L3/4) and Embedded Electronics (L6).

The Tunnelling Operations course is being led by TunnelSkills. It is currently a Level 2 course, although Watson says the ambition is there to "upskill" that to a Level 3+.

Disciplines that will be taught on the course include site safety awareness, soil mechanics, concrete technology and environmental awareness, alongside practical training covering slinger signaller, maintenance of tunnelling plant, tunnel services, tunnel entry and evacuation and working with pressurised pipe systems.

"Another development we're really keen on, post-Crossrail, is to keep the Materials Testing Laboratory going with Balfour Beatty's continued backing, so we're working with them at the moment to try to develop and expand an industry training offer" said Watson. "It is a first class facility and we want to add to it and expand the range of the materials testing CPD and apprenticeship offer [via the Lab Technician course]."

Above: Delegates at the BASF Underground Construction workshop test the properties of spray applied waterproof membrane

As with all the courses at TUCA, tunnelling courses are tutored by industry experts and it's important for the credibility of the academy that the expertise is current and hands-on.

"It goes hand-in-hand with designing a facility that employers in industry have been involved with," said Bigam. "If the tutors delivering the training don't have that same credibility, then people won't come here to learn."

She added that students were likely to see their tutors out on site, providing them with the confidence in their abilities.

While the courses have to be commercially viable, TUCA's mission remains one of providing a skills structure for the tunnelling industry – it's not about turning a profit. So, although the figures have to add up, courses will be tailored to meet the needs of the few as well as the many. Whether there is a minimum number of students required to put a course on will be decided on a case-by-case basis.

"Some of the courses are classroom-based high volume, quick turnover," said Bigam. "But we've also run courses in the past where there has been a requirement for it within the industry but not necessarily huge demand in terms of numbers. Take the SCL facility, for example. We trained 120 in SCL for Crossrail, which is not a massive number, but we couldn't not do it.

"As to whether we would run one course for just five people and never run it again, it would depend on how much development time was needed, whether it was available elsewhere and whether it was relevant to our strategic aims," she added. "What we are doing here is as much about developing a skills strategy for the industry as it is about pure training delivery.

"SCL is a good example. The qualification that exists for that at the moment, EFNARC [European Federation of National Associations Representing Concrete], is internationally recognised but it isn't aligned to any of the UK awarding bodies or accreditation centres, so that is something we could explore further," said Bigam.

"There is a lot of SCL work going on across London Underground, TfL and other tunnelling projects, so we think it would be useful to have a standard qualification."

As TUCA's strategy continues to evolve it is open to suggestions on the training it can provide. Feedback from the sector is welcome and the academy can be contacted by email at tuca@procat.ac.uk or by phone on +44 (0) 203 197 5002. Visits to the site are also welcome by prior appointment.

Below: Concrete core samples in the Materials Testing Laboratory

ACCIDENTS AND DISEASES ASSESSED

M. Tender / J. P. Couto from the University of Minho, Portugal look at the health and safety statistics from Portugal to validate beliefs regarding the most frequent incidents

OCCUPATIONAL HEALTH AND SAFETY risks can increase the probability of occurrence of Accidents at Work (AW) and Occupational Diseases (OD). This article will consider the differences, in terms of characterisation of AW and OD, between the two main tunnelling methods: CEM - Conventional Excavation Method (in this case, as per ITA definition: any non-TBM, non-drill and blast technique), and TBM - Tunnel Boring Machine Excavation Method.

AW and OD can have a very negative impact on the companies involved:

- Deadlines: The occurrence of a serious or fatal AW causes an interruption of works and may even have an impact on the overall execution time. This interruption may be short, lasting a few hours, or long, pending the gathering of all the data necessary for the investigation. In some cases, it may compromise the project's success.
- Related costs: The interruption of works involves high economic implications with direct or indirect costs, such as loss of productivity and yield, low morale, compensation for damages, and time spent in the analysis of the AW. Together with those of OD, they are estimated in 8.5% of the construction (European Agency for Safety and Health at Work, 2014a). Since they lead to a reduction of the company's profit margins, they affect its competitiveness. In addition, it is less likely that the company will become a preferred supplier, namely for project owners concerned with prevention.

