

# Tunnels

AND TUNNELLING

## SPARVO SOIL SUCCESS

*The world's largest running TBM, for which BASF is supplying soil conditioning and tail sealants, has reached half way on the 2nd of the Italian twin tube tunnels*

**BASF**

The Chemical Company

**MEYCO**

Expanding Horizons Underground

Drive your TBM faster -  
Succeed in difficult ground

All your solutions out of one hand:



**Tail sealants**

- first fill and various driving grades including non-oil based
- all sealants Matsumura pressure tested >34 bar
- site references up to 7 bar water pressure

**Main bearing greases**

- MEYCO BSG sealing greases
- MEYCO EPB lubricating greases (EP-0 and EP-2)
- Merkel and James Walker tested

**Foams & polymers**

- RHEOSOIL to prevent clays from clogging
- MEYCO SLF tailor made foams for your site conditions

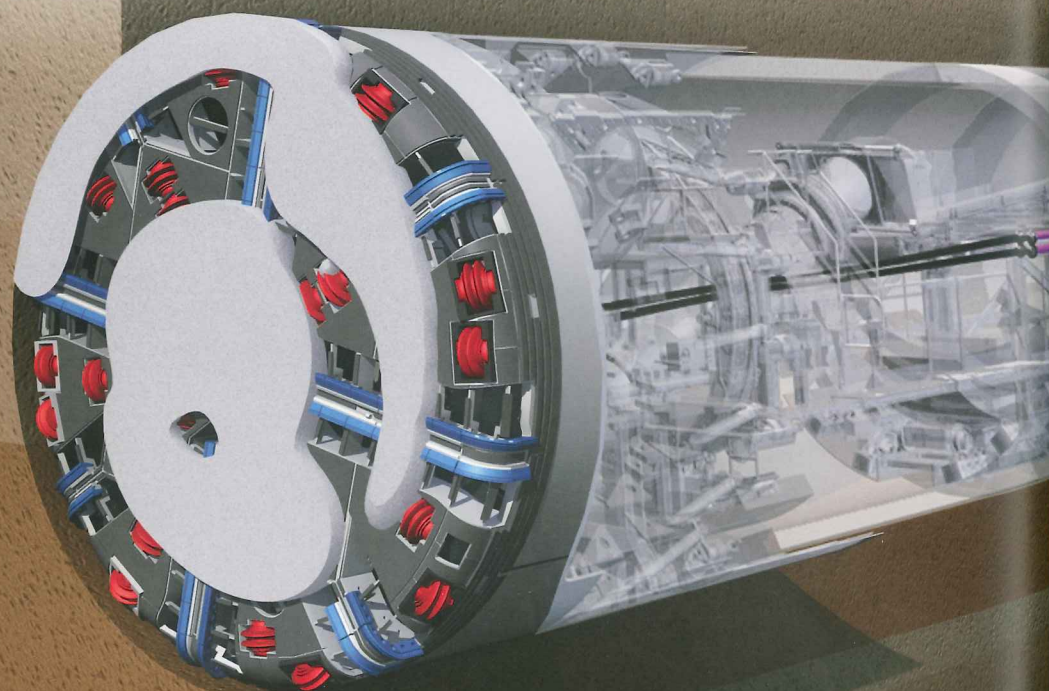
**Annulus grout admixtures**

**Segment concrete admixtures**

**Foam systems**

... and engineering know-how

[www.meyco.basf.com/tbm](http://www.meyco.basf.com/tbm)



Expanding Horizons

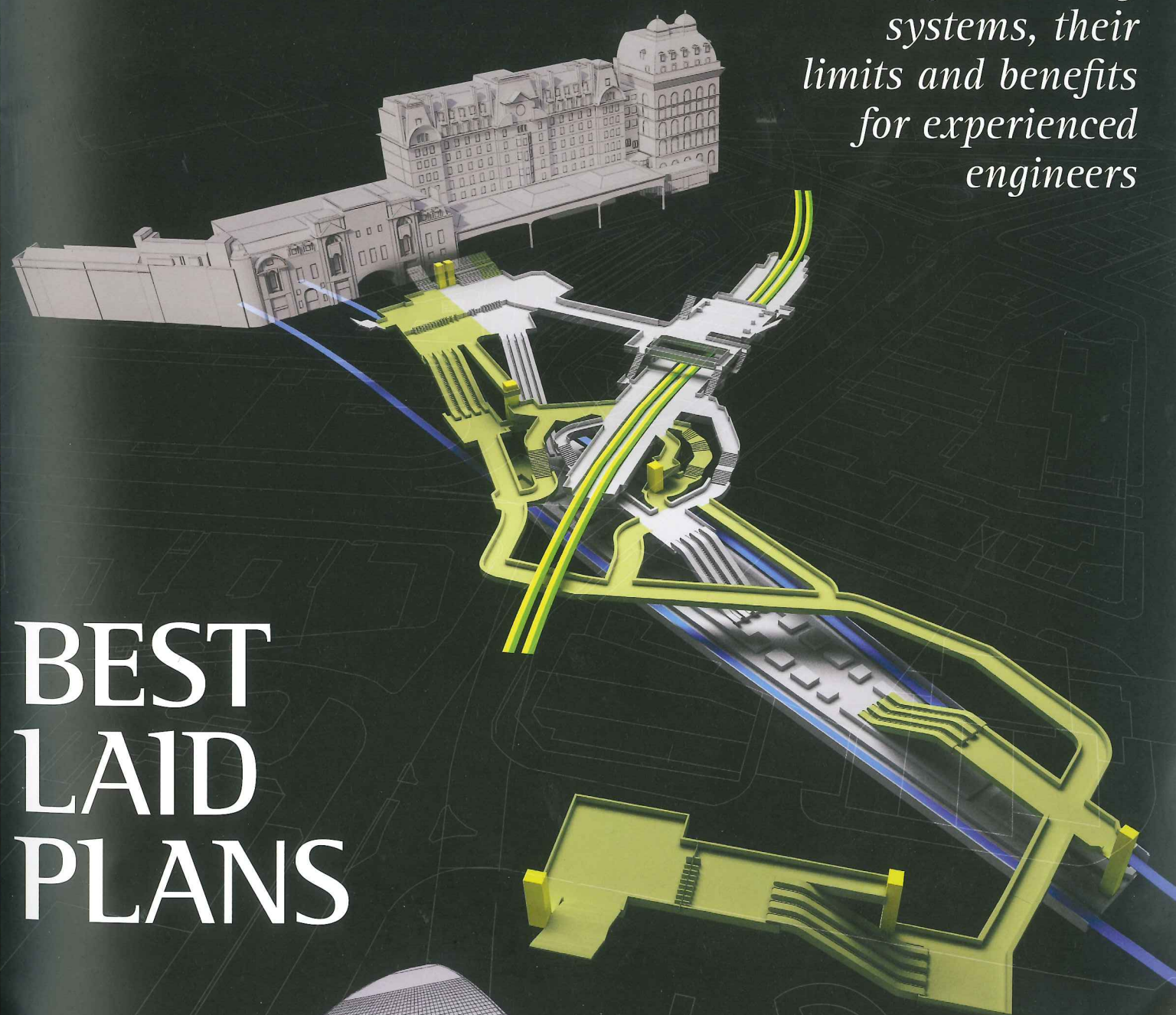
Underground



# Tunnels

AND TUNNELLING

*The practical  
use of modelling  
systems, their  
limits and benefits  
for experienced  
engineers*



## BEST LAID PLANS

WTC • Brisbane Airport Link

## IRON LEGACY

ONE OF Britain's most formidable political figures of the last century died last month. Margaret Thatcher's legacy to the British tunnelling industry is sure to divide opinion in the same way her entire political career has.

During Thatcher's time in office Britain, together with France, completed a fantastic engineering wonder, the Channel Tunnel crossing. It is still the world's longest undersea tunnel and brought true an idea that had been dreamt of by engineers for more than 200 years. Thatcher revived the notion of building a crossing after a 1975 attempt was abandoned due to costs. But she refused to hand over any Government funding and instead championed the project as the first real example of private business's power to deliver public infrastructure.

While the high speed trains racing under the English Channel are proof of the private sector's ability to build infrastructure, the resulting near financial collapse of funder and operator Eurotunnel stands testament to the challenges of making a major capital investment bring the necessary returns in ticket sales.

After refusing funding, Thatcher, with her French counterpart Francois Mitterrand, launched a working group to seek a privately funded project. The winning proposal was a rail tunnel based on the failed 1975 project.

In 1987, Eurotunnel went public to raise funds for the project. The company told investors that building the tunnel would be relatively straightforward and that 10 per cent "would be a reasonable allowance for the possible impact of unforeseen circumstances on construction costs." In reality, those attending the British Tunnelling Society monthly talks would learn, the costs were expected to well exceed the proposed budget.

Once built, the real cost of the project was double the forecasted costs in constant dollars.

According to the authors of 'Delusion and Deception in Large Infrastructure Projects', the misinformation about costs and risks served the purpose of getting the project started.

Jon  
Young  
Editor



From the 1987 IPO until cost overruns hit the project one and a half years later, share prices more than tripled.

Then they fell by two thirds and, when it became clear that revenue projections were as biased as cost forecasts, by another two-thirds.

In 1995, Eurotunnel stopped interest payments on its loans and began a decade-long, tumultuous process of financial restructuring from which it did not recover until 2007. The intended flagship of privatisation became a scare story for business and set back the process of infrastructure privatisation by at least a decade.

Despite these shortcomings, Thatcher's private funding solution succeeded in building a tunnel where public funded schemes had failed.

Arguably, Thatcher's legacy to the tunnelling industry is the world's longest undersea crossing.

Chairman and chief executive officer of the Eurotunnel Group, Jacques Gounon said, "Margaret Thatcher's vision was a driving force behind the building of the Channel Tunnel, one of the most iconic infrastructure developments of the 20th Century" 

www.tunnelonline.info

A world of  
information  
fully archived  
and searchable  
at the click of  
a mouse



## Your Time is Gold

Mining safe and fast is the key to tunneling success. The clock starts ticking when you place your order with us. At Caterpillar Tunneling, we are engineered to operate under pressure. Our project managers are your single point of contact and serve as your hub of information to manage all critical activities. This highly experienced team orchestrates everything it takes to ensure your TBM is delivered on time and in the way you want it.

A Champion for Your  
Enduring Success

**CATERPILLAR®**

### Cover

This month's cover shows a computerised image of a modern design for Victoria Station, London



### Next issue

In the June issue of *Tunnels* we look to Indonesia as a new powerhouse of the global economy. Mega metros are another focus as we get a manufacturers view of one of the major drivers of the industry, and the question of what to do with nuclear fuel is raised

### This month...

#### 10 YEARS AGO

Herrenknecht has just been awarded a deal to supply two 13.2m slurry TBMs to the 9.7km-long SMART project in Kuala Lumpur, Malaysia. The USD 650M drive will be constructed in two drives from a single shaft near the city centre. The central 2.7km section will double up as a toll road during dry periods. The road deck will be two-thirds down the tunnel, with the bottom third still acting as an overflow.

#### 20 YEARS AGO

The Heathrow Express Project in London has leapt back into life with tendering underway and construction to begin in Autumn. The GBP 45M of tunnelling on the Heathrow Express should complete in 1995. The most economical method for tunnelling would be a backhoe face shield, but there may be scope for a TBM if tunnel drives are unified into one contract. Much of the station work will be NATM.

#### 40 YEARS AGO

Mowlem has announced completion of the first tunnel forming part of the Piccadilly Line Extension to Heathrow Airport in London. The job called for up to 6.7m-deep cut and cover works from Hatton Cross to the airport perimeter, followed by deep driven tunnels from there to the new Heathrow Central Station.



TBM.CAT.COM

CAT, CATERPILLAR, their respective logos, "Caterpillar Yellow" and the "Power Edge" trade dress, as well as corporate and product identity herein, are trademarks of Caterpillar and may not be used without permission. © 2013 Caterpillar. All Rights Reserved.



## WORLD CHAMPION IN XXL-FORMAT.

- Mechanized tunnelling technology for all ground conditions
- Traffic as well as supply and disposal infrastructures
- Diameters from 0.10 to 19m
- Around 375 kilometers of tunnel with diameters >10 meters

Construction companies have successfully excavated some 375 kilometers of tunnel worldwide in about 100 projects, using Herrenknecht machines with diameters of more than 10 meters. Multi-lane road tunnels, railway tunnels and expansive metro lines provide sufficient capacities for efficient transport systems.

The world's two largest Mixshields (Ø 15.43m) have built a double-tube, combined road and metro tunnel beneath the Yangtze River in Shanghai. One of the two machines is currently being re-used. Together with a smaller Mixshield (Ø 14.90m), this giant is currently excavating two double-tube road tunnels beneath the Huangpu River. The tunnels will connect the districts of Baoshan and Pudong and/or Minhang and Fengxian. As part of these projects, a total of around 25 kilometers of tunnel with mega-diameters are being built.

For the Miami Port Tunnel, Herrenknecht delivered the largest tunnel boring machine ever employed in loose rock in the USA. The construction crews celebrated the breakthrough of the first tunnel by the Herrenknecht EPB Shield S-600 (Ø 12.86m) in Florida on July 31, 2012.

The world's largest tunnel boring machine, the EPB Shield (Ø 15.55m), is in operation constructing the Sparvo road tunnel in Italy quickly and safely. The first, around 2.5 kilometer long XXL tube was completed with daily top performances of up to 22 meters on July 26, 2012.

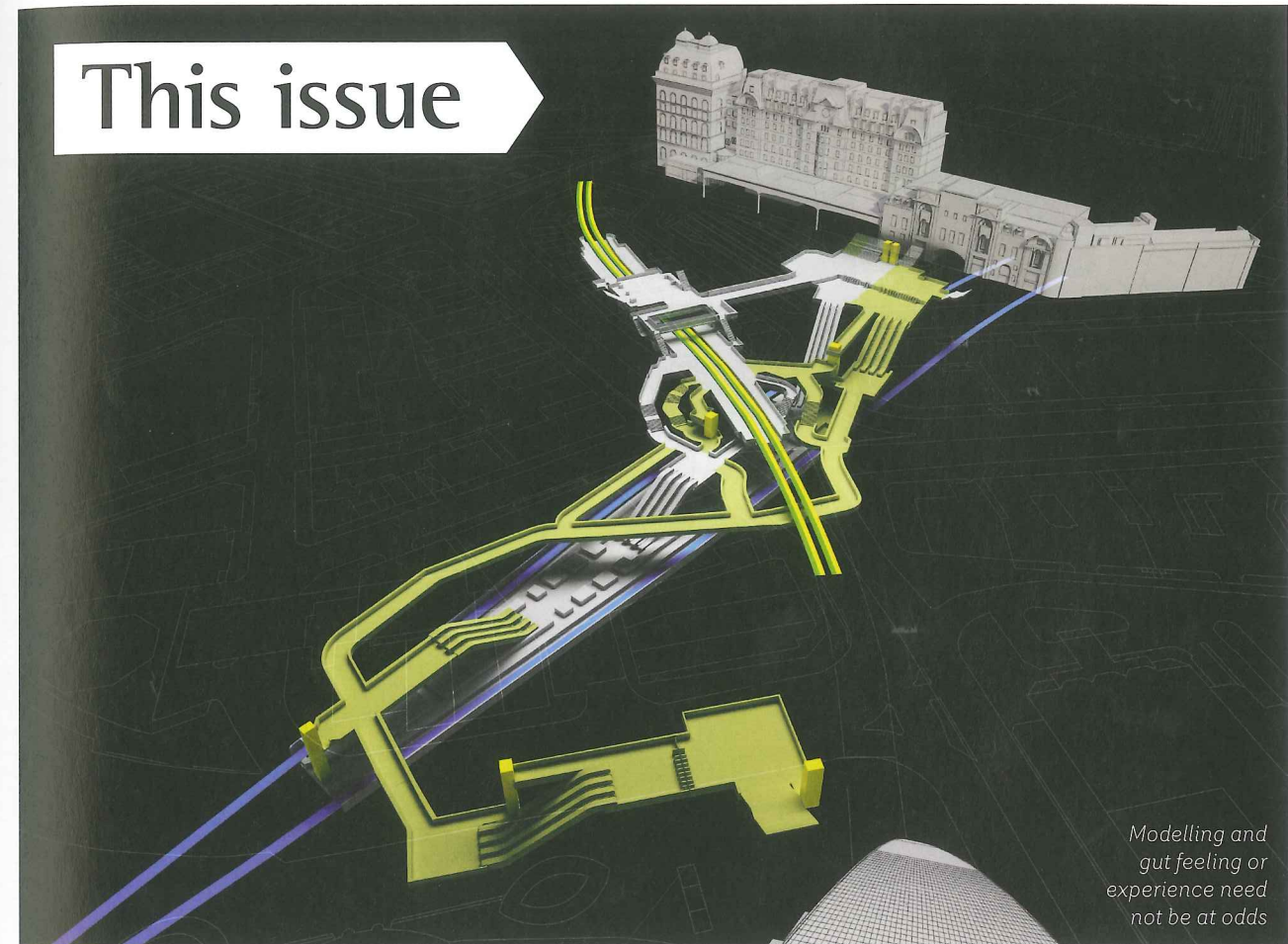
As the only company worldwide, Herrenknecht AG delivers tunnel boring machines for all ground conditions and in all diameters. The Herrenknecht product range includes tailor-made machines for transport tunnels, supply and disposal tunnels as well as additional equipment and service packages.



Herrenknecht AG  
D-77963 Schwanau  
Phone + 49 7824 302-0  
Fax + 49 7824 3403  
marketing@herrenknecht.com

www.herrenknecht.com

## This issue



Modelling and gut feeling or experience need not be at odds

### News

- 7 News  
The latest project updates and corporate moves around the world
- 13 Letters  
A snapshot of the editor's inbox from the past month
- 16 Bigger picture  
This month's photo worth a thousand words in tunnelling

### Australasia

- 21 Brisbane Airport Link  
The market-defining project finally completes. *Tunnels* digs in

### Insight

- 31 Prague Metro  
The second of a three-part article on the history of Prague Metro

- 61 WTC 2013 Preview  
The latest Tunnels guide an industry event builds on a proud history of invaluable advice

### Technical

- 37 Lining Marche-Umbria  
A new lining system is reinforced with tubular arches in Italy
- 45 Practical modelling  
Good modelling should be tempered by the required results and a grounding of experience
- 53 Bond Street modelling  
Computer modelling at the Bond Street Station upgrade in London

### BTS

- 66 Norra Laenken  
The project in Stockholm, Sweden was the subject of the January British Tunnelling Society meeting

### Contributors

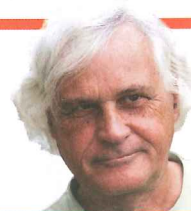
**Ermin Stehlik**  
Ermin is the tunnelling specialist for Czech contractor Metrostav. He has in past years worked extensively with *Tunnels*



**Ali Nasekhian**  
Ali is a senior geotechnical engineer at Dr. Sauer & Partners. He writes in this issue on the Bond Street Upgrade



**Adrian Greeman**  
Adrian is a long-standing regular technical writer for *Tunnels*. His experience is extensive and varied.





## Constructing a Sustainable future.

At VINCI Construction Grands Projets, we engineer solutions that are not only financially competitive, but work sustainably for the planet. It starts with putting Safety first, always, at all times, on every site. Health & Safety training, policies and guidelines are all in place, but to generate the best possible results, we go further with our innovative (A)live on Site programme. We understand that our people are more reactive to what concerns them directly, we have a team who visit the site, shoot a short movie and then broadcast it to the team. Each scene is analysed with behaviour experts, underlining the good (and less good) actions. (A)live on site has been successfully delivered to more than 2,000 people, in 12 languages, across 14 countries, including the UK.

To learn more please visit [www.vinci-construction-projects.com/british-isles](http://www.vinci-construction-projects.com/british-isles)



### News briefs

#### CANADA

Four workers who encountered a pocket of methane on a sewer project in York were sent to hospital after a small explosion, according to media sources local to Ontario. One person suffered severe burns. The Ontario Ministry of Labour has been called in to investigate.

#### MEXICO

Mining Equipment is preparing to send a moveable passing switch to contractor ICA for Mexico City's Tunel Emisor Oriente (TEO) project, a 62km-long wastewater tunnel that will add about 150 cubic meters of water per second to the city's wastewater capacity.

#### SINGAPORE

SP PowerAssets (SPPA) appointed Maxwell GeoSystems to provide the instrumentation data management systems for two transmission cable tunnel projects in Singapore. Then contract is for six years and Maxwell GeoSystems will supply technicians to audit data as the tunnel progresses.

Corporation drops micro tunnelling plan around Srirangam temple

**India** Local authorities in Srirangam, India, have shelved a plan to lay buried sewer lines around the ramparts of the Sri Ranganathaswamy Temple in Srirangam, owing to fears of possible damage to the historic structure.

The Tiruchi Corporation, which is responsible for the project, planned to lay the sewer lines using microtunnelling technology in immediate surroundings of the temple ramparts, according to local press.

The plan was incorporated to provide the underground sewer line in Chithra, Uthira Veedhis and Adayavalanjan in Srirangam as the network has to run across narrow strips of land between the rear side of houses and the ramparts of the temple.

Following a technical study it was felt that the vibration caused by microtunnelling could possibly damage the ramparts. It was also indicated that the move could be taken up only after a pilot project, but sources told local press that the cost

of such a project would be too expensive.

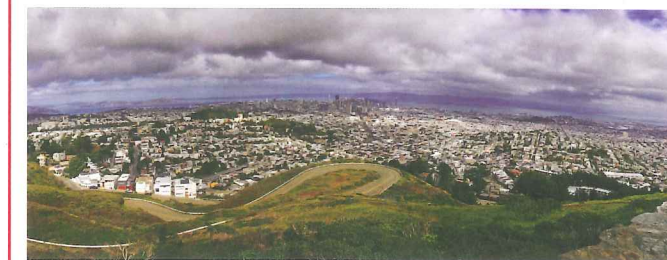
Second TYSSE TBM makes final breakthrough

**Canada** One of the four 6.12m diameter Caterpillar EPBMs mining the Toronto-York Spadina Subway Extension (TYSEE) has completed its final drive in early March.

Breaking through the headwall of Downsview extraction shaft in Toronto, this is the second TBM, named Moley, to finish tunnelling on the project. The TBM tunnelled 1.2km in its final drive and placed 799 tunnel liners. The first TBM, Holey, completed excavation late last year. The contractor for both drives is the joint venture of McNally, Kiewit and Aecon, constructing the southern tunnels package including 5.8km of tunnels in four drives.

The joint venture launched Moley in autumn 2011 and the TBM finished its first northbound drive on 4 June, 2012, at the Keele Street extraction shaft. After being moved back to Sheppard West launch shaft, it started its southbound

## CALIFORNIA PLANS 56KM OF TUNNELS



Extensive twin tunnels would provide water conveyance.

**USA** The California Natural Resources Agency released the first seven of 12 draft chapters on the Bay Delta Conservation Plan (BDCP), which calls for some 35 miles (56km) of twin tunnels to be built in California in March.

Governor Edmund 'Jerry' Brown has proposed 40ft (12.1m) inside diameter tunnels built more than 150ft (45.7m) underground, along with water intakes and habitat restoration to reverse the decline of native fish populations in the Delta and provide reliable water delivery for two-thirds of California's population and much of the state's agricultural economy.

The final chapters were scheduled to be released in late April, as *Tunnels* went to press, and the BDCP's Administrative Draft Environmental Impact Report/ Environmental Impact Statement (EIR/EIS) will be released to the public in early May. A public comment period will be held later in the year.

The newly-released chapters detail the proposed operation of a new system of pumping plants and tunnels to carry water from the Delta. A new water project diversion point on the Sacramento River near Sacramento and 35 miles (56km) of TBM-driven tunnels would secure water deliveries against catastrophe.

"At any time, a flood or earthquake could inundate the below-sea level islands in the interior Delta and draw salt water toward the existing south Delta pumping plants, which would have to be shut down to avoid contamination," according to the agency.

Water deliveries to the Bay Area, San Joaquin Valley, and Southern California have been reduced in recent years in part because of the presence of federally protected salmon and smelt near the existing water pumps in the south Delta.

Last July Governor Brown, joined by Secretary of the Interior Ken Salazar, announced revisions to the plan, including a 40 per cent reduction in the capacity of proposed new water diversion intakes along the Sacramento River.

The Obama administration has been working with various agencies in California to assist in developing a plan that will meet legal requirements and allow for appropriate integration with the federal Central Valley Project.

drive and reached the final breakthrough on 5 March. The Cat TBM bored 2.89km of tunnels and installed 1,813 segment rings through glacial till, sand, silt and clay grounds under Toronto.