The characterisation of the most typical events' causes is of great importance for their prevention[2]. Accidents and diseases can be used to learn from mistakes and from the legacy of previous works.

Statistical data on AW and OD in tunnelling are scarce. Not even the International Tunnelling Association, with its Working Group "Safety and Health at Works", has compiled any statistics on the frequency or nature of AW or OD. The regulatory authorities of each country have compiled adequate statistical data on the construction sector but they seldom distinguish different types of construction, such as tunnelling. This gap led the authors to try and ascertain the most typical and frequent types of AW and OD.

Acknowledgement

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The methodology chosen for the AW and OD analysis used the Eurostat variables analysed in the European Statistics on Accidents at Work (ESAW) and in the European Occupational Diseases Statistics (EODS). The variables were chosen because they enable a basic characterisation of the setting of the occurrence of AW and appearance of OD. Since some variables in the ESAW were not fully suitable for this study, answer choices better suited to the objectives pursued were created.

Data was collected from these sources:

AW: The Governmental Office for Strategy and Planning (GEP) (year 2013- the most updated data GEP had at the time). Since GEP did not have data for 2014 and 2015, and in order to assess whether those years followed the trends of the GEP data for 2013, information of AW occurred in those years was gathered from project owners and contractors of this type of works. A total of 150 AW between 2012 and 2015 were analysed.

OD: The Social Security Institute (the body responsible for producing private sector occupational disease statistics) provided information on 42 OD certified between 2001 and 2015.

ACCIDENTS AT WORK

Occupation of the victim

The occupations most affected by AW are "Handlers/operators/drivers" and "Miner".

"Handlers/operators/drivers" - the specificity of the construction process makes massive use of operators and drivers, for drilling, removal of muck, or concreting, in the case of CEM, or for transport of materials and equipment (namely using rail vehicles), in the case of TBM.

"Miner" – highly exposed to risks associated with proximity of the excavation front, such as fall of blocks from the excavation face or run-overs (especially in the case of CEM).

Time

The time period in which most AW occur is from 5pm to 8am, traditionally considered as supplementary or nocturnal. This can be justified with the fact that working in shifts or in overtime hours, which are traditional ways of organising work in tunnelling, may have implications for the way the human body responds, since the workers' biological clock is altered, causing them to be awake at a time when the body is at a lower capacity level.

Place where the AW occurred

The place in which most AW occur is in formwork and concreting areas. Inside formwork and concreting area many workers gathered to perform the final lining, both in CEM (heavy machinery for waterproofing, installing reinforcements and formwork/concreting), and in TBM (installing prefabricated segments), with tasks carried out simultaneously.

Specific physical activity

The specific activities during which most AW occur are work with hand-held tools, movement, and handling objects.

Work with hand-held tools – hand-held tools are used for the installation of prefabricated parts (in TBM) and stabilisation devices (in CEM), and formwork assembly/disassembly, as well as for the maintenance and repair of equipment.

Movement - personnel colliding with mobile equipment (vehicles) or falls from height or on the same level are included here, and are a major cause of AW[3], as was confirmed in the transalpine experience, in which a great part of the AW occurred during movement and transport[4].

Handling objects- both methods imply handling a large amount of objects, such as stabilisation devices, blocks, rolls of waterproofing systems, rails for reinforcement and formwork panels (CEM), and prefabricated segments (TBM), and pieces of equipment or components of electrical, compressed air, water or ventilation infrastructures.

Deviation leading to AW

The deviations most seen are body movements under or with physical stress (internal injury) / body movements without physical stress (external injury) and slips/falls.

For body movements under physical stress (internal injury) - the authors consider works near the excavation face (in the case of CEM), where blocks falling from the crown are one of the major causes of AW, adding to the vast amount of heavy machinery required, which leads to the risk of run-overs. Also relevant is the road or rail transport of material and workers to the work place (TBM). There is also the important risk of sprayed concrete fragments falling down.