There are two other TBMs working on the subway extension, all supplied by

Caterpillar to the project owner, Toronto Transit Commission, in 2010. The contract works include 10 TBM drives totalling 13.4km of tunnels and were awarded to two joint ventures, the second, for the northern tunnels package, is comprised of OHL-FCC.

# KATHMANDU-HETAUDA HIGHWAY HANGS IN BALANCE

**Nepal** The much-hyped Kathmandu-Hetauda tunnel highway project was in limbo as the company that was supposed to undertake the project couldn't come up with convincing plans to ink concession agreement with the government, sources in Kathmandu said on 8 March.

The government refused to sign the concession agreement after the company couldn't demonstrate a strong payback plan and guarantee that the money people invest would be returned, according to the sources.

"The company has just made a very rough plan and did not convince us," said an official at the Ministry of Physical Planning, Works and Transport Management (MoPPW). "The company also failed to show strong funding sources for development of the project."

The Nepal Infrastructure Development Company (NIDC) that conducted the detailed project report of the tunnel highway has been pushing the government to sign the concession agreement. "But, as a government official, I can't even think of letting them go collect people's money when they don't have any payback plan," said a high ranking official at the ministry.

"We have submitted our financial plans to the government," said Lal Krishna KC, vice-president of NIDC. "We have not heard anything from the government about the payback plan and insurance so far." KC further added that the company was always ready to address the concerns of the government about people's money.

The project that the government handed over to NIDC under build-own-

operate-transfer act-2006 would link Kathmandu with Hetauda.

"The company could not assure us as to how it would generate funds for the project," said Secretary at MoPPW Tuls Prasad Sitaula.

The company has claimed that it would complete the project within four years and has estimated the cost of the project at NPR 22bn (USD 250M). "We are waiting for the company to come up with a strong financial plan," Sitaula added.

The company has claimed that it would generate funds for the project from different sources such as public investment, consortium of different business groups, investment from non-resident Nepali and by issuing shares to the workers and contractors in return for their labour.

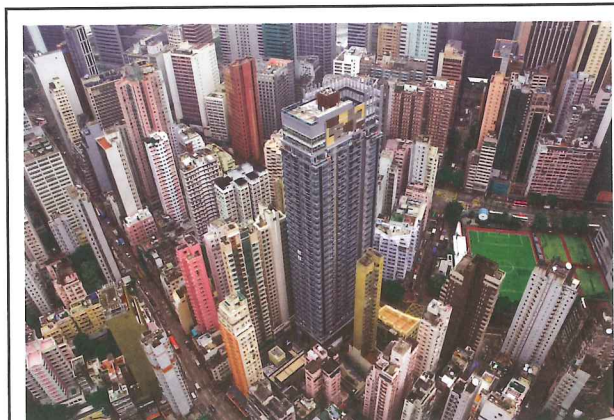
## TBM Betty breaks through at Preston

**Great Britain** The TBM cutting the Preston sewer improvement scheme has broken through, the contractor announced last month. The GBP 114M (USD 173M) sewer improvement scheme is being undertaken by joint venture of Kier Infrastructure and Overseas, J. Murphy & Sons and Interserve Construction (DMI) as part of United Utilities capital programme in west Lancashire and north Manchester.

The scheme, which began two years ago, involved the complex construction of interceptor sewers, stormwater storage tunnels, 6km of tunnelling, rising mains and 13 access shafts, designed to upgrade the city's aged sewer system.

A team of 200 engineers has been working collaboratively around the clock to deliver the scheme, often working 100ft (30m) below the city streets.

Once fully operational, the new sewer network will intercept the flows and divert



Hong Kong's Highways Department has signed a USD 622M contract with China State Construction Engineering for the Central-Wan Chai Bypass. The contract involves the construction of a 300m long section of twin-box tunnel under the seabed of Causeway Bay Typhoon Shelter and a 150m long slip-road tunnel, the department said. Director of highways Lau Ka-keung said this was the project's final contract for tunnel construction. The overall project is a 4.5km dual three-lane carriageway with a 3.7km tunnel. Construction works for the project started in 2009 and are expected to be completed in 2017.

them 10km westward, via a new pumping station, to the town's main treatment works at Clifton Marsh.

A 2.5km stormwater storage tunnel and two linked shafts will regulate the flow of up to 40,500m<sup>3</sup> of stormwater on its route to

the treatment works.

Andy Parker, KMI contracts managers said: "The innovative solutions employed on the project have included one of the most complex grouting and dewatering systems ever installed, and the use of

a German pipe thrusting technique never before used in the UK. The technique achieved record daily thrust lengths and proved to be a cost effective solution in the challenging conditions."

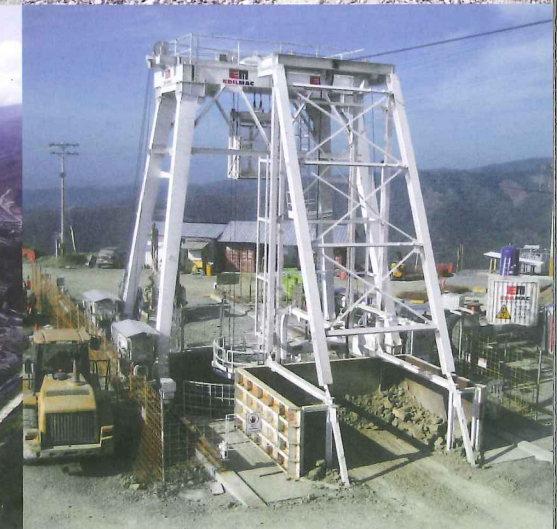
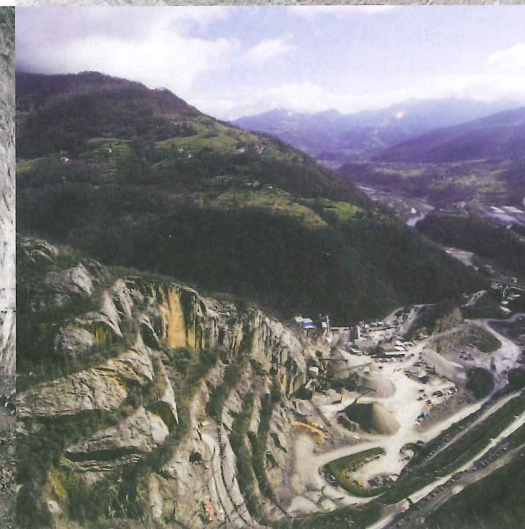
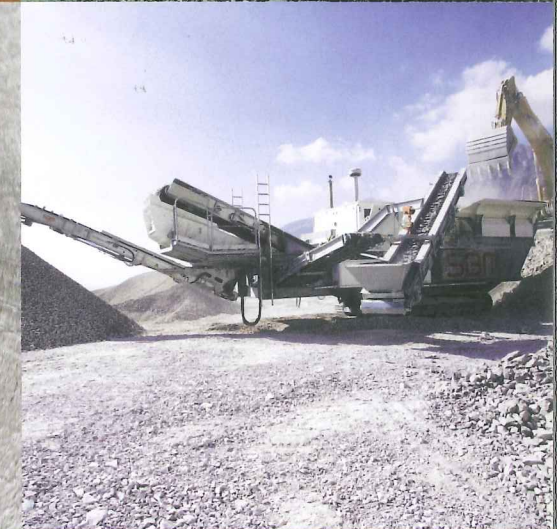
## Panama finishes tunnelling

**Panama** The TBM boring the southbound drive of Panama Metro's Line One made its final breakthrough on 16 March at Carmen Station. The contractor, an FCC-led consortium with Odebrecht, launched the Herrenknecht TBM with a 9.7m diameter in January 2012. Completing a 3.9km drive, the TBM placed 2,361 precast concrete rings for the lining, according to El Metro de Panama.

A second TBM completed the 2.8km northbound drive on December 19, 2012, having launched in June 2012. Carolina also broke through at Carmen Church station, and installed 1,709 rings. Along the route, Marta and Carolina combined extracted approximately 800,000cu.m of spoil, and mined a total of 6.7km.



## MARKS CARVED IN ROCK



QUARRY MANAGEMENT | RAISE BORING | TUNNELS - SHAFT SINKING

[www.edilmac.com](http://www.edilmac.com)

It all began fifty years ago, however, we're young and strong as ever.

We use exclusive 'Raise Boring' techniques, our experience is proven by our achievements

and we offer a timely and reliable service at competitive prices.

You can feel safe with Edilmac. Your satisfaction is our reason for being.

**EM**  
**EDILMAC**

EDILMAC DEI FRATELLI MACCABELLI S.r.l. Via Trento, 16 - 24020 Gorle (BG) Italy  
tel +39 035 661017 fax +39 035 662339 e-mail: [edilmac@edilmac.com](mailto:edilmac@edilmac.com) - [www.edilmac.com](http://www.edilmac.com)

## BBA MULLS TUNNEL UNDER KARNAPHULI RIVER

**Bangladesh** The first ever river tunnel under the Karnaphuli river has been planned.

A study has found a 3.4km passageway to be feasible for it at the estuary of the river as it ensures connectivity of the Chittagong city with the proposed deep-sea port and Cox's Bazar, the tourist town.

Local officials said the feasibility study had confirmed the multi-lane tunnel route would pass through the river with the Navy College on one side and the Korean Export Processing Zone and Karnaphuli Fertiliser Company on the opposite bank.

"A tunnel downstream has been found to be more suitable than other sites as it will also be connected with the outer ring road on the surface, which is being planned to pass along the Patenga sea beach," said an official at Bangladesh Bridge Authority (BBA).

The official added the tunnel would help reduce the road distance between Chittagong and Cox's Bazar, apart from facilitating the heavy highway traffic on Dhaka-Chittagong Highway by relieving it from entering the Chittagong city before going on to other parts of the district.

The joint-venture of China Communication Construction Company and Arup, which conducted the feasibility study over the last

two years, has proposed the tunnel with a total length of over 6km including two approach roads. The estimated cost comes to USD 692M.

The study has also found two other locations, which are very close to three Karnaphuli road bridges, on the river's upstream. But those might turn out to be more difficult for implementation of the tunnel.

In addition, the report showed the traffic movement would be divided into two separate tunnels, each having two road lanes. It kept in consideration the draught and navigability of the ships using the Chittagong seaport.

BBA, the executing agency of the tunnel project, launched the feasibility study from its own funds to determine the economic, financial and technical viability of the construction of the multi-lane tunnel under the river Karnaphuli.

The officials said the tunnel would help expedite industrial growth and urbanisation in other parts of the river.

The width of the river is about 700m and its depth is 9m to 11m and it flows into the Bay of Bengal 19km downstream from Chittagong.

BBA has previously said the three existing bridges crossing the Karnaphuli are not sufficient to accommodate the existing and future traffic. Issues with silt also require a new tunnel as opposed to a new bridge.

**Waterview Connection project accepts 14.5m diameter TBM**

**New Zealand** The start of tunnelling on the NZ Transport Agency's (NZTA) Waterview Connection project in Auckland has moved a step closer with the agency's Well-

Connected Alliance formally accepting the machine it will use to construct the twin 2.5km-long tunnels, NZTA stated earlier this month.

NZTA announced that the 14.5m diameter machine is the world's 10th largest TBM. The machine has been designed specifically

for the USD 1.16bn project - the biggest transport construction project in New Zealand's history.

"The size of this project and the size of the tunnel boring machine are both on a scale the likes of which we have never seen before in New Zealand," said Tommy Parker, NZTA's state highways manager for Auckland and Northland. "Since mid-2012 we have been preparing a trench that will not only form the southern tunnel approach, but provide the TBM's launch pad. This requires us to excavate to a depth of 30m, initially, drilling and blasting through a 15m thick layer of very hard volcanic rock."

To construct two 2.5km tunnels, the TBM will pass beneath rock and tunnel through the softer clays of the East Coast Bay

Formation. It is expected to take a year to complete the first tunnel, with the TBM due to emerge just beyond Great North Road in Waterview where work is already under way to prepare for its arrival and turnaround for the return journey.

**TGV Paris-Strasbourg project still ahead of schedule**

**France** On February 25, months ahead of schedule, TBM Charlotte completed excavation for the two tubes of the Tunnel de Savern, a spokesman for Herrenknecht announced last month. During the tunnelling of the second tube, the site teams achieved a record performance of 1,014m in 30 days.

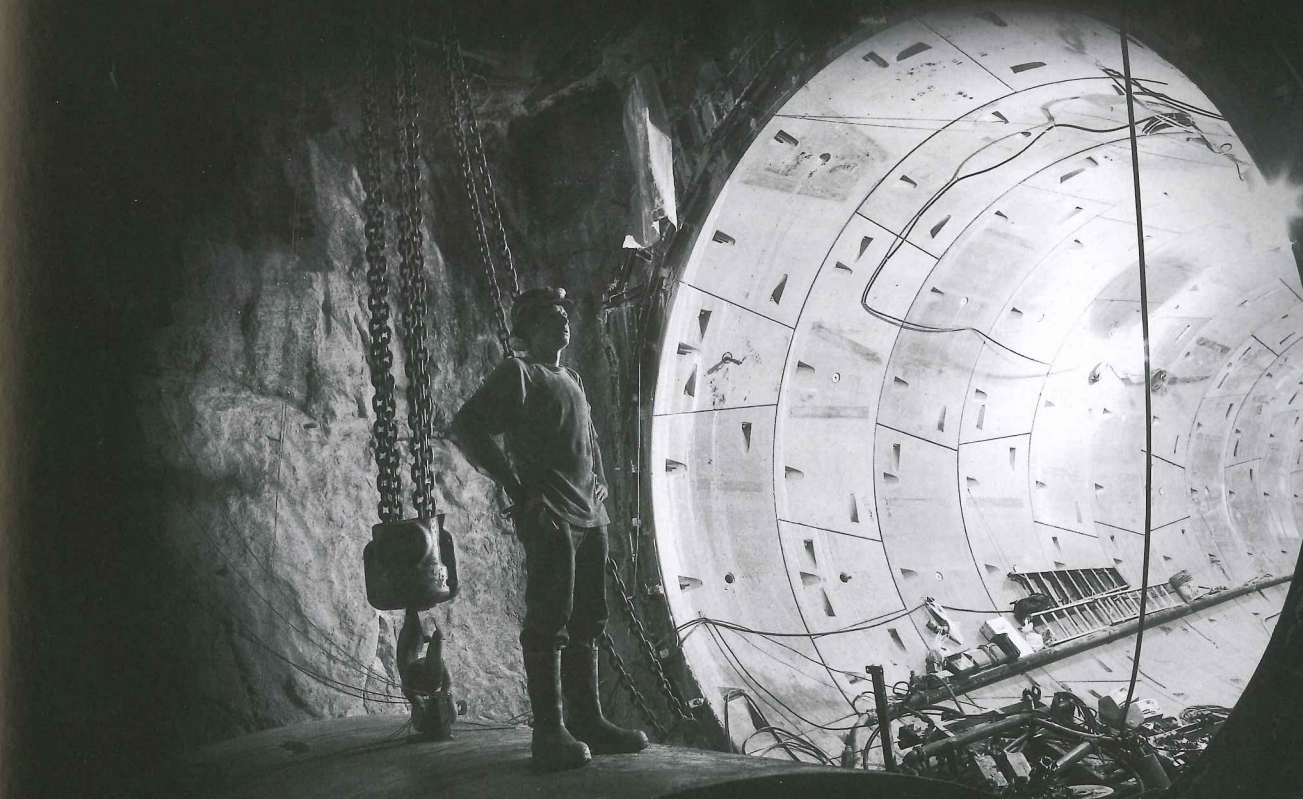
The TBM began excavation of the nearly 4km long north tube on the eastern side of the Vosges at the launch portal near Ernolsheim lès Saverne in November 2011. Two months ahead of schedule it was able to complete excavation of the first tube on the west side of the Vosges in late June 2012. During the advance the site teams achieved daily best performances of up to 46m.

The machine was then disassembled and set up ready to go again at the launch portal near Ernolsheim lès Saverne. In late September 2012 the TBM began with the excavation of the southern tube. During the five months of tunnelling, the site teams exceeded their daily best performances of the first tube.

The rail tunnel is part of the section on the TGV Paris-Strasbourg line currently being expanded. The French TGV currently takes two hours and 20 minutes from Paris to Strasbourg.

Further expansion eastwards over 106km through Alsace to Strasbourg is running at full speed in order to shorten the journey time for passengers by 30 minutes from 2016.

# » ENVIRONMENTAL MONITORING AND MACHINE CONTROL: FROM BREAKING GROUND TO BREAKING THROUGH. SEE THE LIGHT



Trolex is with you from project inception through the lifetime of the tunnel, providing Environmental and Machine Monitoring and Control. With a direct line to project engineers, rapid-response on-site support and a full commissioning and maintenance service, you'll find working with us to be an enlightening experience.

See the light at [www.trolex.com](http://www.trolex.com) or call +44 (0) 161 483 1435

**TROLEX**



Auckland, New Zealand

## How do you drive a train under water? Think Murphy.



First the Channel Tunnel Rail Link, now London's Crossrail. Tunnelling and underground construction specialist Murphy, is working below the River Thames again, in the £200 million project that will link East and West London. We are constructing The Thames Tunnel – two tunnels and portal structures totalling 8km in southeast London – connecting the district of Plumstead to North Woolwich and joining the existing North Kent rail line to Crossrail. Work has begun on this important and innovative transformation which is

due to be completed by the end of 2015.

For more than 60 years, Murphy has been building and maintaining the infrastructure of the nation. We continue to break new ground with the design and construction of high profile projects across a range of key industries. From national tunnelling, power and rail projects to major water and wastewater contracts, pipelines, and process plant construction; with Murphy, the thinking is always as important as the delivery.

# MURPHY

Breathing life into infrastructure

For deeper thinking visit [www.murphygroup.co.uk](http://www.murphygroup.co.uk)

## Letters

### News briefs

#### GREAT BRITAIN

Sustainable transport charity Sustrans is getting ready for the official opening of the Two Tunnels Greenway on a former railway line in Bath. The route between Bath and Midford includes what will be Britain's longest cycling tunnel, the Combe Down Tunnel, at 1,700m.

#### INDIA

An official of the Chennai Metro Rail Limited (CMRL) warned that of the 740 buildings the TBM passed under in the Washermenpet-Mannady stretch of north Chennai, 18 have developed fresh cracks. Most of the cracks were minor settlement cracks and less than 5mm in width.

#### HONG KONG

The Tsuen Wan Drainage Tunnel was commissioned on 28 March, the Hong Kong government announced last month. The 5.1km tunnel is expected to raise the flood protection level of the Tsuen Wan and Kwai Chung areas.

#### GREAT BRITAIN

Crossrail's lead tunnelling machine, Phyllis, has arrived at Bond Street station on Davies Street. The TBM also constructed its 2,000th tunnel ring as it passed through the first metres of the station.

#### GREAT BRITAIN

The government has stated an extra GBP 3bn (USD 4.5bn) will be spent on infrastructure projects a year. Chancellor George Osborne said that additional funds for road and rail projects will be found from cuts to spending.

#### SINGAPORE

Two Herrenknecht EPBMs for Singapore's Downtown Line Stage Three (DTL3) contract 935 have been commissioned in the factory in China in January and March and await delivery to site mid-year.

#### USA

Amtrak and a private developer have tentatively reached an agreement to build a USD 150M tunnel box under Hudson Yards, where rail tunnels from New Jersey could one day connect to New York.

#### CANADA

The British Columbia government revealed five options under consideration for replacing the George Massey Tunnel crossing on March 11, including building a replacement tunnel. The four-lane tunnel opened in 1959.

### Contact us

Send us your opinions: [editor@tunnelsonline.info](mailto:editor@tunnelsonline.info)  
7 Carmelite Street, London, EC4Y 0BS

## DEBATING NATM

Given below is a response to, 'NATM – from a construction method to a system', published in your February, 2013 international edition and authored by Wulf Schubert and Harald Lauffer.

It is exceedingly tiresome to read another self-inflating article about how wonderful is the New Austrian Tunneling Method. In order to build a tunnel you must excavate the ground, you must control the face during the process of excavation, you must support the ground as the tunnel is advanced, and, finally you must install the final lining. Given below is the official definition of NATM: 'The New Austrian Tunneling Method is based on a concept whereby the ground (rock or soil) surrounding an underground opening becomes a load bearing structural component through activation of ring-like body of supporting ground.'

To the best of my knowledge the Austrians have made no significant contributions to ground excavation, face support or final linings. TBMs, EPBMs, roadheaders, drill and blast, compressed air, grouting, construction de-watering, and segmental linings, have all been developed totally independently of anything that has happened in Austria and all of these procedures are readily available to tunnelling professionals in Norway, South Africa, America, Great Britain, or anywhere else for that matter.

No one denies the beneficial, pioneering efforts of Dr. Rabcewicz in the 1950s and '60s relative to using rock bolts and shotcrete to support bad ground, but these procedures do not constitute a 'method of tunneling' any more than does the use of ribs and boards. Moreover, no one denies the benefits of 'monitoring' the ground during the process of tunnelling. Lastly, I am not aware of any advantage that egg-shaped openings have as compared to circles for supporting the ground.

How is it that this NATM propaganda has been allowed to permeate the tunneling industry for all of these years? NATM is one small and insignificant subset of conventional tunnelling that is available to anyone who understands ground-lining interaction. The authors of your article state that their fervent wish would be "for the industry to regard tunnelling as a regular engineering task and reduce the emotions and mysticism." If you want to see someone get emotional, tell an Austrian that he or she has no idea what they are talking about. With respect to mysticism, I am not aware of any aspect of tunneling that is more 'mystical' than NATM. Mysticism: having a spiritual reality that is neither apparent to the senses nor obvious to the intelligence.

Gary Brierley, Brierley Associates

### In response...

It appears that Gary Brierley is not really making reference to our paper, but rather airing his frustration about the dominance of Austrian tunnel engineers, or people who claim to be such. The aim of our paper simply was to show the development in tunnelling from the Austrian perspective, and pointed out that besides proper technology, sound engineering, site organisation, up to date monitoring, skilled and socially competent

engineers and miners, and appropriate contract setup are important prerequisites for successful tunnelling. Creating systemically favourable conditions in our opinion is at least as important as sound technology. It is not just excavate-support-concrete, that makes a project successful! What counts at the end is if you have delivered a technically sound product at reasonable cost, regardless of the method you used or what you called it.

Wulf Schubert, TU Graz

Company	February	March	Change (%)
Aecom (NYSE: ACM)	31.90	31.41	▼ 0.49 (1.54)
Atkins (LSE: ATK)	920.26	913.00	▼ 7.26 (0.79)
Balfour Beatty (LSE: BBY)	265.40	272.00	▲ 6.6 (2.49)
BASF Global (XETRA: BAS)	75.11	73.36	▼ 1.75 (2.33)
Bekaert (BSE: BEKB)	21.97	22.54	▲ 0.57 (2.59)
Bilfinger Berger (DUS: GBF)	81.82	81.62	▼ 0.2 (0.24)
Caterpillar (NYSE: CAT)	89.28	89.74	▲ 0.46 (0.52)
Costain Group (LSE: COST)	286.06	289.56	▲ 3.5 (1.22)
Ferrovial (MCE: FER)	12.60	12.56	▼ 0.04 (0.32)
Hindustan Construction Company (BOM: HCC)	15.60	15.50	▼ 0.1 (0.64)
Hochtief (XETRA: HOT)	54.99	55.09	▲ 0.1 (0.18)
Morgan Sindall (LSE: MGNS)	543.00	542.50	▼ 0.5 (0.09)
Sandvik (STO: SAND)	103.80	104.70	▲ 0.9 (0.87)
Shanghai Tunnel Engineering (SHA: 600820)	8.76	8.88	▲ 0.12 (1.37)
Strabag (LSE: STR)	18.74	18.65	▼ 0.09 (0.48)
URS Corporation (NYSE: URS)	45.17	45.09	▼ 0.08 (0.18)
Vinci (EPA: DG)	35.92	36.49	▲ 0.57 (1.59)

Prices are taken on the 12th of each month. NYSE is in USD, LSE is in GBP, STO is in SEK, BSE, EPA, MCE, STR and XETRA are in EUR, BOM is in INR, SHA is in CNY.

	Rate (%)
AUD	3.00
BRL	7.25
CAD	1.00
CHF	0.25
CNY	6.00
EUR	0.75
GBP	0.50
INR	7.50
JPY	0.10
NZD	2.50
USD	0.25

Rates are taken on the 12th of each month.

to promote its consultancy. "The market is looking good," said Tim Bowen, Costain regional development director. "The region is cash rich as a result of its petrochemical exports and the Costain name and brand is very much associated with engineering excellence."

Herrenknecht recently announced that it has opened a full service branch in Abu Dhabi towards the end of 2012, which offers machine overhauls, field service and supply of spare parts. The company stated that the Arab market provides great future potential, with tunnel construction in the region facing dynamic times.

**Salini launches takeover bid of Impregilo**

Italy's Salini has launched a takeover bid for the construction group Impregilo, it was announced mid-March. Salini owns just under 30 per cent of Impregilo and has offered EUR 4 in cash for each ordinary share it does not already own, valuing the entire company at some EUR 1.6bn (USD 2bn).

The offer started on 18 March and ends on 12 April, as Tunnels went to press.

The plan is to merge the two companies to create a global construction player focused on large civil engineering projects from roads to hydroelectric dams in more than 60 countries.

**Finnish contractor signs financing agreement**

Finland Finish contractor Lemminkäinen has agreed on a EUR 255M (USD 327M) financing deal, the company announced last month. The agreement comprises a three year syndicated revolving

credit facility of EUR 185M (USD 237M) and a two year syndicated term loan facility of EUR 70M (USD 90M).

The company is replacing the bilateral credit facilities, totalling EUR 160M (USD 205M), originally agreed to mature in December 2013, a Lemminkäinen spokesman stated.

The credit facilities include two covenants reviewed on a quarterly basis; average equity ratio over four quarters and the average net debt to EBITDA ratio over four quarters. The facilities are unsecured.

"We are pleased to be able to increase our credit facility. This financing arrangement will strengthen our liquidity and give us more financial flexibility," said Robert Öhman, CFO of Lemminkäinen.

Nordea Bank Finland acted as the coordinating bank for the credit facilities. Danske Bank, Helsinki Branch, Pohjola Bank and Handelsbanken are involved in the arrangement, contributing varying shares of the financing.

**British reach expands in ME**

Middle East Maidenhead-headquartered outfit Costain is increasing its activities in the Arabian Gulf as the company expands the range of services it offers in the region, it announced last month. Costain has provided services to the oil and gas industries of Abu Dhabi for more than 30 years but hopes

**Oil price**



108.5 March 2013  
103.2 April 2013

Values are taken on 12th of each month.



# World Class Tunnel Fire Protection

Promat are the world's largest dedicated manufacturer of passive fire protection materials and global leaders in the Fire Protection of Tunnels, providing fire protection solutions to many of the world's largest tunnel projects.

Since the 1960's Promat materials have protected more than 190 tunnels using PROMATECT® boards and more than 1.4 million m<sup>2</sup> of tunnel linings have been protected using Cafco FENDOLITE® MII\*.

**Fire Protection Board Solutions**

**PROMATECT®-T and PROMATECT®-H**

- Tested to RWS and many international standard tunnel fire curves.
- Fire tested for protection of both concrete and cast iron tunnels.
- Panels can be easily removed and replaced to allow inspection of the tunnel lining.

visit [www.promat-tunnel.com](http://www.promat-tunnel.com)

**Fire Protection Spray Solutions**

**Cafco FENDOLITE® MII \***

- Tested to RWS and a wide range of internationally recognised fire test standards.
- The world's most specified spray applied fire protection system.
- Protecting more than 1.4 million m<sup>2</sup> of tunnel structures globally since 1980.

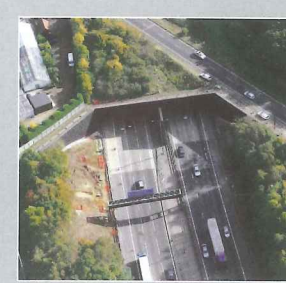
visit [www.promat-spray.com](http://www.promat-spray.com)



Clyde Tunnel, Scotland



Palm Jumeirah, Dubai



Bell Common Tunnel, London



Groene Hart Tunnel, Netherlands

For further information e-mail: [info@promat-tunnel.com](mailto:info@promat-tunnel.com)

\* Marketed as Promat PROMASPRAY® F5 in the Americas

## BRING OUT YOUR DEAD

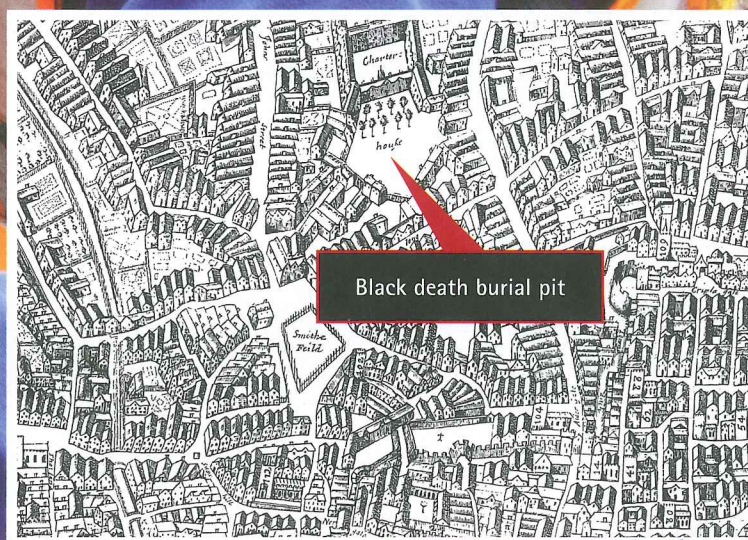
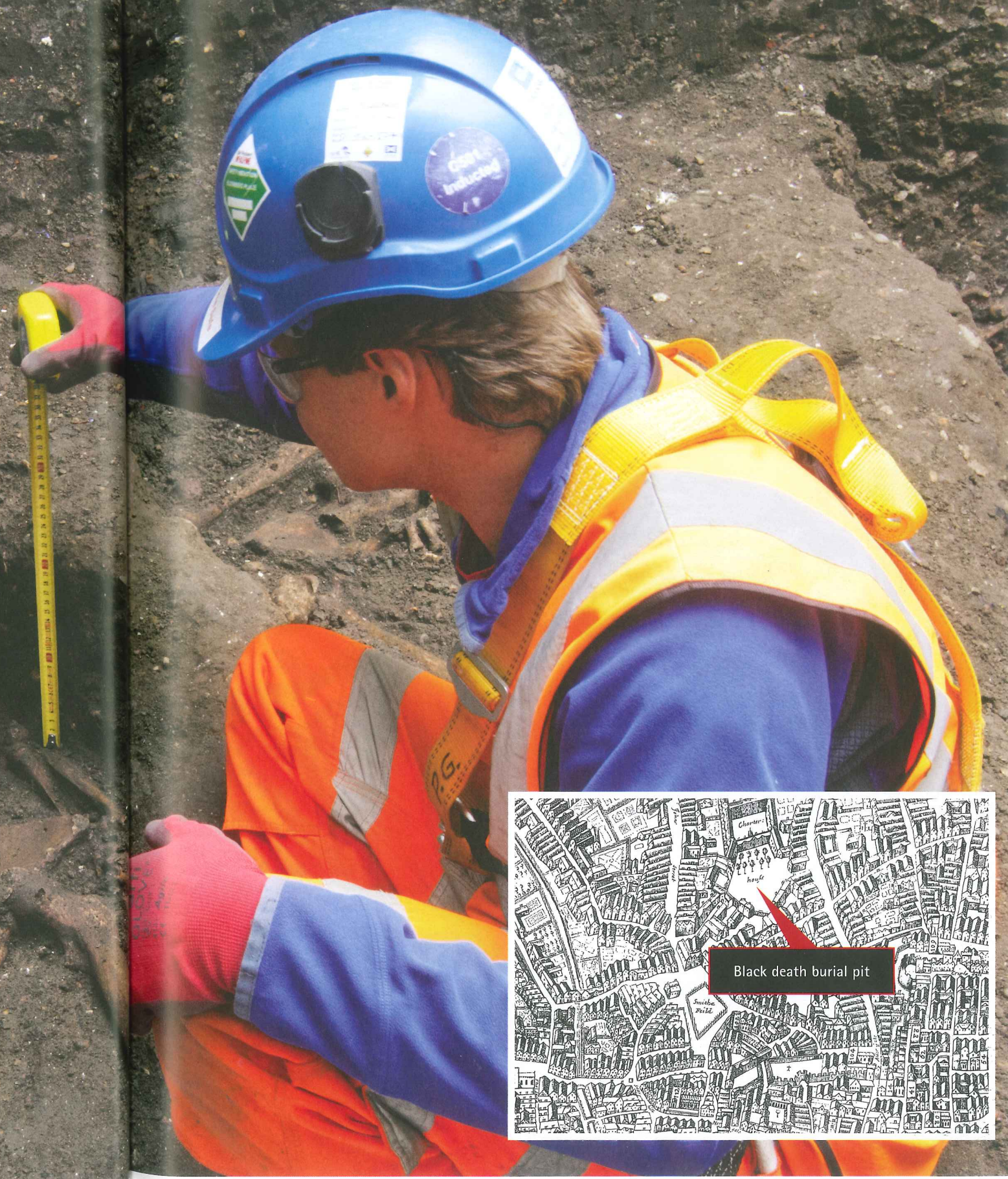
Crossrail has a bone to pick with Charterhouse after workers unearthed a historical burial ground in the centre of the city. Thirteen skeletons had been uncovered, as *Tunnels* went to press, in the 5.5m wide shaft at the edge of Charterhouse Square in Farringdon, and are believed to be up to 660 years old.

Historical records reference a burial ground in the area that opened during the Black Death plague in 1348. The limited records suggest up to 50,000 people may have been buried in less than three years, with the burial ground used up until the 1500s.

Despite development in the area over the centuries, the burial ground, described in historical records as 'no man's land', has never been located. However, Charterhouse Square had previously been identified as a possible site as it was one of the few locations in the Farringdon area to remain undeveloped for the past 700 years.

Last month archaeologists uncovered the skeletons 2.5m below the road that surrounds the gardens in Charterhouse Square. The depth of the burials, the pottery dated up until 1350, and the layout of the skeletons all point to the likelihood that these skeletons were buried during the plague, around 1349. The graves are laid out similarly to those discovered in a Black Death burial site in east Smithfield in the 1980s.

The skeletons are being carefully excavated and taken to the Museum of London Archaeology for testing. Scientists hope to map the DNA signature of the plague bacteria and contribute to the discussion regarding what caused the Black Death. Plague cannot survive long in the soil. After 650 years only bones remain, and present no health risk



### Photo Competition

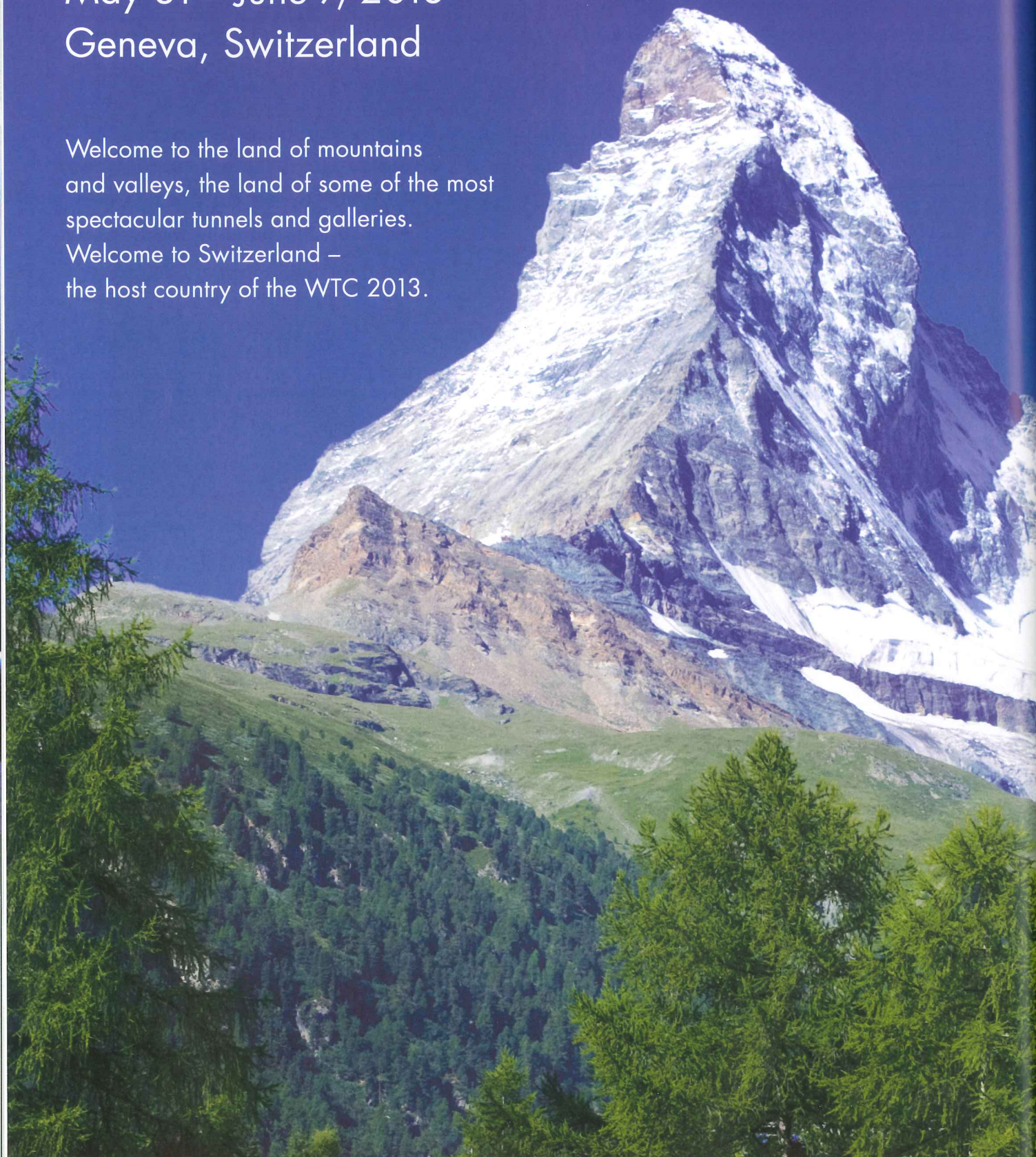
Don't forget to enter the Tunnels and Tunnelling Photo Competition if you think you have what it takes to claim the latest in digital camera technology as your prize.

The closing date for entries is 1 July and the short listed entrants will be announced in the September issue of *Tunnels*. The winners will be announced in the Tunnels Awards supplement in the December issue of *Tunnels*. [awards@tunnelsonline.info](mailto:awards@tunnelsonline.info)

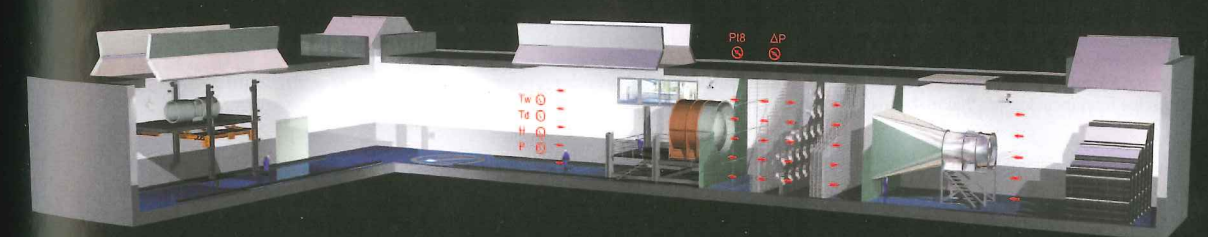
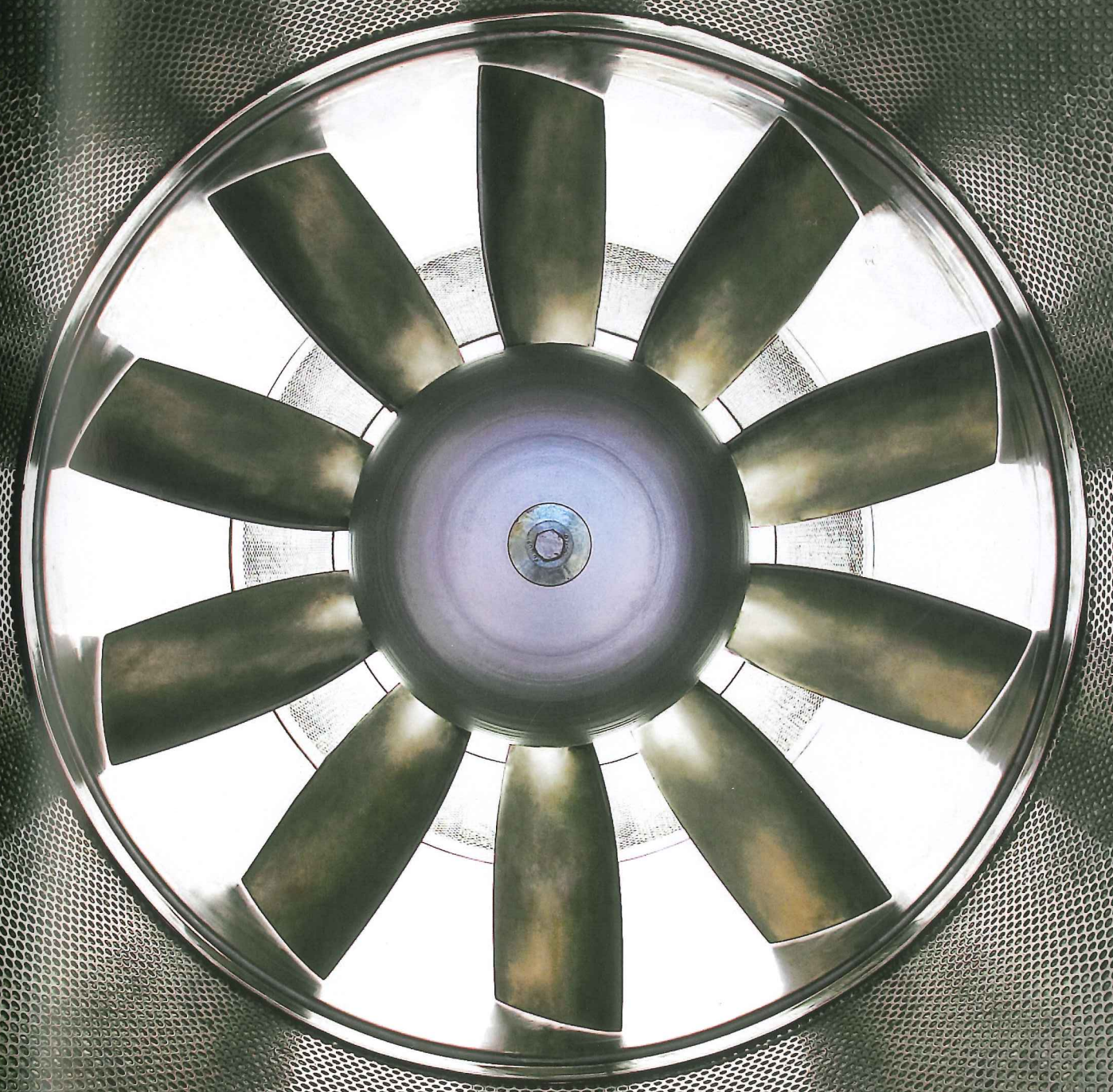
# Join us at the World Tunnel Congress 2013

May 31 – June 7, 2013  
Geneva, Switzerland

Welcome to the land of mountains  
and valleys, the land of some of the most  
spectacular tunnels and galleries.  
Welcome to Switzerland –  
the host country of the WTC 2013.



All you need is  **zitron**



"The biggest certified  
test tunnel in the world"

World Tunnel Congress 2013  
organized by Swiss Tunnelling Society (STS)  
Rheinstrasse 4 • 7320 Sargans • Switzerland • [www.wtc2013.ch](http://www.wtc2013.ch)

**WTC 2013**  
Switzerland - Geneva

*The result of our experience*

Over 45 years of experience, a high degree of technological competence and highly qualified staff  
endorse our work which is among the most valued and acknowledged in our sector.

[zitron@zitron.com](mailto:zitron@zitron.com)  
[www.zitron.com](http://www.zitron.com)

# GROUND-BREAKING TUNNELLING SOLUTIONS

As one of Australia's largest tunnelling contractors, Thies has delivered more than 100 linear kilometres of tunnels over the past 50 years.

We draw on innovative techniques and employ the world's most sophisticated tunnelling equipment to deliver your infrastructure vision. With our strategic partners, we are creating tunnels that will improve infrastructure networks and enhance services for Australian communities.

Find out about our tunnelling capabilities in rail, road, water and utilities infrastructure at [www.thiess.com.au/tunnelling](http://www.thiess.com.au/tunnelling)



CITY EAST CABLE TUNNEL, NSW



AIRPORT LINK, QLD



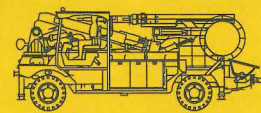
VICTORIAN DESALINATION PLANT, VIC

**THIESS**



## THE PERFECT COMBINATION

FOR CONCRETE SPRAYING IN TUNNELLING



**SPM 500**  
WETKRET

The SPM 500 WETKRET series has proven its efficiency and reliability in a large number of tunnelling projects worldwide. The equipment features a robust spraying arm with a vertical spraying reach of 17, guaranteeing the perfect synchronization of concrete output and additive flow. Thanks to its heavy-duty chassis, the SPM 500 WETKRET series is ideal for the rough working conditions in tunnelling.



**CUSTOMER SERVICE**  
Putzmeister

Counting on our 24/7 technical helpline and worldwide spare parts and after sales service network, you can always be sure to have the required parts and technical assistance at your disposal. Besides, our qualified technicians provide your operators and maintenance personnel with the necessary training, on site or at our premises, to increase the efficiency and working life of your shotcrete equipment.

**BEST SUPPORT UNDERGROUND**



**Putzmeister**  
UNDERGROUND

For over 30 years, Putzmeister has been designing, developing and producing concrete spraying equipment for mines and tunnels. The expertise acquired over the years, together with ongoing investment in research and development, have made Putzmeister a leading company in this field of application. It is this expertise and the search for added value for our customers that makes us different.

**WTC 2013**  
Switzerland - Geneva

VISIT US AT:  
Upper Floor Stands G32/G33  
Geneva, Switzerland, May 31-June 07, 2013  
[www.wtc2013.ch](http://www.wtc2013.ch)

[putzmeisterunderground.com](http://putzmeisterunderground.com)  
[info@putzmeisterunderground.com](mailto:info@putzmeisterunderground.com)  
+34 91 4288100



# AIRPORT LINKED

Financial issues have overshadowed the engineering achievements and innovations for Brisbane's Airport Link tunnel in Australia. Technical journalist **Adrian Greeman** asks some of its engineers to recall their work



**S**TEADILY INCREASING financial problems for BrisConnections, the financier and concession holder for Brisbane's brand new Airport Link tunnel, have overshadowed the project of late. For the hundreds of engineers and thousands more involved in the construction it has cast a pall over their work.

Events culminated in late February with the company being taken into receivership with losses on the AUD 4.8bn (USD 5.03bn) scheme running into billions of Australian dollars. But despite political and legal wrangles and controversy the project has left the city with an excellent new infrastructure development and a record of engineering innovation and construction to equal

any in the world.

Some 1,700 engineers and designers in total and, at peak, some 3,500 constructors from site workers to miners, supervisors, managers and directors, created in under four years a major underground freeway just more than 6.7km long from a busy city centre and passing beneath continuous built-up residential suburbs. ■

It is one of Australia's and indeed the world's biggest road tunnels speeding traffic from the city centre and the south, to the airport area, situated close to the Pacific coast on the north side of the Brisbane river estuary. For the mid-size city of Brisbane with two million residents, it is a project comparable to London's Crossrail or New York's East Side Access in relative terms.

To create the project, the design build partnership of joint venture consultants Parsons Brinckerhoff and Arup, and the contractors Thiess and John Holland have essentially had to carry through two giant tunnel projects, one by TBM and one by rock excavation. Both had significant challenges, and solutions, not the least being the burying of the giant TBMs themselves deep within the tunnel at the end of their drives.

In between these two sections lies an extraordinarily complex interchange of ramps, tunnels and caverns, a further huge project in itself that has produced an almost completely underground junction. It is one of the first like it anywhere in the world and involves some extraordinarily complex interactions and interweavings of tunnels, innovative solutions for their construction and complex site logistics for their completion by the contractor.

The spaghetti of loops and curves has five levels, of which three are in tunnel, one at grade and one elevated. Below ground are two sets of huge twin parallel caverns on the main line of the tunnel, each up to 28m wide in places and accommodating as many as five lanes of traffic as they merge into the traffic flow.

So tight are twists and turns among the on and off tunnels, that it was necessary at one point for two of the ramp tunnels to touch, invert to crown, requiring a complex engineering solution for both the design of the tunnels and particularly the temporary works solution for their construction.

**UNDERPASS**

Another part of the scheme has seen the building of a huge concrete underpass beneath a live railway carrying five important passenger and heavy freight services. Five rail lines run parallel, diverging into six, for both passengers and heavy freight trains.