Body movements without physical stress (external injury) covers people coming into contact with objects, equipment, tools, ground, etc., leading to external injuries, such as cuts, lacerations, enucleations, haematomas, burns, etc. Relevant for this is the assembly of formwork panels (CEM) and the application of prefabricated segments (TBM).

'Slips and falls' can be explained with people falling down while using temporary working platforms for waterproofing, reinforcement and concreting (CEM) and during the assembly, disassembly and positioning of the tunnel boring machine (TBM). It can happen due to uneven ground (CEM) or during walking along the TBM. The manual handling of loads can obstruct visibility and worsen this situation[5].

Type of injury

The most common types of injury are classed as 'wounds and superficial injuries', 'dislocations, sprains and strains'.

Wounds and superficial injuries are common when using the hand-held objects and materials required by this type of work. Dislocations, sprains and strains are a common result of a person falling over (not from height).

Part of body injured

The parts of body most injured are the upper and lower extremities

Upper extremities are typically injured by the use of hand-held tools (usually heavy in nature, such as bars for scaling and crowbars, or contact with rolling

material or prefabricated segments. Also, the high amount of loads handled, and the manual handling of loads, both in CEM (e.g. stabilisation devices), and in TBM (e.g. handling parts of the TBM for assembly and disassembly, or prefabricated segments for positioning and assembly) means there is a high tendency to have contact with hands, arms, legs and feet, whether due to falls or to other types of contact.

The lower extremities, meanwhile, are more prone to be injured during slipping or falling, can also be connected to objects falling, e.g. bocks, or to strains due to uneven ground, namely in CEM.

Number of lost days

The average number of lost days is 60.8, which is very high. One possible explanation is the greater severity of 'wounds and superficial injuries', resulting in a high number of days lost.

OCCUPATIONAL DISEASES

Occupation of the victim

The occupational groups with a higher number of OD is "Miners".

Miners, working close to the excavation face, are exposed to breathable dust, sometimes with a high level of silica.

They are also exposed to fumes from explosives, dust from sprayed concrete, oil mists and exhaust gases in the confined space of the excavation face.

Diagnosis

The most common diagnoses are respiratory/pulmonary disorders and Hearing disorders.

For respiratory/pulmonary disorders it is important to distinguish the disorders affecting the airways from the ones affecting the lungs. As for the inflammation of the airways, exposure to particles and gases from diesel combustion products (heavy machinery, in CEM, and locomotives, in TBM) and from blasting of explosives (CEM), namely ANFO-based explosives, has been associated to the on-set or worsening of asthma and chronic bronchitis conditions[6]. Dust from the cement used in sprayed concrete can contribute to worsening asthma conditions, reducing the lung function of con-crete spray robots operators[7]. Due to their composition, the oils used to protect machinery against concrete splatters and build-up or to clean the formwork moulds can also lead to airways problems, namely asthma. As for pneumoconiosis, it is important to distinguish the ones caused by deposition of silica dust from the rock mass, more typical in this type of work from the ones caused by the dep-osition of asbestos particles, less typical. The occupations most affected by dust and gases are borers and boring machine workers, but these risks affect those working nearby as well as those working far away, in places crossed by fumes, vapours or particles.

As for hearing disorders, underground this problem is aggravated by the reverberation of the noise made, e.g. by drilling equipment, fans and compressors.

Table 1 - Accidents at work

Occupation	Mobile equipment operators
Time	Between 5 pm and 8 am
Place	Formwork and concreting area
Activity	Working with hand-held tools
Deviation	Body movement under physical stress
Type of injury	Wounds, or superficial injuries
Part of body	Arms, hands, legs or feet
Lost days	60.8 lost days

Table 2 - Occupational diseases

Occupation	Miner
Age	50 to 59 years old
Diagnosis	Respiratory/pulmonary disorders

CONCLUSIONS

The statistical data obtained are now a source of information available to anyone who wants to use information on AW or OD to improve risk analysis.