These could not be held up. So to



Above: Figure 1, The Airport Link project area in Brisbane, Australia

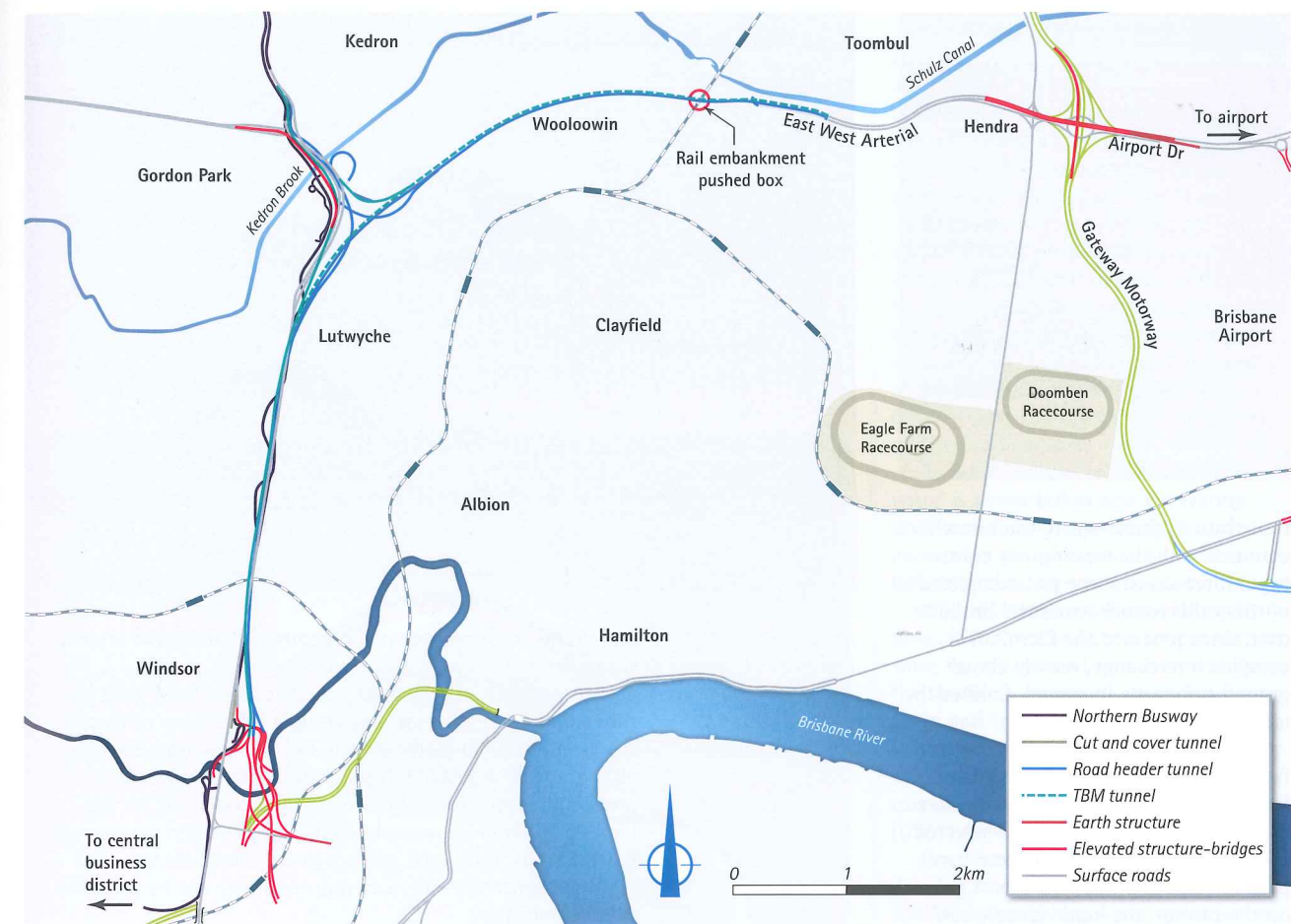
avoid line possessions, a complex and innovative operation of ground improvement engineering and push-jacked caissons was devised that succeeded in driving the tunnel in a 21st century variant of Brunel's original Thames Tunnel.

Work on the project also included a massive starting chamber for the TBMs formed in difficult ground, part of which was a marine clay close to toothpaste in consistency; a loop ramp around a small underground hard rock hill peak in otherwise soft ground; a second complicated interchange above ground in the south but with impacts on the tunnel line; and finally three major ventilation stations that fulfil Australia's stringent 'no portal exhaust' requirements and provide a completely separated emergency smoke venting system for fire and disaster incidents, making the tunnel possibly the safest in the world.

Each of the vent stations is like a "small cathedral," says Dave Rankin, a tunnel engineer initially with Arup and then working during the construction for BrisConnections where he is now operations manager. Rows of five fans with intakes each 2m in diameter sit in three-storey-high buildings capable of extracting hot smoke in emergencies from small sections of the tunnel. A system of automatic flaps will focus extraction over a fire incident. In daily operation the stations draw exhaust air

Adrian Greeman

Is a technical journalist and a long-standing regular contributor to *Tunnels*



from near the portals and vent it. "Two of these are almost all below ground in excavated chambers," he says, "with only the vent stacks visible." A third, above ground has twice the capacity with the fans in two ranks, one above the other.

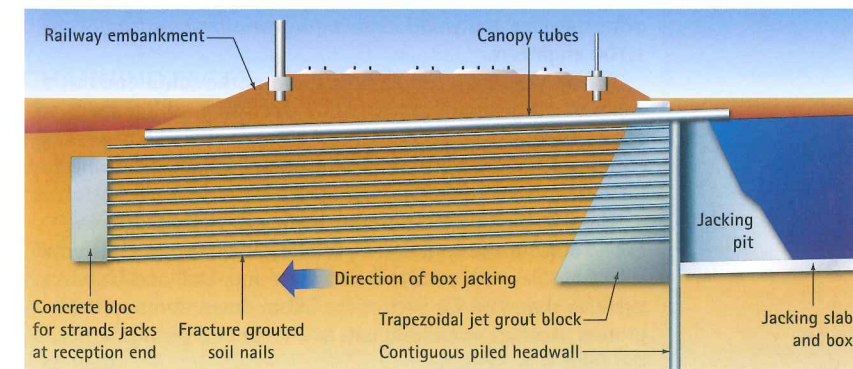
**EXTRA CONTRACTS**

And as if all that was not sufficient, a second tunnel project had to be built almost along the southern leg of the main alignment. This additional kilometre of 16m wide tunnel was a separate project, the Northern Busway, running higher in the ground but with a route line that interweaves with the main tunnel. Because of the engineering impact on the tunnels below, and logistical and contractual issues of building in virtually the same footprint, this AUD 4.5bn (USD 4.72bn) project was awarded to the concession contractor to carry out, alongside the main works.

A second contract was also awarded for similar reasons at the airport end of the project. It was to modify a roundabout

Above: Figure 2, Excavation methods for Brisbane's mega project

Below: Figure 3, Box jacking underneath railway embankment



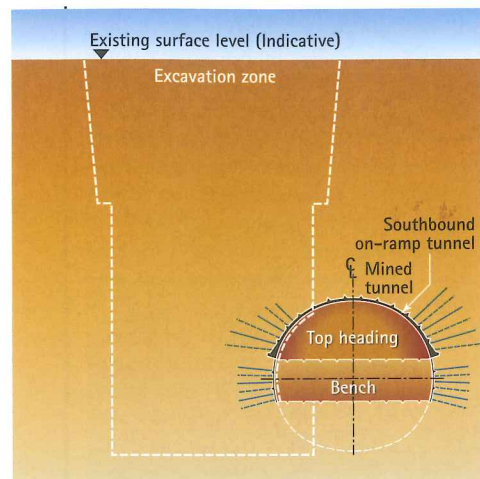
and an overpass junction close to the airport where major traffic holdups were endured almost daily. Work involved building a 750m long segmental flyover.

The additional works were let by the Queensland government as design and build contracts, while the main project was a public-private partnership scheme, with an operational toll collection concession for the return on the investment. Taken together the entire scheme is usually valued at AUD 4.8bn.

**TUNNEL REQUIREMENTS**

The main tunnelling work is really two projects in itself. Different traffic requirements split the overall route. The eastern end, which makes up the connection to Brisbane's airport, requires a dual two-lane freeway. This size of tunnel could be tackled by TBM, albeit two of the largest yet used in Australia at 12.4m in diameter. Twin machines had to bore soft alluvial ground near the start of their drives westwards, as well as a hard rock further along.

At the big Kedron interchange halfway along the 6.7km road link, the tunnel picks up further traffic, collecting the daily commuter runs from the northern suburbs. This requires a dual three lane highway for the rest of the



route into Brisbane where the tunnel connects with the existing city centre bypass freeway and the just completed north-south tunnel across the Brisbane river, since renamed the Clem7. A complex interchange, mostly above ground but partly in tunnel, finishes the route here.

At 15m wide each way for the finished three lane tunnels, and 16m for the initial unlined basic excavation, conventional construction was selected for these tunnels, not least since they pass through potentially the best ground on the project, the hard volcanic tuff that occurs extensively around Brisbane. The route was carved through the hard rock using some 17 roadheader machines and also drill and blast.

**GEOLOGY**

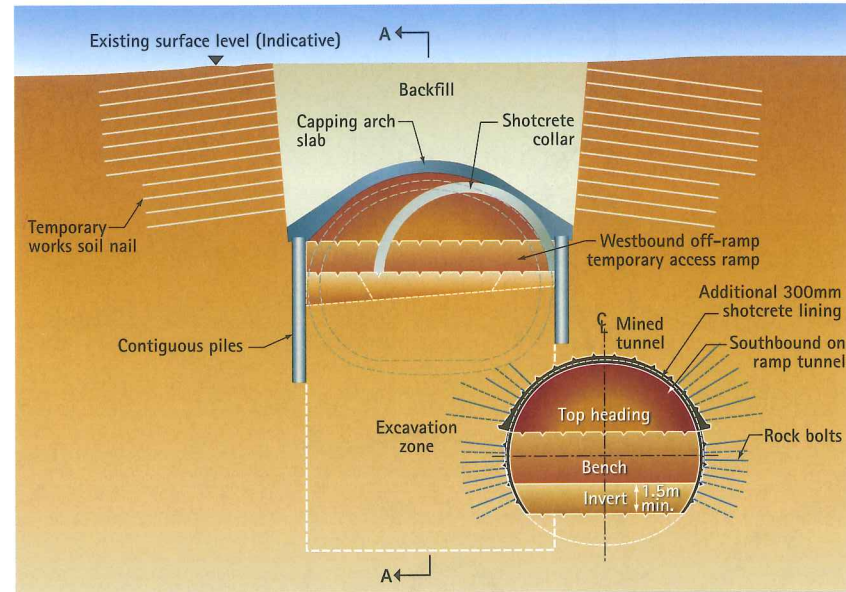
"The geology in the first section outwards from the central area is primarily volcanic tuff," says Marty Scrogings, Arup's technical director for the project and closely involved with both the initial bid preparations in 2006-2007 and throughout construction.

"It is a classic igneous rock from eruptions several hundred million years ago and is hard enough, about 90-100Mpa at the southern end and perhaps as much as 200MPa as it reaches the Kedron interchange."

But this layer dips down and the tunnel alignment passes into a zone of sedimentary but largely metamorphosed rocks after about 2km, he explains. Known as the Neranleigh-Fernvale deposits these are variable and can range from 5MPa to 80MPa.

**VISION TO REALITY**

Construction work got underway on the scheme in November 2008 with Gordon Ralph, project director for Thiess John Holland and a veteran of such large schemes as the Melbourne Eastlink,



Above and right: Figure 3 a, b, c and d, Stages of tunnel constructions in close proximity

mobilising construction simultaneously all along the project, with nine major sites for the work.

For the conventionally excavated sections there were six tunnelling faces set underway using a small army of large roadheaders. Eight of these were big MT720s from Sandvik, all but one brand new and purchased specifically for the project. Six Japanese S300 Mitsuis were also used for the high reach areas in particular and there were also four smaller Wirth Pirautt units used with an in-line head, though high production needs in the rock proved mostly too hard for the smaller machines.

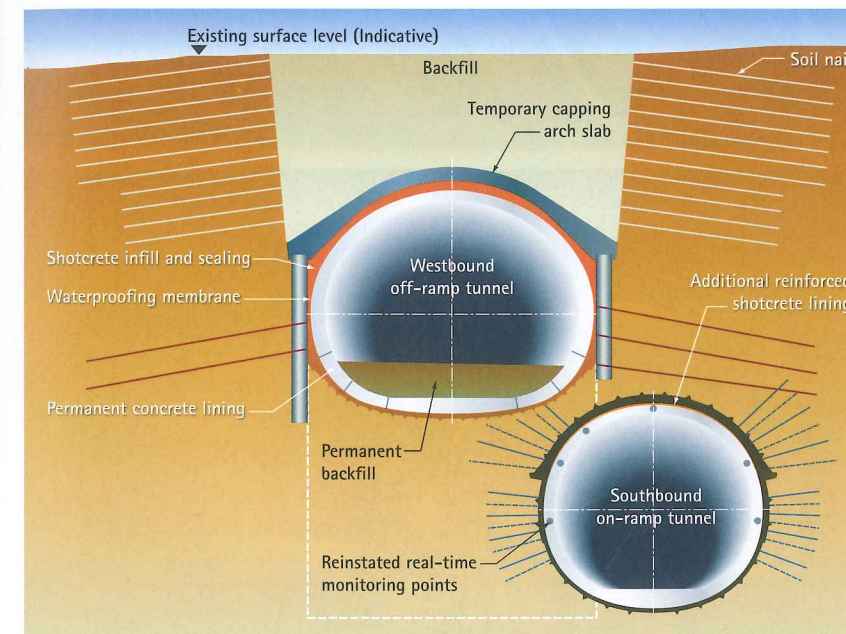
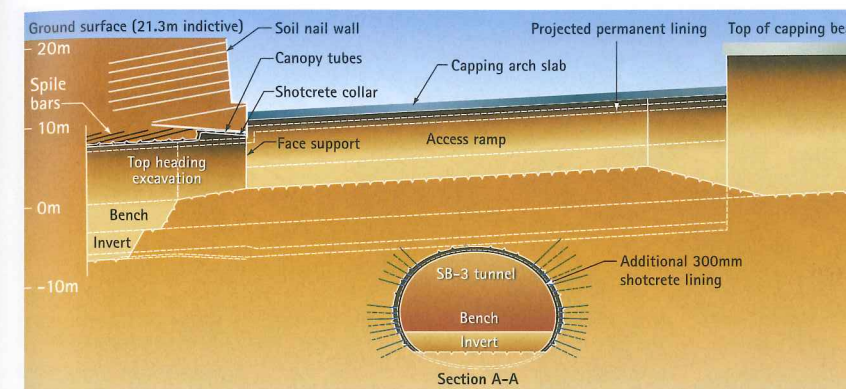
"Even for the large one there was a constant need for changing the teeth," recalls Scrogings, "and we had two boilerworks on site specifically for welding work on the machines." Tuff, he added, is just that "tough."

The tunnel was excavated from a point midway along the southern drive via a construction adit from which two north faces and two south were opened up, says Scrogings. Two other drives worked in from the southern end where the link begins with a complex interchange. Much of this is above ground with elevated ramps linking the tunnel to the existing Brisbane city centre road network, the Clem7 tunnel and an area of the city called Fortitude Valley, coincidentally the location of Arup's offices.

The multiple destinations of the southern interchange meant some complexity to the tunnel drives says Luke van Heuzen, Parsons Brinckerhoff's major projects executive in Australia. He took on the role of project director for PBA-JV's work within the overall design and build partnership with contractor TJH. At the peak of the work he was coordinating design and design checking in Arup, PB and subconsultancy offices around the world, drawing in contributions from some 1,700 engineers.

"There was not a simple bore to do at the south end but a complex 3D geometric trace with a three-way split as the road connects into the existing network. That included bridge ramp entrances and links but also a single lane tunnel ramp which merged into the main line," he recalls.

Here, in the Bowen Hills area there was also a massive excavation for the southern ventilation building which is now hardly visible, with parkland across the top. Drill and blast was used for that, and for part of the initial drives. Another below ground ventilation building sits at the far end of the tunnel, the third is at Kedron.



The building footprint for all three of the ventilation buildings stretches 120m long and 40m across. The end two buried structures are built 30-35m into the ground says Rankin. "The main hall is three stories high and the fans dwarf you when you stand inside."

Southern portals, tunnelling and the cut and cover ventilation work were all hugely challenging for the contractor says van Heuzen, because of the complex logistics needed to operate close in to the central business district. Multiple traffic management schemes were required. For the main tunnel, drives were made with a split heading 6.25m deep, remembers Rankin. This was followed up by a three-part benching operation, taking out the centre first, then one side and then the other. The spoil was loaded on to standard Volvo road truck for disposal, travelling to an area close to the airport.

**CHANGING FACES**

The construction design was constantly adjusted for value engineering and because this was a design-build-operate project, to fit with the complex and tight schedule of the contractor, particularly in the difficult ground further up.

For the excavated tunnels there were daily modifications. Though not done with specifically a NATM observational method, there was scope to amend support classes needed. Six grades of support, each with further sub grades, were available with rock bolting between 3.7m and 5m long, and shotcrete and mesh.

"We mapped the face every morning and assessed the convergence record and then sat down with the contractor to discuss the situation before issuing a permit to tunnel, and quite often that meant we could reduce the necessary support to be installed," says Scrogings.

In the main bores the rock proved a good match with predicted quality, which was hard and competent though to some extent blocky. It was possible to extend the excavation advance lengths after a while from 1.25m to 1.5m and as much as 1.75m which made a big difference to the contractor's cycle times and cost efficiencies.

As on all Australian sites no 'man entry' is permitted in new excavation until rock is fully supported, so each excavation round requires a minimum length of time for work to continue.

"Clearly it reduces the overall cycle times if the he can have a longer section, since for each round he has to wait for the shotcrete to go off, for rock bolts to go in and to mobilise the muck loading. It is more efficient," says Scrogings. "The savings are big on a high cost site which can be getting through over a AUD 1M (USD 1.05M) every hour at peak times."

Once into the drives it was also decided to use drill and blast for the follow-on benching, again speeding up the work. Both Sandvik and Atlas Copco rigs did anchoring and drilling work.

**BUSWAY**

Work in this southern half of the project and up to the Kedron interchange, also involved construction of the busway project, a dedicated highway route for suburban bus services.

Some of this was above ground work but as the route reached the suburbs about a kilometre of it dips in and out of tunnel along the alignment. The impact of these tunnels, themselves 16m wide excavations, on the big tunnels below had to be calculated, the logistics worked out for their construction particularly near the complex Kedron interchange, and their own construction problems had to be tackled.

"They run much higher than road tunnels, which are up to 55m deep," explains Scrogings.

"The bus route has stations every 500m and that means bringing the bus to surface again at these points, as there are various reasons not to use underground bus stations. Passenger security is better in open surface stations and they avoid the need for multiple stairs, escalators and lifts which greatly increase the footprint needed."

The shallow level of the tunnels

17

Roadheaders used on the project

16

Metres width for the Busway tunnel running along the main alignment

meant much of their construction had to be done in more difficult ground and with very little cover. "At one point we took the tunnel line along a road that had a gradient the opposite way to that of the tunnel, so the cover increased faster than the shallow tunnel gradient would have allowed otherwise. But we still had some 30 to 40m to run with just a few metres cover."

Parts of the bus tunnel required cut and cover work but even where the tunnel was fully underground there was often little cover. "These were big tunnels" says Scrogings. "The tuff at higher levels is not such good rock, a result of the volcanic material cooling faster on the surface and cracking more. Weathering was extensive through the top 3m."

The bus tunnels required considerable tube canopy work, he says, and a lot of long anchors in areas with just 6m to the surface. "Even 6m is not a lot when your tunnel is 16m across." Maximum cover on the bus tunnels was about 20m.

"We were very nervous about settlements," he says, though not so much for buildings as for road services and utilities.

#### FUTURE PROOFING

A further design issue with the bus tunnels was making provision for more tunnels to be bored in the future, which Brisbane city will do when finance is available. Like the tunnels already bored, these could run within 10m of the road tunnels. "It has significant effects on your design assumptions, such as the rock arching strengths," says Scrogings.

The roadheader work on the main drives also included the construction of the big caverns at the end, 200m long and up to 27.5m wide. "Though in fact they varied according to the various ramp entrances and exits," says Rankin. There are parallel tunnels for the merges as the tunnel comes into the Kedron junction and another set on the far side.

Like the main line tunnels these were much deeper and constructed more or less the same way as the main line tunnels but on a larger scale. The first caverns went without problems in the tuff. "We put a heap of convergence pins up but it didn't move," Rankin says.

The second caverns were more difficult because it has a mixture of tuff and siltstone, he says, and with an interface that dipped across. Rock was fractured and needed more support. A design modification to allow for a larger pillar between the caverns, some 20m rather than 12m, was necessary.

The TBM drives meanwhile had



Above (top): The box jack site aerial view showing existing railway infrastructure

Above (bottom): The box jack was divided into cells for the excavation

begun at the far eastern end of the project. The first work was the creation of a large launch pit while the machines were manufactured by maker Herrenknecht in Germany. These were Mixshield machines capable of operation in sealed EPB mode as well as with open face for rock conditions.

The ground at the start of the drives was extremely soft, alluvial deposits overlying harder sedimentary rocks. The machines had to cope with literally mixed faces, half in hard rock and half in the sands, clays and silts above, with a transition after around 900m of their drive to hard rock both sedimentary and later into the volcanic tuff.

Constructing the deep boxes, formed between heavily strutted diaphragm walls 1,200mm thick was difficult, says Rankin, because the ground was extremely soft clays in the main. "The contractors mucking out of the starter pits had to be done with excavators sitting on steel plates and they even lost one a couple of times." They did find them again.

The diaphragm rigs were also used to make deep barettes for foundations along the centre line of the pits' base slab to resist uplifts.

The box construction had its own logistical problems, says Rankin, because the site was hemmed in by local buildings, a park and a creek with a major railway embankment running

#### Undertaking an underpass

One of the most complex parts of the project was the jacked box push beneath the rail lines out of Brisbane which cross the road near the eastern portal.

The problem was to pass the wide railway embankment without disrupting the five different lines for both commuter and passenger trains, as well as heavy freight trains. Possessions were effectively ruled out because of the difficulties synchronising the different services, with 380 trains a day, and because other infrastructure work competing for possession time in that period.

The solution devised by the constructors team was to use jacked boxes push through the embankment. Two boxes would be used, 12.5m high and 65m long. The two, one wider than the other had a total 38m width.

With a steel cutting edges on the front these would be pushed through while excavating the face from the inside.

But to get them through was complex, not least because ground conditions of the mixed fill in the old Victorian embankment were uncertain.

Potentially there were old timbers from an original rail trestle embedded inside, as proved to be the case.

A specialist temporary works team was brought in using ground specialist Duncan Nicholson from Arup's London office working with URS-Scott Wilson-Benaim's Hong Kong office.

A first answer was to divide the face of each box into nine small sections for stability, much as Brunel had divided a tunnel shield into partitions when boring the first Thames tunnel.

The smaller faces would be less unstable than one large one or even four faces. Excavation cells were created inside with concrete planking.

To build the two boxes a deep diaphragm wall launching pit was built alongside the embankment. To support the rail along the embankment a contiguous piled wall, anchored into rock, created a vertical face.

behind. Another small creek crosses the box site and had to be diverted into a new permanent concrete channel over the box. The big cranes and grabs for the work had to come in to site through under a rail bridge where the creek passed through.

This was an even bigger challenge when the TBMs were delivered to Brisbane docks, arriving on site in late 2009 and early 2010. "The various components just got through the underpass with millimetres to spare," he remembers.

Once assembled the big machines headed out through soft eyes in the box. Each was guided by a VMT system for the drives, which were separated by just 20m, taking a year to construct the total 2,500m long drives.

Each 12.34m diameter machine assembled a 2m long ring comprising eight segments and a key, with a flat face between rings. A single neoprene gasket was fitted to each segment and they used a temporary bolt connection until grouting was completed. The machines could grout at the tail but the ring segments also had grouting points.

"We used a steel fibre reinforcement for the segments with additional polypropylene in the mix for fire resistance," says Scrogings. Getting the mix design right was complex, he says, particularly in adjusting the precise level of the plastic fibre.

The fire design standards for the tunnel are some of the most stringent in the world, particularly for tunnel underneath buildings deemed critical. Not only is no collapse of the tunnel allowable, but no deformation either.

The segments, some 22,000 in all, were cast at a facility set up near Brisbane Airport, using Herrenknecht-supplied forms

The boxes were built on a 900mm deep concrete slab which became the reaction point for ranks of huge 1,000t jacks pushing the boxes forwards. Another set of 750t strand jacks sat behind a concrete wall formed on the other side of the embankment, hauling the boxes on wires through.

But first the embankment needed stabilising. First a row of large tubular steel pipes were augured beneath the rail lines and filled with concrete.