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What's on

2017

ICTUS 2017
28 August - 1 September 2017
Seoul, South Korea
The Korean Tunnelling and Underground Space Association welcomes you to Seoul. The theme is "Frontier Technologies in Tunnelling and Underground Space Technologies". It will play host to these sessions: innovations in mechanised tunnelling, developments in UG space tech, improvements in conventional tunnelling, structural and hydraulic interactions, extreme conditions, and stability.
www.i-asem.org

Shotcrete for Underground Support XIII
3-6 September 2017
Irsee, Germany
SUS XIII aims to pool the consolidated efforts from engineers, researchers and project managers from across the world in order to share and update state-of-the-art technology and best practices in rock engineering, rock support methods, TBM tunneling and deep excavation.
www.engconf.org

13th Expert Conference on Safety in Tunnels
6-7 September 2017
Kassel, Germany
This annual conference provides an overview of changes to existing regulatory frameworks and the issue of new regulations plus an insight into the latest technical developments.
www.dmt-group.com/

International Symposium on Aerodynamics, Ventilation & Fire in Tunnels (ISAVFT 2017)
13-15 September 2017
Lyon, France
Tunnel ventilation is a small part of the cost of a tunnel, however, it is often crucial for sizing the civil engineering works, and in allowing a given type of traffic. There is pressure upon designers and engineers to develop more cost-effective solutions for tunnel construction without compromising safety. This has been the premier international event to discuss new research and developments.
www.bhrgroup.com

Underground Infrastructure of Urban Areas
24-26 October 2017
Wroclaw, Poland
This ITA endorsed conference is being organised by Wroclaw University and the Polish Tunnelling Group. The conference will cover the theme: "discussion on problems related to underground Infrastructure".
www.pbp-ita.pl/.org

TBM Digs
16-18 November 2017
Wuhan, China
Following the success of the first two TBM Digs events, the conference returns for the third time. This year it heads to the city of Wuhan in China's Hubei Province.
www.tbmdigs.org

12th Iranian Tunnelling Conference: Tunnelling and Climate Change
27-29 November 2017
Tehran, Iran
Drop in total precipitation around the world, especially in the Middle East and Iran has resulted in rapid decline of water resources. Water conveyance tunnels by transferring water form water-rich regions to arid regions can have a significant role in reducing consequences of this phenomenon. In some countries climate change has given rise to precipitation and has caused massive floods. In these countries drainage systems and water conveyance tunnels can have an important role in mitigating negative effects of flooding and climate change. Iran recently approached the highest temperature ever recorded on the planet, and is an ideal location for this conference theme.
www.itc2017.ir

Stuva Expo 2017
6-7 December 2017
Stuttgart, Germany
The premier tunnelling event in Germany returns to Stuttgart in December. The 2015 event's trade fair accompanying the Stuva conference exceeded all expectations. With 1,850 conference delegates and more than 550 trade visitors, around 2,400 visited in 2015 and the 2017 event is expected to build on this.
www.stuva-expo.com/en/

2018

NASTT No Dig 2018
25-29 March 2018
Palm Springs, USA
Since 2001, this show has nearly doubled in size, keeping pace with the rapid growth of our industry. Cutting-edge technologies are continually being developed and introduced, see them at the largest trenchless technology show.
www.nastt.org

World Tunnel Congress 2018
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 organisers invite you to experience true Arabian hospitality and enjoy Dubai, which claims to be the world's most cosmopolitan city.
www.uaesocietyofengineers.com

North American Tunnelling Conference
24-27 June 2018
Washington D.C., USA
The NAT is the premier biannual tunneling event for North America, bringing together the brightest minds in the tunneling industry.
www.natconference.com

11th International Conference on Geosynthetics
16-21 September 2018
Seoul, South Korea
The technical program will include a Giroud lecture, 5-6 plenary lectures (special lectures), 2-3 short courses and approximately 50 parallel sessions.
www.11icg-seoul.org