The canopy tied to the top of the pile wall.

Behind the pile wall a jet grouted block was then formed by Keller Australia to stabilise the initial excavation face.

The main embankment fill of sand and soft clay was strengthened with fibre glass soil nails, which were given greater grip by fracture grouting each one. The sleeves around each one were also used for penetration grouting of the sands.

These techniques, or even soil nailing in such soft ground, have not been used before, Nicholson tells *Tunnels*.

Queensland Rail had asked for minimum settlement of 25mm if the job was to proceed. To help achieve that the team also did track levelling on a daily basis. Monitoring with over 200 prisms was set up.

With the embankment stabilised as much as possible the boxes were pushed forwards with the huge jacks anchored into the base slab. In the box faces mini-excavators removed the ground instead of a miner with a shovel as in the 1800s.

The operation, once it had begun, had to continue on a 24-hour basis with some 27,000t of spoil removed to move the box forwards an average 1.1m daily.

Once in place the boxes could be connected to cut and cover boxes built either side of the embankment. These carried the road on to the TBM launch pits and on the far side extended it through the space it had vacated in the launch pit. The tunnel ascended to its portal just beyond here.

**20**  
Metres separated  
the TBM drives

**20**  
Metres is the  
maximum cover  
achieved on the  
Busway tunnels

and delivered to the site by truck. Once lowered into the launch shaft they were delivered to the machine using rubber tyred purpose built delivery vehicles.

The machines ran on a flat floor to the tunnel, which was installed just behind the machines with precast invert units, a U-shaped centre box and two flat side slabs sitting between it and the lining. The tunnel also had a ceiling slab to form the top smoke duct, a critical safety feature.

For the spoil the construction team opted for a conveyor system supplied by H+E Logistik. The contractor was able to take advantage of a viaduct for the elevated airport rail link which runs just beyond the project at the eastern end, using the piers as support for a 2km-long, above-ground spoil conveyor delivering the total 2.8Mm<sup>3</sup> of excavated material from the drives.

Drives for the tunnels went reasonably well, says Rankin, taking about 15 months in all. "And in fact they could comfortably have driven faster." Peak rates were 110m a week and the average 85m.



Left: One of the 17 roadheaders used on the Airport Link tunnel project

There was one hold up on the first of the drives caused by damage to the screw conveyor, which took a week to fix, and the machines suffered heavy wear in the tuff towards the end of the drives, requiring substantial additional wear plating on the cutterheads.

This was taken care of when the TBMs arrived at the first set of caverns in the drives. The machines used partial ring sections in the invert to jack themselves forwards through the caverns. The cavern slabs had been shaped for the operation.

#### OUT OF THE EQUATION

Perhaps the most unusual aspect of the drives, which continued for another kilometre, was the end point.

No easy means to extract the machines was available, says Rankin, "without building a new shaft which would have been both expensive and highly disruptive above ground."

The heads at least could not easily be extracted back through the already lined and invert-fitted tunnels, though the back-up train was removed.

The contractor decided therefore to bury the machines, each in a pit in the tunnel floor, "which was a major task in itself," says Srogings. "These had to be excavations 14.5m wide, 16.5m deep and 15m long, which required major anchoring support."

To lower the machines a rail system had to be installed with anchors in the tunnel roof from which the massive TBM head sections could be suspended and pulled forward on strand jacks.

Once in place the still 'barely used' machines were surrounded with concrete.

Meanwhile at the Kedron interchange there were also major complications in the ramp and tunnel excavations, all made within highly mixed and complex ground, which proved a lot more difficult than expected. Work there consumed a huge amount of Scrogings' time on the project.

"There is a creek passing through the Kedron area, quite small now but much larger during the past. Over the millions of years this had filled with classic alluvial deposits, siltstones, mudstones and soft ground," he says.

There were also volcanic events that had formed two layers of tuff separated by a conglomerate of varying thickness. The layers were extremely mixed and constantly changing he says "and far more than could really be picked up with the 100m spaced cores we were able to do during the bid period."

Among the many challenges in this area, was a looped ramp that turned out to be positioned just around a projecting peak of hard volcanic rock within the sedimentary deposits.

"It meant the diaphragm walls hit hard rock a few metres down on one side but plunged straight on down through soft alluvial ground on the other just metres away," says Scrogings.

The 350m-long circular ramp threatened to slide off the steep sided peak and took months of work to sort out.

An equally challenging issue was construction of the overlapping tunnels for two of the ramps into the main tunnel line. These crossed obliquely, a west bound off-ramp higher than the other southbound on-ramp, but so close in the ground that the invert effectively touched the crown of the other. Not only was this a complex design issue in itself, but it also created a major challenge for the construction, not least because the upper tunnel was primarily in soft ground.

The designers considered half a dozen options for the construction. In all of them the lower tunnel was driven first, passing through hard tuff.

The question was then how to do the upper tunnel, partially in softer ground. The obvious solution was cut and cover, "but this would have meant doing a 35 to 40m deep excavation which produced unacceptable deformations," says Scrogings.

In the end a partial cut and cover was the solution with a steep-sided trench 25m deep supported with soil nailing. At the base an arched slab was poured spanning 16m and with a 1m thick central arch increasing to 2m at the arch base. Here it was supported with a row of bored piles 1,200mm in diameter, initially to take lateral loads.

The point of the slab was to act as a kind of falsework beneath which the upper tunnel could then be excavated, he says. "The curve of the arch was also a kind of formwork for the spray concrete below forming the tunnel in the usual way."

Once completed the trench was backfilled. As it was loaded so the piles in the ground transferred vertical load downwards, which required some careful analysis to see how they affected the lower tunnel lining, he says.

The analysis of all this was further complicated by the speed of the construction, with the lower tunnel barely complete when work began above.

Kedron also included a completely new shaft, decided on in the middle of the project to speed up work on the eastern caverns particularly.

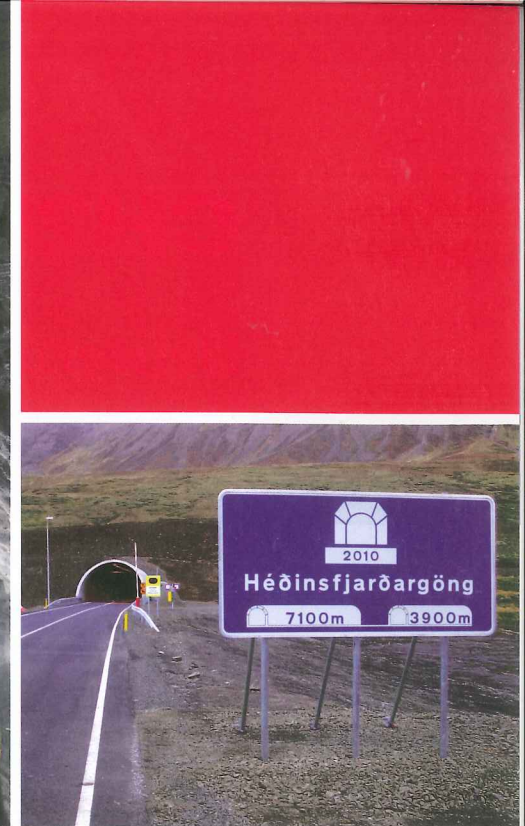
But to do justice to those and other aspects of the project a small book would be needed.

The result, as a road project, is well received and particularly for the quality of the finished structures.

Financial calculations and the global economic crisis had the overriding impact however. That is another and even more complex story to come in a later issue of *Tunnels*

www.tunnelsonline.info

A world of information fully archived and searchable at the click of a mouse



## Metrostav – your partner for wide-range cooperation

Quality, accuracy and consistency in every detail. The coordinated effort of professionals from many fields. The ability to solve problems and the courage to search for new approaches. Is this an art-form? Maybe. In either case we do it well.

- |   |   |   |
|---|---|---|
| 1 | 2 | 1/ Prague Metro Line A Extension, single-vault mined Petřiny station, mined tunnels (NATM, TBM) |
|   | 3 | 2/ The Länsimetro – Western Metro Project, Finland (Drill & Blast method)                       |
|   | 4 | 3/ Road tunnels in Iceland, 10 km long (Drill & Blast method)                                   |
|   |   | 4/ City circle road in Prague, Blanka tunnel complex (NATM)                                     |

Metrostav a.s.  
Koželužská 2246, Prague 8, Czech Republic

**METROSTAV**  
člen DDM Group

www.metrostav.cz

# CH2MHILL®

## Delivering Tomorrow's Solutions Today



Employee-owned, CH2M HILL is one of the world's leading full-service consulting, design, design-build, operations and programme management companies. We have 28,000 employees worldwide and over 3,300 people across the UK, with our European headquarters based in London.

CH2M HILL is working on some of the largest and most complex water, environmental and infrastructure programmes in the world including the expansion of the Panama Canal, Crossrail, the Thames Tideway Tunnel and High Speed 2. Our work is concentrated in the areas of water, transportation, environment services, energy, facilities and resources. Since 2004, CH2M HILL has been ranked number one for programme management by *Engineering-News Record*.

[Learn more at ch2mhill.com](http://www.ch2mhill.com)



A member of



# PRAGUE METRO

Metrostav's **Ermin Stehlik** and **Vaclav Soukup** bring us the second part of their trek through the construction and engineering history of the Prague Metro. This part expands on the period from 1989 with the associated political changes and will be followed in the final part next month by present and future plans

The change of political system, and therefore the possibility of importing modern technologies, was a turning point in Prague's metro construction. The application of NATM gained pace, and was used for stations, escalators and running tunnels. For drilling, jumbos were employed and for the primary support bolting and shotcrete with lattice girders were used. The lining of both running and station tunnels was double-pass. After the primary lining application, the installation of a waterproofing layer would follow, and in the end the secondary (final) lining was cast

**Ermin Stehlik**

Ermin is the tunnelling specialist for Czech contractor Metrostav. He has in past years worked extensively with *Tunnels* and has decades of experience in the industry



**Vaclav Soukup**

Vaclav is the immediate past director of Metrostav's Division Five, the arm of the contractor that specialises in tunnelling and underground construction works





into the formwork. Contrasting with the earlier projects, the application of precast segmental linings was completely abandoned. For subsequent running tunnels however, this construction was considered not quite suited to the situation. This was often championed by the noted Czech consultant Zdenek Eisenstein. He was a keen promoter of TBM use for running tunnels in Prague and it is regrettable that he is no longer here to see them on metro extension V.A. The domination of NATM for construction of running tunnels ended in 2010, when Metrostav purchased two EPBMs for construction of metro extension V.A.

A very significant achievement on the Prague Metro has been the underpassing of Vltava River on the IV.C extension. Applied technology is one of the biggest contributions made by Czech tunnelling to the global industry.

### NATM APPLICATION

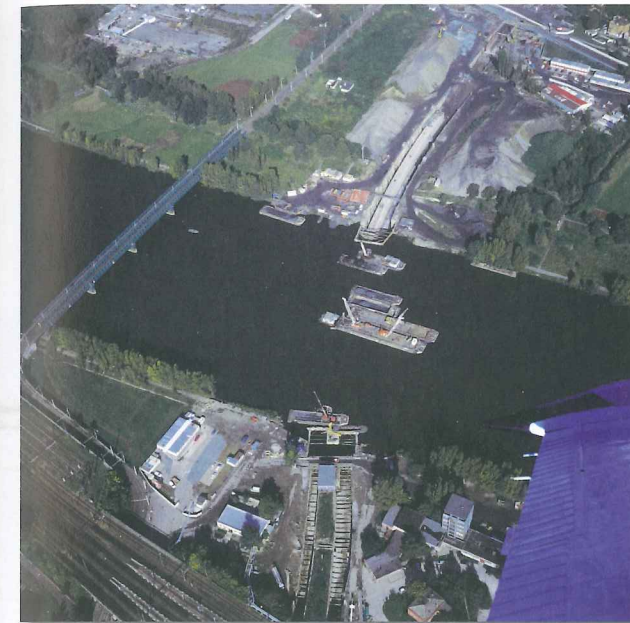
It was only matter of time before the ring method with segmental lining would gradually be replaced by NATM, which was a dream of many tunnelling



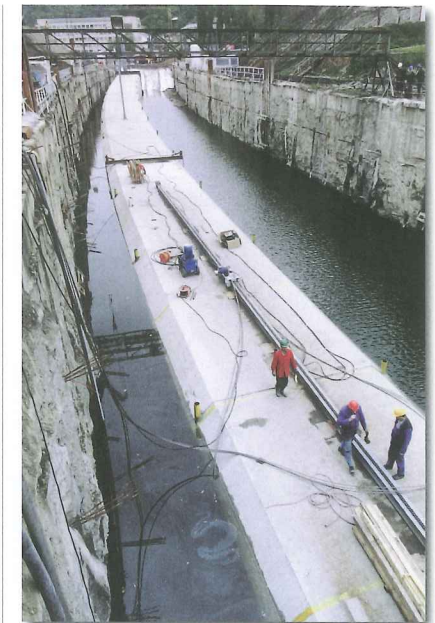
Above (top): Cerveny Vrch Station work

Above (bottom): Figure 1, The Prague Metro network lines

experts during the 1980s. Introduction of the method was done with help of the State Research Project, which was approved in 1989. The main coordinator was Metrostav and the research started as planned in 1990 and continued through 1991, financing of the research besides the state was by Metrostav, Vojenské Stavby, Subterra and Železniční Stavitelství. In 1991 the research ended due to the changes in financing, but the results gained during two years were used and NATM



Left and right: The crossing of the Vltava River was a key milestone for the metro's development



had started on site.

At the start of 1989 the first experimental application of NATM took place for the excavation of a gallery for special purposes on Florenc (formerly Sokolovská) Station. As a part of the experiment it was required to verify and evaluate the geological conditions, prepare the design documentation, evaluate new support elements, create monitoring documentation and prepare testing of shotcrete. After this first approach, a few drifts and parts of station tunnels in primary lining were executed at stations Vysocanska and Hloubetin on metro line IV.B, and already more than 2km of running tunnels with double-lining and intermediate waterproofing were built on the same line.

The first double track metro tunnel built by NATM, between 1995 and 1997, was also on the same project (IV.B). For its construction, the machinery and equipment customarily used for NATM abroad, was for the first time used on site. For four escalators tunnels on this line, three of them have been constructed by NATM.

Another turning point in NATM application was the construction of the first single vault station on the line IV.C [7]. The first attempts to build single vault stations happened in the 1980s and it was another dream of a whole generation of tunnelling experts, being fulfilled in 2002, when the excavation of station Kobylisy was performed by Metrostav.

The cross sectional area of the station was 228m<sup>2</sup>, the length of the station was 148m. The primary lining thickness with lattice girders was 400mm, and the final lining with intermediate waterproofing has a thickness of 600mm. The excavation was with both vertical and horizontal subdivision of the tunnel face, using both mechanical excavation by tunnel excavator and drill and blast. Permanent monitoring was contracted to Stavební Geologie-Geotechnika Prague, the maximum measured settlement above the station was 45mm and the effects on buildings were minimal.

### UNDERPASSING THE VLTAVA RIVER ON THE LINE IV.C EXTENSION

Underpassing the Vltava River by the so-called immersed tube 'launching' method was, and still is, one the most important contributions of the Czech tunnelling community to the wider industry [8]. The chosen method was based on the construction of a complete tunnel tube in the dry dock, which in later stages

served as an open pit for construction of running tunnel structures on the Trója river bank. The trench for the first tube was dug in the riverbed, the trench for the second one was dug after complete placement of the first tube. The dry dock was separated from the river by steel sheet pile wall, part of which was opened after completion and fitting out of the tube and flooding of the dry dock. Fit out included the installation of internal water balance tanks and provided both faces with a temporary steel cap. Two towing systems were fixed to the cast-in anchor elements in the ceiling slab. A horizontal system (towing and braking) fixed the tube position during launching and, a vertical system, in the form of suspension cables, set the height of tube above the trench bottom. The rear part of tube was shifted on the prepared track in the dry dock.

The tube was moved by help of two towing cables anchored on the opposite Holešovice river bank. The rear brake suspension prestressed the cable system and enabled braking of the movement. Vertical suspension was connected to the pontoon, which carried the weight of the tube in the front part, reduced by the buoyancy. The rear sliding part of the tube carried a majority of the weight and secured the stability of the whole body.

The forces required to move the tube were relatively small, the weight in the water was only one per cent of actual weight. After the support structure, built in a cofferdam on the Holešovice bank, was reached, the tube was supported on both banks and was stabilised. The support to the river bed followed, by concreting in the regular intervals and

## 3

Of the four total escalators on the IV.B line were built by NATM.

## 1995

The year that saw the start of construction on the first double track metro tunnel built by NATM



anchoring the tube. The weight of the tube was 6,700t, the length 168m, outside dimensions 6.48m by 6.48m, the thickness of the invert and ceiling 700mm and thickness of walls 730mm. The horizontal curvature was 750m in the right track and 670m in the left track, vertical curvature 3,800m. The construction method was completely new and unusual and therefore during planning and construction there was a need to solve important technical problems, some of them requiring large rate of innovative approaches:

*Above: The political situation has changed extensively during the Prague Metro's history*

*All references will be included with the third part of the series*

- Watertightness of concrete structure - the tunnel has no insulation and therefore it was necessary to solve sequence of casting, joint sealing and reinforcement in a way to avoid creation of cracks;
- The tube balancing - the curved shape of tube is the cause of its instability in the water. The reliable establishment of tube reactions was an essential factor for maintaining sufficient structural stability during manipulation. The weight calculation might be encumbered with a high degree of uncertainties, therefore the experimental verification of actual weight and its distribution both in transversal and longitudinal direction was required. This was achieved by help of hydraulic cylinders placed under the tube, which after the dock flooding lifted the tube and from pressures in cylinders the actual

weight and reactions were recalculated and the final loading by water tanks designed;

- Additional tube loading system - the tube dimensions were chosen to allow floating, but due to the instability caused by the curved shape this was undesirable and therefore the water tanks were filled in such way that the tube was not floating, but at the same time its weight was adequate with respect to the bending stresses and stability (approximately one per cent of actual weight);
- Foundation strip - the tunnel in the dry dock was cast on specially treated sub-base, which allowed flowing of water under the tube, providing the required buoyancy for manipulation. Concrete foundation strips reached under the tube only to the distance of 0.5m and the remaining part of the space was filled by gravel, and plastic pipes served for water supply;
- Tube launching - the movement had to be fluent, which superimposed considerable demands on hydraulic equipment, and also accurate, because the tube passed through a narrow opening in the sheet pile wall. Geodetic monitoring also allowed for steering of the tube when it was submerged.

Execution of the running tunnels, by the exceptional technology of launching into the Vltava River, was very successful thanks to all involved, namely IDS Praha, Metroprojekt Praha, Zakládání Staveb, VSL Systems CZ, Peri, VUT Brno, Professor. Tichý (risk analysis), Professor Šmerda (calculations). Division Six of Metrostav was responsible for execution; the author of the construction method was Professor J. L. Vítek from Metrostav's head office team.

The designed method brought savings in time and budget when compared with alternative methods.

The original project contributed to the reliable and high quality construction of metro tunnels and received prestigious awards and recognition from the International Federation for Structural Concrete (FIB) and the Engineering Academy of the Czech Republic



Tunnel Design, Technical Assistance and Monitoring  
ADECO-RS® approach

Tel: +39.02.65.54.323

Fax: +39.02.65.97.021

e-mail: rocksoil@tin.it

http://www.rocksoil.com

"Cellular Arch" technology: huge underground cavities with no surface settlements

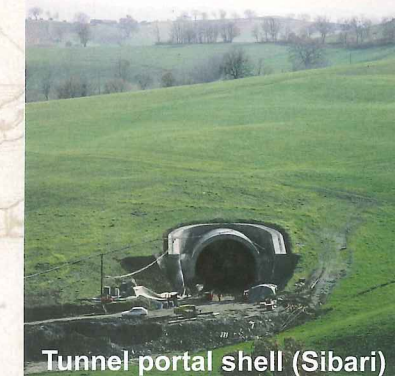
Horizontal and vertical jet-grouting technology to respect the environment

INDUSTRIALIZATION  
IN TUNNELLING  
IS NOW AT HAND!

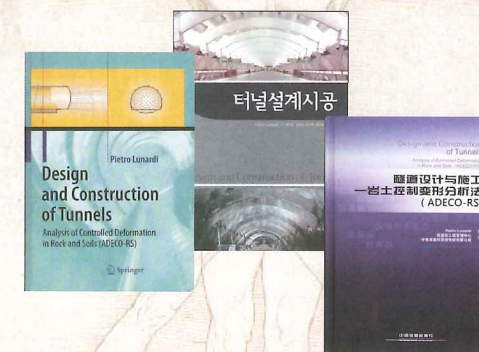
ADECO-RS®



Venezia station (Milan)



Tunnel portal shell (Sibari)



"RS method": the pilot tunnel as a design tool

Fibre glass reinforcement of the core-face: no tunnel is impossible



M. Olimpino tunnel (Italy)



Tunnel No. 8 (Sochi, Russia)

The most modern  
and reliable approach  
to tunnel design and  
construction

More than 1000 km of tunnels  
designed and then constructed safely  
on schedule and to budget

NO MORE LIMITS IN TUNNELLING !

Innovation in  
tunnel mechanization

The invert close to the face  
to control the "extrusion surface"

Old tunnel widened  
without interrupting traffic



Sparvo tunnel (Italy)

The world's largest EPB TBM (Ø 15.625 m)



Tartaguille tunnel (France)



Nazzano tunnel (Italy)

# LINING INNOVATION AT MARCHE-UMBRIA

Italy's Quadrilatero Marche-Umbria project is benefitting from a new tunnel lining system reinforced by tubular arches. **Pietro Lunardi, Fabrizio Romozzi, Andrea Simonini, Dino Bonadies, Cesare Avignone and Carla Luigina Zenti** describe the application, installation and safety aspects of this new system

**Pietro Lunardi**  
Pietro is a consultant with Rocksoil s.p.a. of Italy

**Fabrizio Romozzi**  
Fabrizio is the director of Quadrilatero Marche-Umbria in Italy

**Andrea Simonini**  
Andrea is a technical manager for Quadrilatero Marche-Umbria

**Dino Bonadies**  
Dino is the chief executive officer of rpa s.r.l in Italy.

**Cesare Avignone**  
Cesare is the technical director of Strabag Italy

**Carla Luigina Zenti**  
Carla is a consultant for Elas Geotecnica, and Maccaferri, Italy

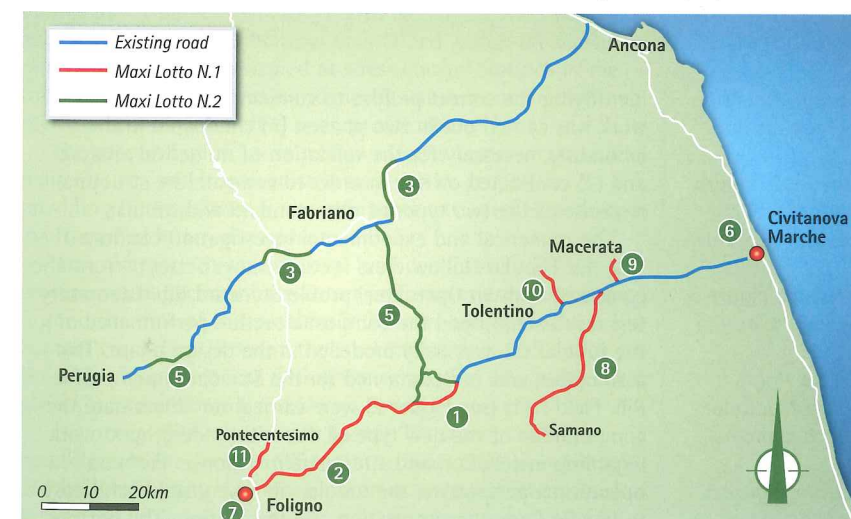
**G**ROUND-LINING interaction control is one of the most critical processes during a tunnelling project's implementation. Some of the design and construction decisions during a tunnel project are very critical to reduce the ground movements around the excavated tunnel.

These movements have a direct effect on the tunnel stability and the design load of the lining system (Lunardi et al., 1994).

Tunnel linings are structural systems installed during and or after excavation to provide ground support, to maintain the tunnel opening, to limit the ground water inflow, to support appurtenances and to provide a base for the final finished exposed surface of the tunnel. Tunnel linings can be used for initial stabilization of the excavation, permanent ground support or a combination of both (Hoek E. et al, 1981).

Tunnel linings are structural systems, but differ from other structural systems in their interaction with the surrounding ground, which is an integral aspect of their behaviour, stability and overall load carrying capacity. The loss or lack of support provided by the surrounding ground can lead to a failure of the lining. The ability of the lining to deform under load is a function of the lining relative stiffness and the surrounding

Above: The Quadrilatero Marche-Umbria project area



ground (Beiniawski, 1984). Frequently, a tunnel lining is more flexible than the surrounding ground. This flexibility allows the lining to deform as the surrounding ground deforms during and after tunnel excavation. This deformation allows the surrounding ground to develop strength and stability. The tunnel lining deformation allows the moments in the tunnel lining to redistribute the main load inside the lining which are axial or eccentric load. The most efficient tunnel lining is one that has high flexibility and ductility.

The open steel profiles (IPE, HE, IPN) typically used as first lining support, show performance weakness in their static structural properties in directions other than the normal and central position. With reference to particular local conditions a closed circular profile will offer better performance conditions compared to an open profile. An example of a specific local condition is when there is a non-homogeneous contact between the profile and the



**World Leaders in Temporary Electrical Systems for the Construction & Tunnelling Industries**

UK Office Tel: + 44 (0)1206 596 100  
Italy Office Tel: + 39 0289 501 730  
Email: info@rutherfordpower.co.uk  
www.rutherfordglobalpower.com

*We Put The Power "ON"*

## Tailor Made Safety

MineARC Systems can custom design and build an emergency refuge solution to suit any tunnelling project, anywhere in the world.

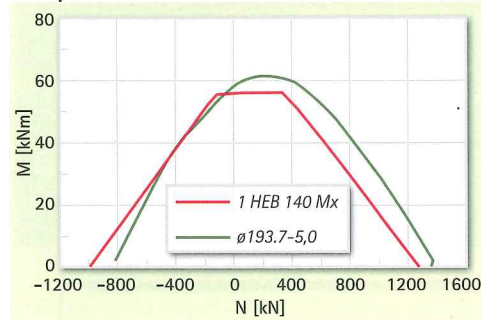
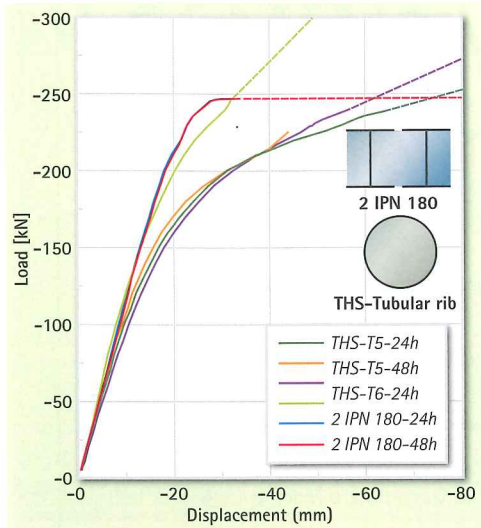
- ✓ Fully custom-engineered design and build
- ✓ Safe entrapment duration to suit project
- ✓ Manufactured to 'world's best practice'

Custom TBM-Gantry mounted Refuge Chamber

**WTC2013<sup>®</sup>**  
Switzerland - Geneva  
May 31 - June 07 2013  
**Stand L12**

**mineARC SYSTEMS**

Call or visit the web site +61 (8) 9333 4966 www.minearc.com/tunnelsolutions

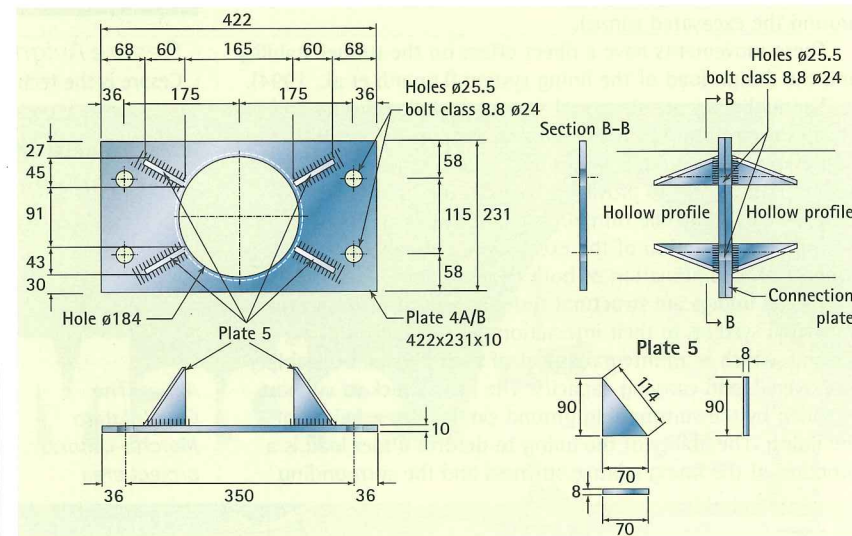
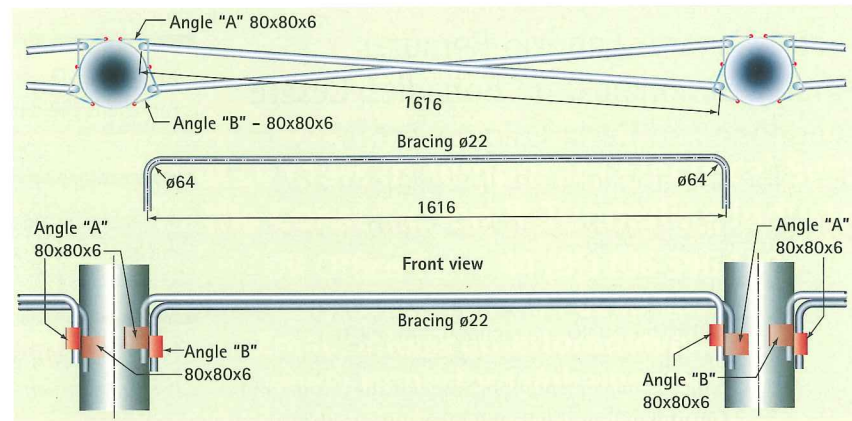
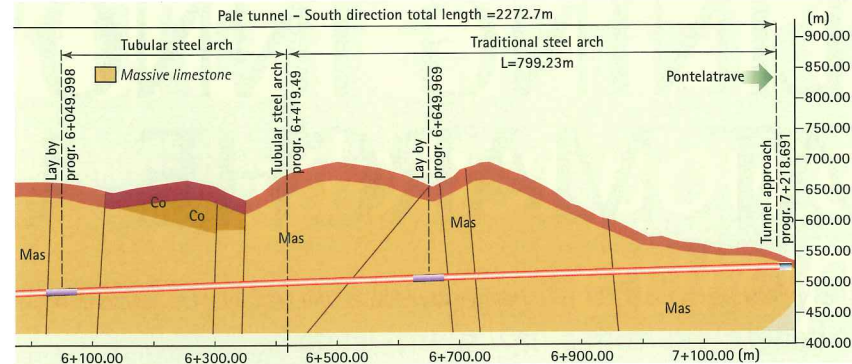


soil, which may occur during the tunnel excavation progress and not always found in a plane strain state. It is also acceptable to assume the worst performance conditions for a double "T" profile in the presence of a horizontal load component. These problems can be solved using a symmetrical axial cross, like a tubular rib. Substituting the open profile with a circular profile of the same area, provides a better stress redistribution. This enables the resistant cross section the capability to accommodate and control axial and eccentric loads, acting along any direction (Bringiotti, 2003).

In this paper the authors describe the application, installation and safety aspects of this New Tunnel Lining System reinforced by Tubular Arches utilized on the Quadrilatero Marche-Umbria Project, Italy. The system, consisting of the Tubular Steel Arch, shotcrete (with blended accelerants) reinforced with steel mesh and/or fibres, has been inserted into the project after the job site test validation described in a previous paper (Zenti, et al., 2012).

**EXPERIMENTAL ACTIVITY**

Extensive numerical analyses were performed prior to the experimental activity (see Figure 1). Those focussed on



Top, left: Figure 1, average results

Above, left: Figure 2, Ultimate strength domains

Top, right: Figure 3, geological profile

Middle, right: Figure 4, double crossing chains

Bottom: Figure 5, junction plates

identifying the correct profiles to compare. The experimental work was carried out in two phases; (1) conducted in the laboratory, necessary for the validation of numerical analysis and (2) conducted on site in order to compare the structural response of the two types of ribs, standard and tubular.

The numerical and experimental investigation confirmed that the Tubular Hollow cross section shows better performance compared with an Open Steel profile Standard Rib. Laboratory test results confirmed the composite section performance of the tubular rib as usually modelled in the design phase. This assumption was not confirmed for the Standard open profile Rib. Field tests (see Figure 2) were carried out to evaluate the compatibility of the new type of ribs with underground work regarding installation and stress-strain response. From an operational perspective, the tubular rib is very stable and easy to handle during transportation and installation. This ensures

Table 1. Project outline

Contract	Lot	Project and intervention	Stage
Maxi Lotto 1	1.1	SS77 Collesentino - Pontelat-rave (2,7 km)	Finish and open to traffic on 2009, December 3rd
	1.2	SS77 Foligno - Pontelat-rave (34,7 km sub lotto 1+2)	Job Site start to work on 2009, November 9th
	1.3	Allaccio SS77 - SS16 Civi-tanova Marche (1,3 km)	Final Design Discussion
	1.4	Allaccio SS 77 - SS3 Foligno (8 km)	Final Design Approved
	2.1	SS77 Foligno - Pontelat-rave	Job Site start to work on 2009, November 9th
Maxi Lotto 2	2.2	Intervalliva Macerata (3 km)	Final Design Internal Discus-sion
	2.3	Intervalliva Tolentino - San Severino (7,2 km)	Final Design Internal Discus-sion
	2.4	SS78 Sforzacosta - Sarnano (31 km)	PD in corso di istruttoria interna
	2.5	SS3 Pontecentesimo - Foli-gno (5 km)	Definite Project Plan - Next opening Job site
	1.1	SS76 Serra S. Quirico - Albacina, Fossato di Vico - Cancelli (22,3 km)	Job Site start to work on 2009, February 16th
	1.2	SS318 Pianello - Valfabbrica (8,1 km)	Job Site start to work on 2009, May 29th
	2.1	Pedemontana Fabriano - Matelica nord	PD approvato dal CIPE
2.2	Pedemontana Matelica - Muccia/Sfercia	PD conclusa procedura Conferenza dei Servizi	

Source: Authors

The high rigidity of the proposed profile eliminates the potential risk of buckling during the installation

a higher level of safety to the site operatives. The high rigidity of the proposed profile eliminates the potential risk of buckling during the installation. In all sections tested, the deformation responses recorded were always maintained within the elastic range. The tensions measured at stress control stations in the tubular ribs showed significantly lower values compared with the corresponding standard open profile ribs.

The tubular hollow cross section offers a better stress redistribution and improved structural statics properties, providing the capability to accommodate axial and eccentric loads applied in any direction.

With reference to specific local load condition, hollow profile circular sections have better performance characteristics. A good example of this problem is the non-homogeneous contact conditions between the steel supporting profile and the soil, which can occur during the excavation of a tunnel. A plain strain condition is not always found.

It is acceptable to assume a double "T" worst working conditions in the presence of eccentric loads. These problems can be solved using a symmetrical cross section, such as in a tubular rib.

60

Per cent of the 35km section is in tunnels

111

Steel arches are saved per kilometre by using the tubular arches

The design method and experimental activity detail have been described in a previous paper: "Zenti C.L., Lunardi G., Rossi B., Gallovič A. (2012) - A new approach in the design of first lining steel rib - Proc. World Tunnel Congress, WTC 2012, Bangkok, Thailand, 18-24 Maggio 2012."

**THE PROJECT**

The Quadrilatero Marche-Umbria Project features the construction of infrastructure, whose axes ideally represent the four sides of a quadrilateral.

The project consists of the completion and upgrading of two main highways; roads the Foligno-Civitanova Marche freeway (S.S.77) and the main roads Perugia-Ancona (S.S.76 and S.S.318). This new road system connects existing industrial areas and, more generally, improves and increases the access to the internal areas of these central Italian regions.

From a strategic infrastructure perspective, this project is part of the main arterial road system of Italy, reducing the infrastructure deficit experienced by Marche and Umbria and creating an efficient link with the surrounding regions and Europe.

**Pale Tunnel**

The new solution for the primary lining, made by B.ZERO-Tondo tubular steel ribs, has been applied in Pale Tunnels, which are currently under construction (Spring 2013).

The previous section described the Quadrilatero project and the Pale Tunnels are within the section from Foligno to Pontelat-rave (Table 1- lot 1.2). This element is 35km long and includes 13 tunnels (Table 2), eight cut-and-cover sections and 16 viaducts. With 60 per cent of this section provided by tunnels, the result is a project with a lower environmental impact.

The Pale Tunnels are being excavated within the Massive Limestone rock mass with good mechanical characteristics (Figure 3). Within this type of rock mass a category A behaviour "stable core-face" (diagnosis phase, Lunardi, 2008) was expected.

The excavated tunnel section designed for this stretch corresponds to a section type Ac. This section is characterized by shotcrete reinforced by a traditional standard rib made of a single HEB 140 installed every 1.50m (single profile HEB 140, Steel Grade S275). The B.ZERO-Tondo Tubular Rib was selected to substitute the traditional system with a Tubular Hollow Section;

193.7mm diameter with 5mm wall thickness in steel Grade S275. The Tubular Rib Ultimate Strength Domain resistance domain is comparable to that one of Standard Rib (Figure 2).

The geological conditions are similar to those encountered in the field test (Figure 3). The project engineer designed a solution using tubular steel arches at 1.8m centres spacing with a pair of crossed chains as bracing between the arches. This connection between the two arches guarantees out of plane stability, because it works in the same way as a rigid bracing (Figure 4). Furthermore, this decision was taken on the evidence of the good results recorded during experimental activity carried out in the Varano Tunnel, characterized by similar geological condition (Zenti, et al. 2012).

**Tubular Steel Arches Installation**

The installation process for this new primary lining system are similar to the traditional approach. Tubular steel arch assembly and installation consists of the following phases:

- **Component handling:** one worker secures the components for lifting/hoisting and indicates any obstacles along the route to the machine driver.
- **Component carriage:** during transportation components are lifted to the necessary height to overcome any obstacles if present.
- **Pre-assembly:** steel rib components are positioned in the final configuration using a mobile crane and linked together by bolted junction plates. This stage could be performed near to the excavation face or outside the tunnel, depending upon the job site management.
- **Placement:** Tubular steel arch, placed adjacent to the excavation face, lifted up and laid as close as possible to the excavation profile.
- **Filling:** The tubular steel arch is then filled with concrete, pumped into filling ports on the tubular profile.

The tubular rib has good compatibility with underground operational needs. The tubular rib is very stable and easy to handle during transportation and installation. The buckling risk during installation has been eliminated due to its high rigidity. This reduces the risk to operatives and is therefore safer to install than other less rigid support arches. The filling phase is rapid and functional to ensure the complete filling of the profile. The junction plates of the tubular arch are characterised by a central hole that

Table 2. Foligno-Pontelatrava tunnels

Tunnels S.S.77 Foligno - Pontelatrava	length [m]	
	North	South
Belfiore	1,100	1,109
Pale	2,319	2,045
Sostino	2,820	2,834
La Franca	1,052	1,075
Cupigliolo	2,182	2,100
La Palude	1,166	1,226
Varano	3,455	3,472
Serravalle	1,341	1,341
Bavareto	1,682	1,661
Muccia	2,126	2,223
Costafiore	565	552
Maddalena	670	550
Rocchetta	840	980

Source: Authors

www.tunnelonline.info

A world of information fully archived and searchable at the click of a mouse



This connection between the two arches **guarantees out of plane stability,** because it works in the same way as a rigid bracing

enables the creation of a continuous concrete arch within the tubular profile at the completion of the filling phase. This Tubular Arch System assures the effective collaboration between the steel circular hollow profile and the concrete filling, thereby produces a composite system with enhanced performance behaviour. The remaining operational phases necessary for tunnel construction remain unchanged.

**Monitoring Results**

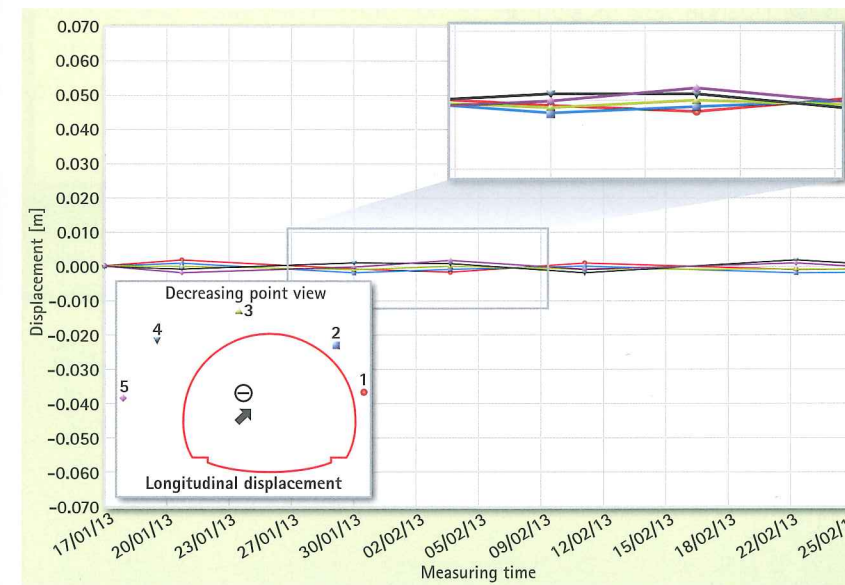
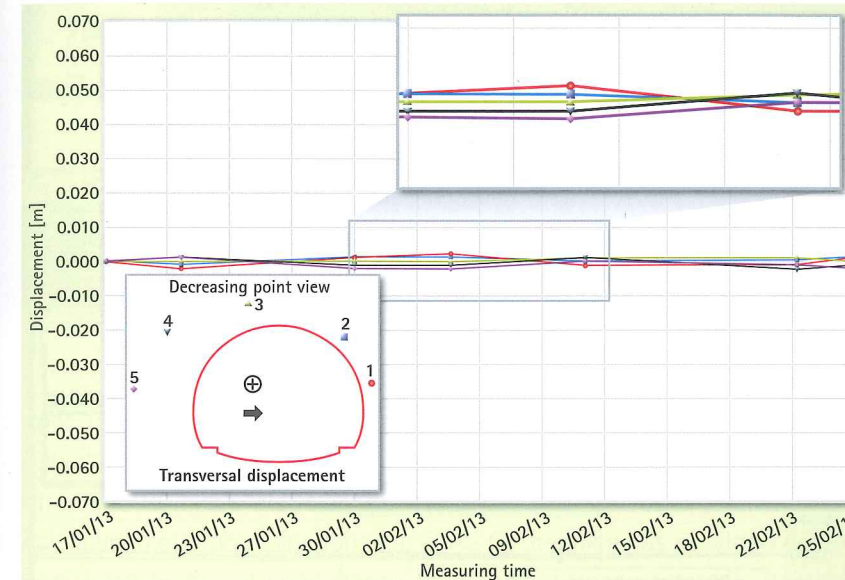
The mass presents homogeneous characteristics (Figure 3); this has been demonstrated by geological surveys carried out upon the face. The deformation in-plane response recorded was always within the elastic range, with displacement and convergence values below 0.5cm, in rapid stabilization.

The difference between the behavior of traditional and tubular ribs can be underlined by the evaluation of transversal and longitudinal displacement. Figure 6 shows the transversal (Figure 6.a) and longitudinal (Figure 6.b) displacement of a single HEB 140 arch installed every 1.50m. Figure 7 shows the transversal (Figure 7.a) and longitudinal (Figure 7.b) displacement of a B.ZERO Tondo tubular arch (193.7mm-th.5mm) at 1.8m centres spacing with a pair of crossed chains as bracing between the arches. Evaluating the monitoring results (Figure 6.b and Figure 7.b), it is clear that the out of plane displacement affecting tubular ribs are lower than those corresponding to standard ribs. In the case of the tubular rib (Figure 7) after an initial movement due to the natural load stabilization, the displacement remains more or less constant. In the case of traditional the rib is not possible to record the same fact.

Table 3. Steel arches

Profile	Steel Arch Characteristics				1km Tunnel length		SAVES
	Steel [Grade]	Length [m]	Installation Step [m]	Weight [kg]	Number [n°]	Weight [tons]	
HEB 140	S275	27	1.5	1293	667	862	111 ARCHES 16.7%
Diameter 193,7 - Th.5mm	S275	27	1.8	1112	556	618	244 Steel Tons 28.3%

Source: Authors



With reference to transversal displacement (Figure 7.a) the constant response of the tubular rib is due to Composite Section behaviour, in which steel tubular hollow section and its concrete fill work together (Eurocode 4). This fact endows the system with the capability to accommodate axial and eccentric loads in any direction.

With reference to longitudinal displacement (Figure 7.b), it is possible to underline the benefits due to crossed chains as bracing between the arches, despite the significant increase in spacing between the arches, 1.5m for traditional system and

Above: Figures 6.a and 6.b, HEB arch installation

Next page: Figures 7.a and 7.b, tubular arch installation

1.8m for B.Zero Tondo tubular Arch.

**Project Cost Analysis**

The tubular rib installation offers numerous advantages, not only from the technical perspective, but also from an economic point of view.

In the Pale Tunnels, as a consequence of good geological conditions, it has been possible to increase the spacing of the ribs installation. It was increased from 1.5m (related to the standard solution using HEB 140) to 1.8m by using the tubular profile (external diameter of 193.7, thickness of 5mm) which has a greater resistance performance envelope when compared to the open sections originally proposed (single HEB 140), see Figure 2). Additionally, the new solution is lighter than the one offered by the HEB 140. The use of a lighter and more rigid profile enables the operatives to work in a rapid and safe way.

The savings within each kilometre of tunnel are summarized in Table 3. It is possible to save 111 steel arches, with a total weight of 244 steel tons. Immediate cost savings are possible due to the reduced steel and, as a consequence, it is possible to generate further saving due to the reduced operational work during the complete construction of the tunnel.

The application of this new Tunnel Lining System consisting of Tubular Arches with double-crossed bracing chains within a steel fibre reinforced sprayed concrete lining, in general, could increase the speed of installation from 10 per cent to 20 per cent, depending on local geological conditions.

Another important saving is due to the absence of rebound during the placement of shotcrete between the tubular profile arches.

From an operational point of view when an operator tries to fill the space between the webs of an open profile support arch, a significant rebound of 50 per cent (or more, in the case of coupled profiles) of the shotcrete has been recorded.

This problem does not occur in the

### Photo Competition

Don't forget to enter the Tunnels and Tunnelling Photo Competition if you think you have what it takes to claim the latest in digital camera technology as your prize. The closing date for entries is 1 July and the short listed entrants will be announced in the September issue of *Tunnels*. The winners will be announced in the Tunnels Awards supplement in the December issue of *Tunnels*. [awards@tunnelsonline.info](mailto:awards@tunnelsonline.info)

case of tubular profile arches and a complete shotcrete filling between the arches is possible.

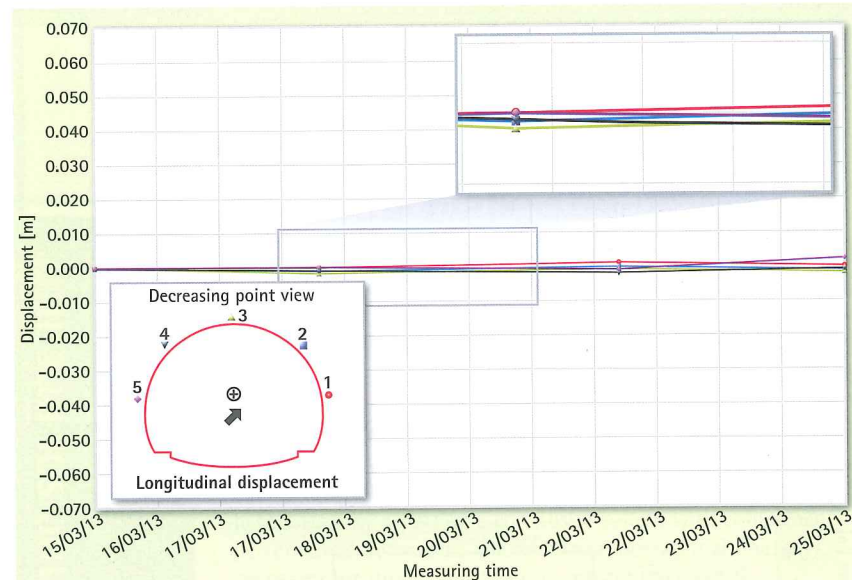
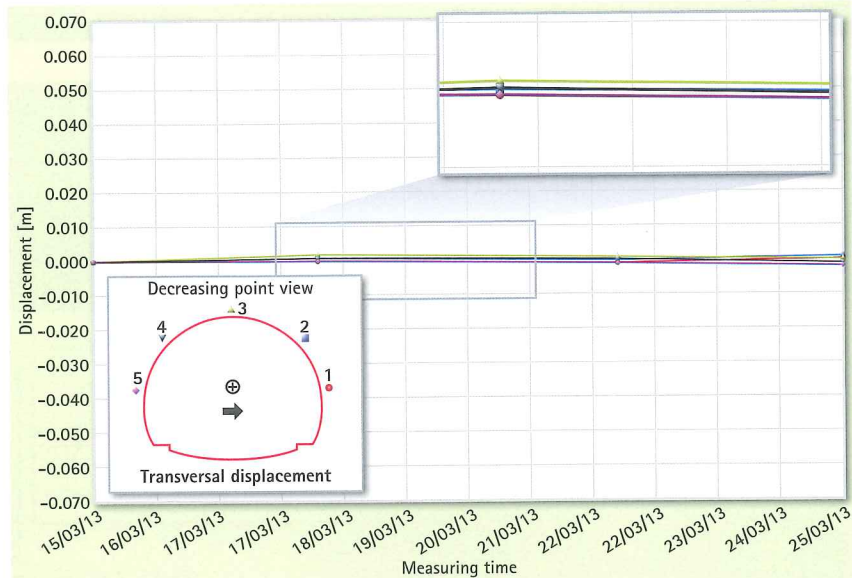
### CONCLUSIONS

The use of tubular steel ribs in tunnelling and underground mining operations offers numerous technical, operational, safety and cost benefits compared to traditional steel section arches. The tubular arch hollow sections accommodate axial and or eccentric loads applied from any direction, enhancing the performance of the support system and reducing the required number of supports over the tunnel length. The concrete fill to the steel arch forms a composite structural member. The rigidity of the tubular section arches also eases transportation and installation of the arches, improving the safety of the tunnel operatives.