PIARC International Conference on Road Tunnel Operations and Safety
3-5 October 2018
Lyon, France
This World Road Association endorsed event comes amidst increasing interest in the emergence of new types of vehicles in the driving environment, and how tunnels will keep pace with continuing technological advances.
www.piarc.org

10th Asian Rock Mechanics Symposium
29 October-3 November 2018
Singapore
Asia is witnessing the greatest growth and demand in the world for infrastructure and resource development. According to Asian Development Bank, approximately US$8 trillion needs to be invested in overall national infrastructure before 2020, 68% of which is for new capacity. Certainly, rock mechanics and rock engineering will have a critical role to play in many of these infrastructure and resource development projects. The theme for ARMS 10 is "Rock Mechanics in Infrastructure and Resource Development".
www.arms10.org

2019

World Tunnel Congress 2019
3-9 May 2019
Naples, Italy
The one tunneling event that is unrivaled in its international reach. The World Tunnel Congress is coming to Italy and tunnellers representing owners, contractors, engineers and suppliers will be exhibiting. The event is expected to attact as many as 600 technical papers, 250 exhibitors and up to 3,000 attendees.
www.facebook.com/events/1753343481565751/

ECSMGE 2019
3-9 May 2019
Reykjavik, Iceland
The Icelandic Geotechnical Society are pleased to welcome you to the XVII European Conference on Soil Mechanics and Geotechnical Engineering, held in the Icelandic capital. The theme of the conference is "Geotechnical Engineering, foundation of the future" and will embrace all aspects of geotechnics.
www.ecsmge-2019.com

World Road Congress
6-10 October 2019
Abu Dhabi, UAE
The World Road Congress will cover a number of areas, including Road policies, Environment, Economics, financing, Governance of authorities, Planning, Risk management and many more.
www.piarcabudhabi2019.org

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.

BTSYM: Challenges in the drilling and blasting method at the main access tunnel for the Uma Oya Project
7 September 2017
The Uma Oya multipurpose project is a hydropower project in Sri Lanka with several tunnels over 25 km in length, mostly in hard rock. This presentation will describe some of the challenges and solutions in the Drilling and Blasting method used in this project during construction. Excavation of the underground powerhouse complex and associated tunnels will be explained and improvements in the drill and blast patterns implemented will be described.
Speakers: Mehdi Hosseini, London Bridge Associates

High Speed Railway Tunnel Projects & General Tunnelling Status in China
21 September 2017
This presentation will be given by the China Railway Tunnelling Group Contractors & China Railway Engineering Equipment Group. It will discuss the status of high speed rail technology in China with a particular emphasis on the design, construction techniques and use of TBMs in the tunnel sections of current major projects. An overview will be given of how the roles of client, designer and contractor operate in the Chinese market. The presentation will cover the past, present and future of high speed rail in China.
Speakers: Kung Wang and Yali Han

Finsbury Park Squareworks
16 November 2017
A presentation on the Finsbury Park Station step-free access scheme for London Underground. This will include information on squareworks tunnelling, shaft sinking and undertrack crossings, all carried out from within a live station.
Speakers: Farid Achha, London Underground; John Elliott, Alan Auld Engineering; Menelaos Lydakis, C Spencer Group

Waterview Tunnel, New Zealand
14 December 2017
The Waterview Connection in Auckland, New Zealand is the largest and most complex road project ever undertaken in New Zealand. The project involved two tunnels, each comprising three lanes, with an outside diameter of 14.41m excavated under residences, the Great North Road, and Auckland's western rail corridor.
Speakers: TBC

Tunnel Design Life of 120 years - Definition, Assessment and Improvement
18 January 2018
The first meeting of 2018 will focus on design life requirements of tunnels and how these are assessed by designers; and improvements and cost savings that can be made on projects when the concrete mixes are tested early on in the design stage.
Speakers: Charles Allen, Phil Bamforth, Jon Knights

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

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