Monitoring results confirm the "Composite Section" (Eurocode 4) behaviour of tubular hollow section filled with concrete and the effectiveness of bracing between the arches constituted by crossed chains, which ensures out of plane stability.

During shotcreting of the primary lining, tubular section arches dramatically reduce shotcrete rebound and "shadowing" where voids can occur behind traditional section support arches. The Pale Tunnel application, within the Quadrilatero Marche-Umbria Project, demonstrated the excellent performance of the system consisting of the Tubular Steel Arch, shotcrete (with blended accelerants) reinforced with steel mesh and or fibres.

The authors are grateful to Strabag's Technical Department and particularly to Roberto Manna for his constant support and assistance



### References

Beniawski, Z. T., 1984. *Rock Mechanics design in mining and tunneling*, Balkema.

Barton, N. R., Lunde J., 1974. *Engineering classification of rock masses for the design of tunnel support*, International Journal of Rock Mechanics and Mining Science Et Geomech. Abst.25, No. 13-13.

Bringiotti, M., 2003. *Guida al tunnelling: L'evoluzione e la sfida, 2nd Edition*, Parma, pp.403-406.

Eurocode 4, EN 1994-1-1:2004. *Design of composite steel and concrete structures. General rules and rules for buildings*.

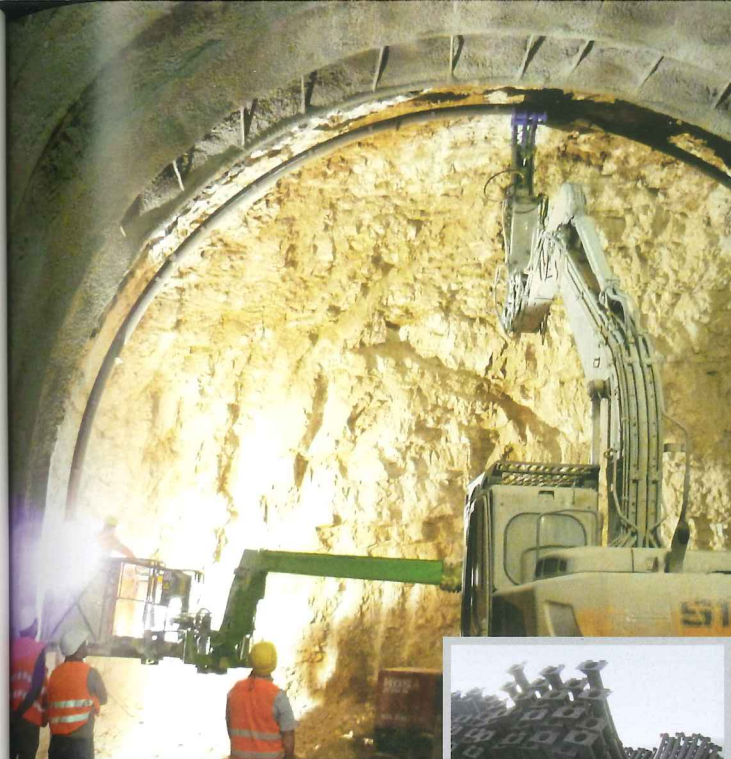
Hoek E., Bray J.W., 1981. *Rock slope engineering*, Institution of Mining and Metallurgy, London.

Lunardi, P., Frolidi, P., Fornari, E., 1994. *Rock mechanics investigations for rock slope stability assessment*, International Journal of Rock Mechanics Vol. 31 N.4, p.323-346.

Lunardi, P., 2008. *Design and construction of tunnels, analysis of controlled deformations in rock and soils (ADECO-RS)*, Springer, Belin, p.576.

NTC 2008 - Nuove Norme Tecniche per le Costruzioni - DM 14 gennaio 2008.

Zenti C.L., Lunardi G., Rossi B., Gallovich A. (2012) - "A new approach in the design of first lining steel rib" - Proc. World Tunnel Congress, WTC 2012, Bangkok, Thailand, 18-24 Maggio 2012.



Tubular Steel Arches offer greater structural efficiency saving costs and time

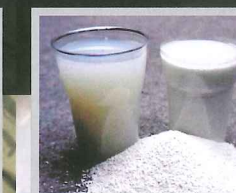


Glass Fibre (GFRP) profiles for cost effective, high performance face consolidation

For over 15 years, ELAS Geotecnica has been supplying the construction market with exclusive, highly innovative and distinctive products for underground construction to meet the specific technical project requirements. In road, railway, dam, metro and mine tunnels, ELAS Geotecnica has provided customers a specialized technical consultancy from project analysis to the identification of products and installation. From tunnel support to soil consolidation, and from the primary lining phase to waterproofing, ELAS Geotecnica products improve efficiency and reduce costs in all phases of tunnel construction.



P.E.R. Ground provides high pull-out strength reinforcement, reduced grout loss and optional drainage



Grout Master provides soil consolidation, compensation and waterproofing, reducing ground settlement

## Build a better world and brighter future at CH2M HILL.

As an employee of CH2M HILL, you will make a difference in our world and in your career.

### Technical Director Rock Mechanics (Designate) – Wiltshire, UK

This is an exciting and rare opportunity to lead and develop a well-established team of rock mechanics, rock slope and rock tunnelling engineers within CH2M HILL's Tunnelling and Earth Engineering Practice. Based in our modern office complex in rural Wiltshire, you will work alongside our existing Technical Director and, over the next 6 months, progressively take over responsibility for our growing rock mechanics workload in road and rail tunnels, hydropower, water transfer and underground storage markets worldwide.

You will be competent in rock mechanics analysis and design and have a thorough knowledge of international design standards and associated technical literature. You will have a record of high level involvement in major civil engineering projects from conceptual design through to construction and a proven record of solving complex rock mechanics problems for civil engineering projects. You will have experience of international work and a willingness to travel and undertake short overseas assignments.

Ideally you will be a Chartered Engineer with a first degree in civil engineering and a post-graduate qualification (PhD or MSc) in rock mechanics (or closely related subject).

For an informal discussion regarding this exciting opportunity, please contact Scott Gisby. Email: [scott.gisby@ch2m.com](mailto:scott.gisby@ch2m.com) Tel: + 44 (0)203 479 8454

For this and many other exciting opportunities visit [ch2mhill.jobs](http://ch2mhill.jobs)

**CH2MHILL®**



Developing People through Challenging Projects

EOE

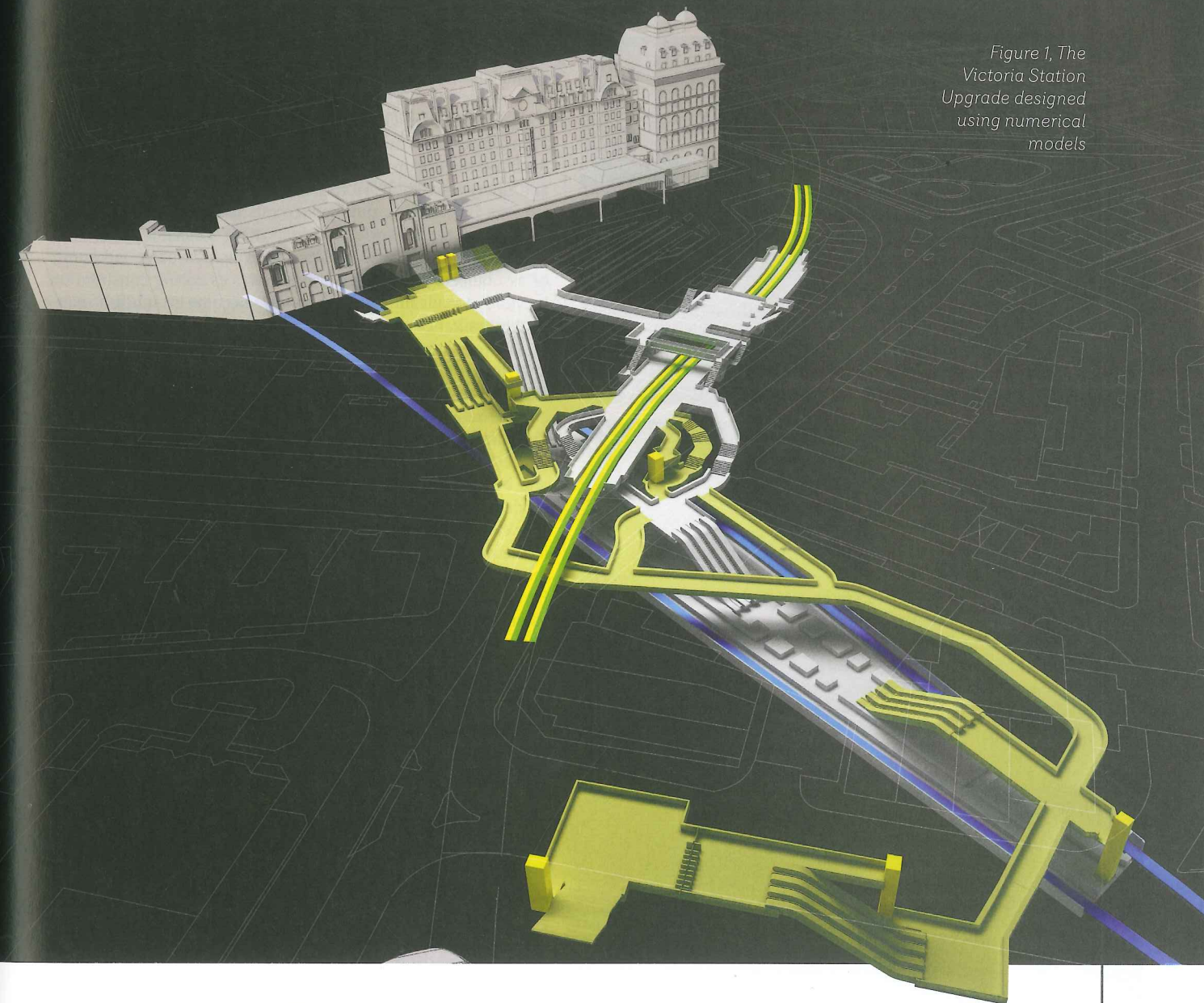


Figure 1, The Victoria Station Upgrade designed using numerical models



## The global marketleader in tunnel seals

### Immersed Tunnels

#### Gina Gaskets & Omega Seals

The rubber Gina gaskets and Omega seals are used between the sectional elements of immersed tunnels to prevent water ingress due to external waterpressure.

### Cut & Cover Tunnels

#### Waterstops

When concrete structures are submitted to outside waterpressure, the joints between concrete sections are made watertight with rubber waterstops.

### Bored Tunnels

#### Tunnel Segment Gaskets

Tunnel segment gaskets (TSG's) are placed in precast grooves encircling the mating faces of each segment, giving a secure rubber-to rubber waterproof seal as soon as the segments are bolted together.

Trelleborg Ridderkerk BV, PO Box 4007, 2980 GA Ridderkerk, The Netherlands  
Tel: +31 180 49 55 55 [ridderkerk@trelleborg.com](mailto:ridderkerk@trelleborg.com) [www.trelleborg.com/infrastructure](http://www.trelleborg.com/infrastructure)



# PRACTICAL MODELLING

This paper attempts to offer practical information and disclose significant aspects of numerical simulations in tunnelling based on the authors' experiences in research and applications on a wide range of projects in and outside the UK. Authors Panos Spyridis of Dr. Sauer, Angelos Gakis of Dr. Sauer and Anmol Bedi of Imperial College London explore

AS COMPUTER technology evolves, numerical modelling appears to be an increasingly popular tool to obtain solutions for static or dynamic structural problems in all engineering fields. Tunnelling, on the other hand, is one of the most empirical engineering disciplines; so applicability and reliability of such numerical solutions may often be challenged. Yet, in the famous words of G.E.P. Box, "all models are wrong, some are useful," [1]. Numerical methods have become standard practice and are indeed a very useful tool for the analysis of complex tunnel structures, as many recent design and consulting projects have shown. In the authors' perspective a well prepared simulation of an underground structure can give a good and communicable description of the structural behaviour, indicates risks,

**Panos Spyridis**

Panos is a lead tunnelling and structural engineer at Dr. Sauer & Partners based in London, UK

**Angelos Gakis**

Angelos is a geotechnical and tunnel engineer, also at the London office of Dr. Sauer & Partners

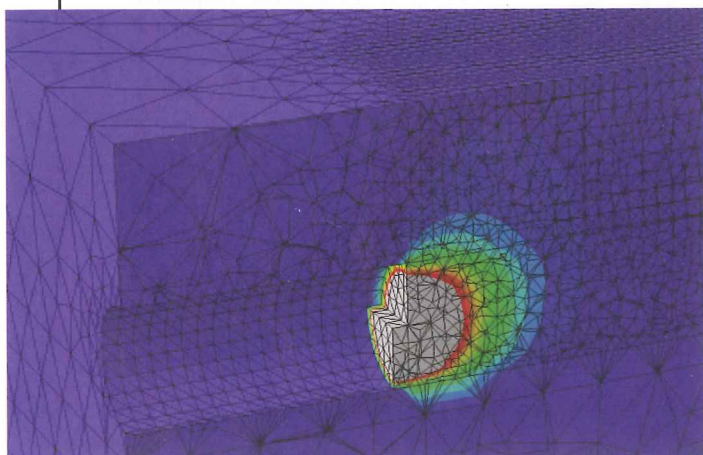
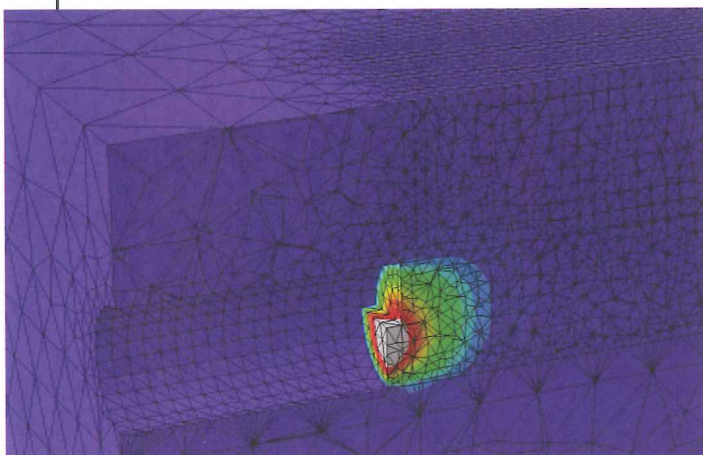
**Anmol Bedi**

Anmol Bedi contributes his knowledge from his position at Imperial College, London

and highlight issues deserving additional attention during design or construction, and provides substantial aid to the project development.

In the first part of the paper, the purpose of using numerical solutions in tunnelling is explained, together with a discussion on the advantages and disadvantages in engineering terms. Furthermore, some practical rules and hints on the implementation and verification of numerical models are outlined. The paper concludes with advice on the use of numerical models

*Below and opposite: Figure 2, Face stability and pre-support measure design - development of a failure wedge represented by total displacement contours*



in design projects and some rationalisation of a modelling campaign in terms of cost (or effort) efficiency.

**THE PURPOSE OF MODELLING**

The primary objective of tunnelling engineers is arguably to facilitate the design and construction of tunnels as efficiently and safely as possible. In this endeavour, we are often required by clients to produce reports quantifying, or at least identifying, the potential risks to existing surface and sub-surface infrastructure in an attempt to provide some measure of assurance against adverse consequences during construction. Inevitably, modelling appears to have become an inherent part of this assurance process.

The purpose of engineering models – whether physical or analytical – is essentially to try to anticipate or simulate the expected response of the ground to excavation, as well as loads and deformations induced in the structural support elements of the new and existing infrastructure. The reality is however, no matter how thorough we may believe our ground investigation and interpretation is, or how numerically sophisticated our models to be, every model is only an abstraction of reality. This can be attributed to lack of knowledge, to randomness in the nature of materials and phenomena, to mathematical indetermination, or even decisions on budget allocation. Particularly in geotechnical engineering, the inherent variabilities of the ground mean that the predictions resulting from the modelling process contain uncertainties.

For centuries, prior to the advent of numerical models, tunnels have been successfully designed and constructed using empirical and simple analytical methods. The empirical approach makes use of past experience in similar conditions to define temporary support and lining thicknesses. Of course experience must be relied upon (probably most in SCL tunnelling), and this aspect can hardly be matched by numerical calculations. However, the authors are of the opinion that using such an approach alone cannot adequately quantify risk and uncertainty during the design phase, which are then to be managed during construction. The closed form analytical solutions often employ grossly simplifying assumptions, one of which is that the ground is CHILE [5]: continuous, homogeneous, isotropic, linearly-elastic. However, this is barely the case. In fact, the ground is more likely to be DIANE [5]: discontinuous, inhomogeneous, anisotropic, non-elastic. Besides, these methods are typically valid for very simple planar geometries. Numerical models can be used to help quantify the risks during the design phase, as well as capture the DIANE nature of the ground and complex tunnel geometries.

The requirement to quantify uncertainty and manage risk coupled with the inherent simplifications in closed form solutions has perhaps been a driving factor in the increasingly frequent use of numerical models for tunnel design. This is ever more apparent as urban development requires engineers to push the boundaries of experience and in some instances, propose new construction schemes that are without precedence. The numerous station upgrade schemes currently underway in London are typical examples.

*The debate for and against numerical models*

We are all too familiar with the situation seen in many consultancy offices where the boss walks in and says: "Team, here are the details of the new tunnel project that we've won. What I want you to do is design the lining and support elements and give me a prediction of imposed deformations". At which point, someone is charged with 'doing the numbers'. This, usually young, engineer fires up the numerical modelling software, dives in to designing the tunnel and comes back

with results. Yet often the modeller's results may not fit with a design that experience has shown to be adequate for similar conditions. For instance, the predicted lining loads may fall outside the theoretical capacity of the shotcrete lining, calculated in accordance with Eurocodes; the code checks and results of the model indicate a lining thickness far greater than what more experienced practitioners consider 'reasonable' for the problem in question. Thus, we are faced with a dilemma: on the one hand, we have a modeller who has perhaps received formal tuition in numerical methods and has some experience with its implementation at the office; on the other hand, we have the practical engineer who has spent years on site building tunnels, both with differing opinions. The question is whose advice we should take. Whether the design should be driven by the model, or if the model should be adapted to suit what we believe to be the correct design.

It is perhaps these situations that prompted Professor David Potts to address this debate for and against numerical modelling in his 2003 Rankine Lecture [12]. In this, Potts raises concern over the frequent examples of poor practice which have led others [6] to question the validity of design using numerical models. In the authors' opinion, it is perhaps not the numerical model to blame; the model is but a mathematical calculation based on fundamental laws of physics and engineering theories, the latter of which are prescribed as inputs by the user.

Indeed, the input of the model dictates the output. Victoria Station's original 1960s design (created without numerical models), compared with the modern vision (Figure 1) demonstrates the variability that can result based entirely on the users approach to modelling. It is perhaps such variability that has led to the disparity between the two schools, for and against modelling. From the authors' experience it appears that the generation of practically trained engineers tend to doubt numerical models because the new-age engineers-cum-modellers often lack practical experience, or it is that they do not understand the expected behaviour, which leads to their blind faith in the results of the model.

But then again, in any solution (numerical, empirical, analytical), the quality of input defines the quality of output. Regardless of the approach being empirical, analytical, or numerical, if the result stems from good engineering, it will provide a correct solution. Numerical modelling carries certain benefits, but solutions from all three approaches should be consistent with each other. And of course, modelling engineers should have a broad practical understanding of their subject, in order to deliver a practical product with their work.

**IMPLEMENTATION**

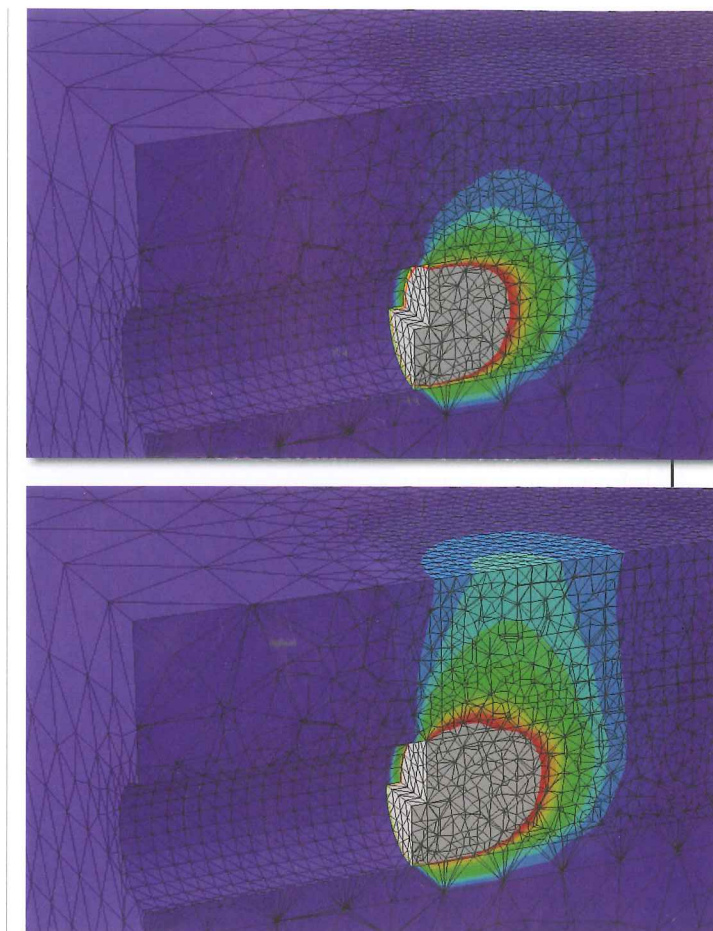
There is a "thin line" between detailed, accurate structuring and result-oriented manipulation of the model and yet this very argument may compromise the credibility of numerical methods. Thus, it is of high importance for the modelling engineer to make the necessary assumptions and simplifications, getting rid of superfluous details and produce the best possible product. To achieve that, a process of improving the model in terms of simulating all the relevant features as accurately as possible shall take place prior to running any analysis.

*Type and scope of numerical models*

Various model types can be used depending on the nature of the structure.

In terms of the scope of the model, three cases are distinguished: check, design and back analysis.

When the aim of the model is checking, typically tunnel



lining and predefined excavation and support sequences need to be validated. A simple yet conservative model can be initially set up. If the check results don't confirm the expected, the sophistication of the model can be gradually increased. This is a sequential approach, aiming to optimise the effort-efficiency relation.

If on the other hand the task is to design a tunnel, a model that calculates the minimum lining thickness, construction stages and induced settlements is required. All possible load cases have to be considered, complying with the national or the project's specific regulations, lying on the thin line between cost-efficiency, accuracy and reasonable degree of conservatism.

Numerical models can also be used to perform back analyses, i.e. building models that result in a known stress/displacement state from monitoring results. As an example twin NATM tunnels were excavated in a natural Flysch slope resulting in the activation of a landslide. The scope of the analysis was to produce a model that back-calculates both the actual mode of failure and the inclinometer displacements in order to acquire a starting point for the design of the mitigation measures, optimising an

initial model prepared by [7]. The back analysed model, exhibited a close match to both the Inclinator measurements and the mode of failure.

*Simulating the soil*

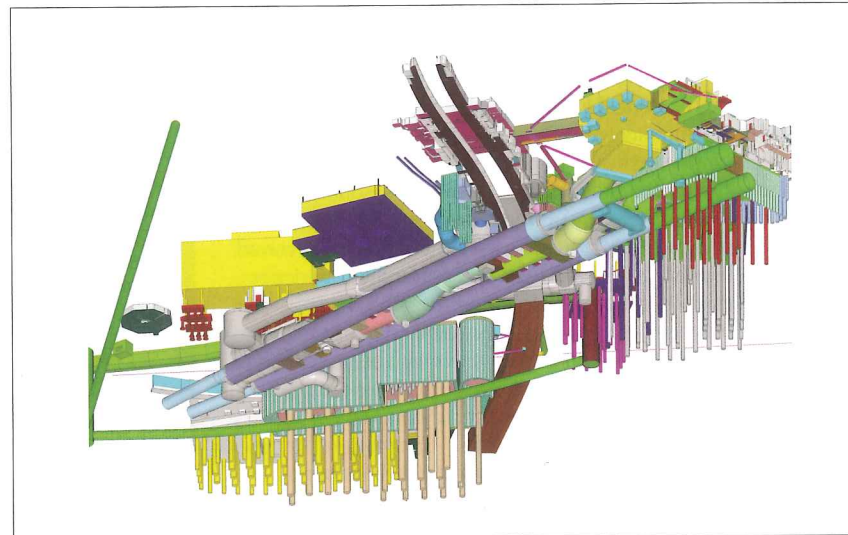
For the simulation of the soil, the engineer needs to derive the appropriate soil parameters for the selected constitutive model, mainly based on the geotechnical investigation. As tunnelling deals with unloading, it is of high importance to consider the dependency of bulk and shear stiffness on the stress and strain level and to be aware that soil exhibits a stiffer behaviour on unloading than in primary loading. However, the uncertainty in soil mechanics is reflected in the derivation of most parameters (such as  $k_0$ ) and the final outcome should reflect a reasonable implementation of factors such as the anisotropy, heterogeneity or the presence of geological faults. In any case, some simplifications can be applied to make a reasonable model, making use of previous experience in similar projects or ground conditions.

*Structural components*

The most commonly simulated structural components in tunnelling are the linings. Once the acting loads on the supports have been calculated, the simulation can be performed using either solid (continuum) elements or shell (beam) elements. A great advantage of using solid elements is that they allow for complex shapes and excavation sequences to be simulated. However, the structural section forces (M, V, Nhoop) cannot be calculated directly and the small thickness of the lining compared to the size of the model requires detailed meshing and usually a large number of elements. With shell elements, the structural forces can be acquired directly, the mesh quality is not being compromised and they can be used together with joint elements in order to simulate construction joints (common in SCL tunnelling).

*Excavation and support sequences*

A great feature of numerical methods is that they allow the simulation of various construction phases and especially in tunnelling, for the implementation of the so called "soil relaxation". The excavation and support sequence simulation is a straightforward procedure that shall be done as accurately as required by the nature of each individual structure. Focusing on the soil relaxation, the main principle is the



Above: Figure 3, The underside of Victoria Station

following: when a simplified numerical model is used instead of a full 3D one, a relaxation factor can be applied on the soil prior to its excavation in order to simulate the deformation that takes place prior to the installation of the support.

There are several ways to estimate the relaxation factor (analytical methods, simplified numerical models), and to implement it in the model (internal pressure reduction, stiffness reduction, volume loss control). When it is possible, the most direct method should be used in order to avoid additional time consuming calibrations of the model (e.g. using internal pressure reduction, which is directly related to the relaxation factor, instead of stiffness reduction, which will have to be calibrated to estimate the appropriate stiffness reduction factor that yields similar results).

*Trials and calibration*

The calibration of a model, refers to the execution of trial analyses in order to validate it against analytical or well established numerical solutions. This is done to match monitoring data (similar to back analysis) or to investigate the effect of various parameters (sensitivity analysis). It is up to the judgement of the engineer, whether the model should be calibrated in order to optimise its performance or increase the output confidence.

*Checks and verification of results*

As already discussed above, quality of numerical models – especially in geotechnics – is strongly dependent on uncertainties in their input and consequently their output. And then it comes to the hands of the modelling engineer to prepare a tool that fits the needs of a problem with adequate accuracy, precision and reliability. In order to achieve that, one should try to fully understand the functions of the model, eliminate all errors, and verify the results in the post-processing phase. Bottomline, a model must make sense; and its creator must be able to defend this.

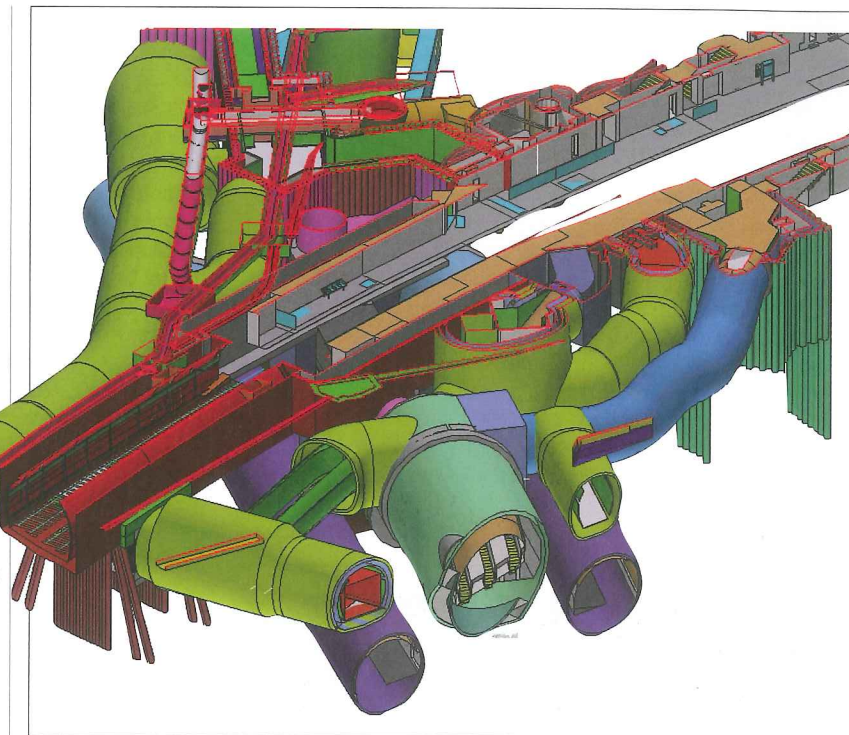
In the pre-processing phase, a thorough check should be performed in order to identify any flaws in the geometric formulations and the mesh (e.g. wrongly assigned boundary conditions, ill meshing, or incompatible types and orders of finite elements), or the input parameters; a very common mistake is the oversight of the unit system; sometimes the apparently trivial matters most. It is also important to "escalate" the complexity of the model as this is being built: From the authors' experience, approximately 50 per cent of troubleshooting in a model is associated to material non-

linearity, so it seems logical to simply test-run an elastic model before assigning any soil plasticity. Why not allow for an easier breakdown of the error-hunting?

But even before all that, it is of great importance that the user understands the model's functions, i.e. the way it receives the input and the way it produces the output. For that, one could create a simplified trial model to identify potentials and limitations of the program. What can prove quite helpful is a cross-check with analytical solutions (as for example arch-statics, [10], [2], [3], or [11] – see also (Jones, 2013)), or empirical solutions and previous experiences – this can be a review of previous projects, available monitoring data or a discussion with a senior colleague. Such solutions can also be used for the verification of the output. Moreover, agreement between the outputs of two independently prepared models can substantially increase confidence in the results and accommodate justification for decisions to be made based on them.

**DESIGN ASPECTS**

Once the required results are extracted and verified, they can be infused into the design process, which may include the structural design, as well as the design of excavation sequences, settlement mitigation measures, or monitoring layouts. Nonetheless, this process is not straightforward and it shouldn't be neglected that it typically includes several iterations between the modelling and the design team in order to optimize the design outcome, while the construction team is often also involved in such decision making processes. Obviously, this leads to a necessity for a thorough reporting of the modelling procedure and archiving of the respective data, and definitely a perceptive budget allocation and time scheduling. This will become more critical if the modelling engineer is absent at a future stage – e.g. departed from the project team after the delivery of the first outputs – so revisiting a sophisticated model can become particularly laborious. The transfer of information between the various teams shall be devoted additional attention in order to avoid misinterpretations, especially when it comes to large bulks of data in raw formats and spread-sheets, or when a third member inspects the output to extract information. Essentially it should be a modelling engineer's pronounced responsibility to build the model in both



Above: Figure 4, Tightly packed development at Victoria Station with new works shown in green

an editable and retraceable way.

*Structural design through capacity limit curves*

The development of advanced numerical methods in tunnel analysis and design, led characteristically to a large amount of output information. When it comes to tunnel linings, which in most cases are elements with uniform thickness and reinforcement (or unreinforced / fibre-reinforced), the design can be expeditiously performed using the so-called Capacity Limit Curves (Sauer et al., 1994).

These curves can present all design combinations of axial forces and bending moments (potentially shear forces too) juxtaposed to the envelope of the cross-section's design capacity, providing a transparent and comprehensive graphical and numerical structural verification, as well as the design's safety factor (Hoek et al., 2008).

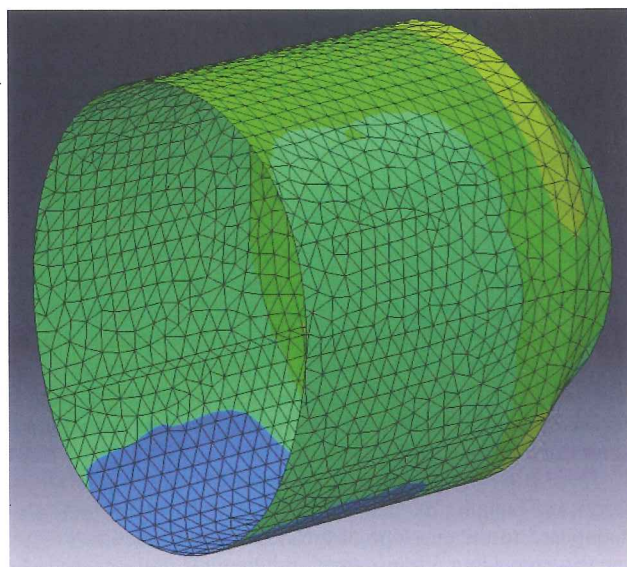
**EFFORT - EFFICIENCY**

Recent years have seen an accelerated advance in computing technologies. Even until the 1970's when the first pocket calculators became available the most commonly used calculation tool among engineers would be the slide rule, already in the 1980's a desktop PC became a standard for design consultancies, and relevant technology has constantly advanced. Yet, although computing technology never stops advancing, a remarkable shift is taking place when it comes to analyses in the world of civil engineers: not long ago, time in numerical analysis tasks was mainly perceived as that needed to run a calculation, but nowadays it is much more time allocated to building, troubleshooting, and post-processing a model than running it itself. Increased computing capacities allow for much more competent models, e.g. in term of geometry precision (3D), or material constitutive laws (non-linearities). Consequently, efficiency of a modelling exercise has now become clearly associated to the abilities of the modelling engineer, than the abilities of the machine.

At the same time, the effort and money put in the modelling campaign needs to be aligned with the requirements of the project, i.e. the technical questions that need to be

## References

- [1] Box, G.E.P., Draper, N.R., 1987. *Empirical model-building and response surfaces*. John Wiley & Sons.
- [2] Curtis, D. J., 1976. *Discussions on Muir Wood. The circular tunnel in elastic ground*. Geotechnique 26, pp. 231-237.
- [3] Duddeck, H., Erdmann, J., 1985. *Structural design models for tunnels in soft soil*. Underground Space; (United States) 9.
- [4] Gakis, A., 2011. *Investigation of the analytical approach of landslides in soils*. PhD thesis, Aristotle University of Thessaloniki.
- [5] Hudson, J.A., Harrison, J.P., 1997. *Engineering Rock Mechanics - an introduction to the principles*. Pergamon Press
- [6] Hindle, D., 2012. *Can someone please explain exactly what is SCL?* Tunnels and Tunneling-. August 2012: 46-47.
- [7] Hoek, E., 2005. *Part of the Twenty Third Report by Panel of Experts Geotechnical / Tunneling on Egnatia Odos Highway Project*, Egnatia Odos S.A..
- [8] Hoek, E., Carranza-Torres, C., Diederichs, M., Corkum, B., 2008. The 2008 Kersten Lecture Integration of geotechnical and structural design in tunneling, in: 56th Annual Geotechnical Engineering Conference. pp. 1-53.
- [9] Jones, B.D. 2013. *Being analytical*. Tunneling Journal. December 2012 - January 2013: 44-45.
- [10] Muir Wood, A. M., 1975. *The circular tunnel in elastic ground*. Geotechnique 25, 115-127.
- [11] O'Reilly, M.P., New B.M., 1982. *Settlement above tunnels in the United Kingdom - their magnitude and prediction*, Institution of Mining and Metallurgy, Tunneling 82, p. 173 - 181.
- [12] Potts, D.M., 2003. *42nd Rankine Lecture: Numerical analysis: a virtual dream or practical reality?* Géotechnique 53, 533-574.
- [13] Sauer, G., Gall, V. Bauer, E and Dietmaier, P. 1994. *Design of tunnel concrete linings using limit capacity curves*. in *Computer Methods and Advances in Geomechanics*, Eds.:Siriwardane & Zaman, Rotterdam, NL. 2621 - 2626.



answered by the analysis in a feasible budget. A model that gives less than requested is of course inefficient. But yet again, a model providing superfluous information is also not necessarily a good solution.

An obvious example, if the sole concern of a design project is the dimension check of tunnel linings, is the question of why should one pursue a model that accurately estimates surface settlements.

A common waste of computational time is caused through the creation of a very dense meshing, beyond the point that the results are sensitive to the element size. A well-engineered numerical model should provide an appropriate balance between the output it provides, the effort needed to be managed, and the project-specific added value it offers. This is, after all, often considered to be essentially the core of what engineering is about.

Above: Figure 5, Cross-checking and verification of hoop-force results was done between a 3D model as above, and a separate 2D (plane strain) model

## SYNOPSIS

The intention of this paper has been to present numerical modelling for tunnelling from a less academic, more practical point of view and to provide some useful concepts and insights for engineers.

As a summary, the following points are recommended:

- Even the most sophisticated numerical model is incapable of giving an exact answer. Numerical models do have limitations, and peril to the project lurks when the results of a model are trusted blindly. However, when the limits of the model are understood, numerical solutions can yield very useful information. As with most tasks, we need to know what we know, but we must also know what we don't.
- Models are but mathematical calculations based on fundamental laws of physics and engineering theories. Engineers should always question and challenge their models up to the point they are able to explain and defend the results based on theory and/or experience. Confidence in the analysis results should arise from agreement with relevant past experience, cross checking with analytical or simplified numerical solutions, and above all common engineering sense.
- Modelling engineers should know the 'habits' of the software they are using, its pros and cons, and to develop a thorough checklist that simplifies the modelling and moreover the debugging process. Note also, in a poorly constructed model, debugging may take up to 90 per cent of the overall effort.
- Decisions on the analysis approach need to be aligned with the characteristics of the project team. It is sometimes preferable, depending on the capacities of the parties involved, to use simpler models (e.g. simple constitutive laws) that are better understood and communicated. Numerical models are built in order to support a pre-specified engineer's decision and they should be understood in this context. This, when balanced with the project budget can lead to an efficient analysis campaign.

## FINAL THOUGHT

There are no certain rules to be followed when modelling comes to play. In the end, the aim is always to achieve reliable results with minimum effort, a procedure that is always subject to optimisation as the engineers' skill and experience, and as computational capacities increase.

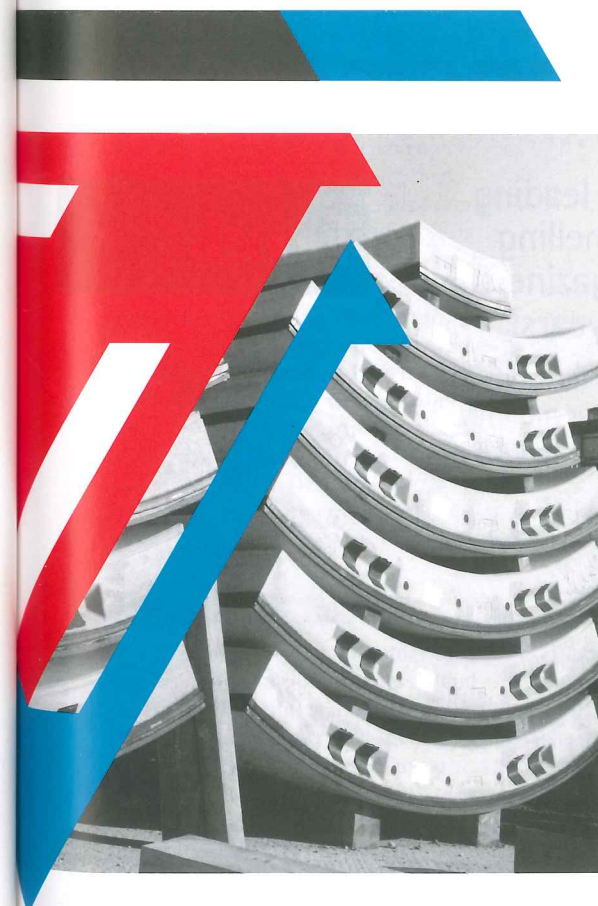
INFRASTRUCTURE SOLUTIONS

BECAUSE EVERY CHALLENGE OFFERS AN OPPORTUNITY FOR SUCCESS.



HOCHTIEF Solutions has been operating successfully in tunneling for many years, among others in Scandinavia. Just one example: Currently we are building for Trafikverket in Stockholm at the E4/E20 tunneling project.

Your contact: Tel. +46 8 5883 7020  
www.hochtief-solutions.com/scandinavia



## HIGH QUALITY GASKETS

International Experience – Proven longevity

Reliable tunnel segment sealing gaskets

- monoepdm
- coexslide
- coexswell
- composite blackswell
- monoanchored gaskets

for road, railway, metro, cable, sewage and water tunnels

Visit our booth G22 at WTC 2013 in Geneva



www.datwyler.com

Sealing Solutions

# BOND STREET MODELS

**Ali Nasekhian**  
Ali Nasekhian is a senior geotechnical engineer at Dr. Sauer Et Partners' London office. He works on Crossrail and LU



**Thomas Schwind**  
Thomas Schwind is a technical director for the Dr. Sauer Corporation and has been heavily involved in the company's US operations



**Stefan Pinter**  
Stefan Pinter works for the Dr. Sauer Group and lends his technical experience and knowledge to this paper



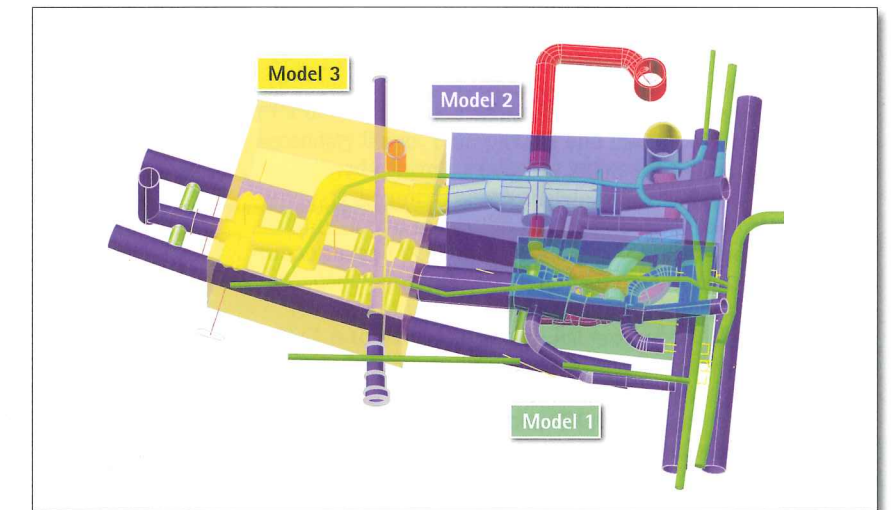
Congested Bond Street Station at the heart of London's Underground is one of the key challenges for an upgrade project. **Ali Nasekhian, Thomas Schwind and Stefan Pinter** of Dr Sauer explain 3D modelling for the project

**B**OND STREET Station serves an interchange between London Underground (LU)'s Jubilee Line (JL), Central Line (CL) and the future Crossrail Station. A number of new tunnels will be built including two access shafts, one lift shaft, four construction adits, two binocular cross passage tunnels, four large concourse and connection chambers, three underpass tunnels, two over-bridge tunnels cutting through existing platform tunnels, two niches for electrical and mechanical equipment and four inclined tunnels for escalator barrels. This challenging design currently makes Bond Street Station Upgrade Project (BSSUP) one of the most complex tunnelling projects in the UK. The total length of tunnels amounts to approximately 450m, with tunnel widths ranging from 4m to 10.2m. The complexity of the project is not only due to the fact that the new tunnels are located in close proximity to many existing tunnels but also that the tunnels are situated in one of the most congested areas in London.

The BSSUP contractor was the Costain-Laing O'Rourke JV.

## IMPORTANCE OF 3D-FE ANALYSIS

At RIBA-E design stage, in order to dimension the tunnel thicknesses and design construction stages, a series of 2D analyses over critical sections were undertaken. It is necessary to make certain assumptions in 2D analysis to take into account 3D geometrical effects, construction sequences and stress variations due to previous tunnelling activities. It is



Above: Figure 1, A 3D rendering of the BSSUP

common practice to assume a so called relaxation factor in order to consider 3D effects in a 2D analysis. However all these assumptions are subjective, and depending on the complexity of tunnel geometry and subsoil condition, sometimes it is a difficult task to estimate a reasonable and sound factor in such complex tube system. In fact, there is no simple procedure to validate the assumptions other than performing a 3D analysis. In addition, since the plane strain conditions don't exist at tunnel breakouts or tunnel connections therefore 3D analysis is necessary in

these situations to analyse tunnel lining and ground stability.

Due to the complexity of BSSUP, the impact of new structures on third party assets are of great importance, comprehensive 3D analysis was inevitable at the detailed design stage (RIBA-F).

## MODEL LAYOUT

Bond Street Station is an interchange point between two LU stations comprising platform tunnels, concourse and connecting tunnels with close proximity of each other and existing urban utilities such as post office tunnels, Thames water and sewer system. Upgrading the station affects the entire



## We understand our business

Our many years of experience in the planning and production of simple to complex conveyor systems have made us into a reliable partner worldwide. Conveyor systems and transport systems are individually adapted to your needs.

Marti Technik AG produces tailor-made, practical solutions based on its own construction site experience.

Talk to us. We will provide you with professional and correct consultation and know all the possibilities that can be used for a qualified realisation of your projects.

We also offer gravel plants, formwork systems, electrical engineering and special constructions.

**Marti Technik AG** Lochackerweg 2 CH-3302 Moosseedorf  
Fon +41 31 858 33 88 Fax +41 31 858 33 89 info@martitechnik.ch www.martitechnik.ch



## Consulting Engineers for Railway, Road, Subway and Utility Tunnels:

- Tunnel Ventilation
- Aero- and Thermodynamics of Tunnel Networks
- Tunnel Equipment
- Emissions and Air Quality Modelling
- Safety and Risk Analysis

**HBI** More than 600 tunnel ventilation systems worldwide since 1963!  
**HBI HAERTER CONSULTING ENGINEERS**

Stockerstr. 12 8002 Zurich Switzerland  
Tel. +41 44 289 3900 E-Mail: info.zh@hbi.ch  
Fax +41 44 289 3999 Web: www.hbi.eu  
Zurich/Berne CH • Heidenheim D • Forest Row UK

# Tunnels

AND TUNNELLING

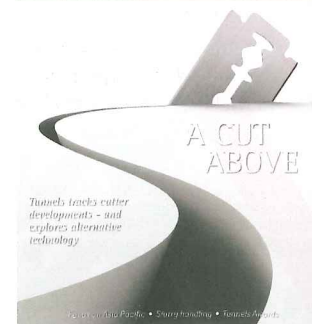
The leading tunnelling magazine for 42 years!

Don't miss out on your monthly copy of *Tunnels*

■ Continues to hold the highest reputation of any magazine in the field of tunnelling

■ The dedicated international monthly magazine, distributed in more than 107 countries

■ Keeping today's tunnelling professionals informed and ahead



For each new subscription we donate 10% to RedR, an international disaster relief charity



redruk

To subscribe, call our subscription hotline on: +44 (0) 845 155 1845 or visit us on: www.tunnelonline.info. When subscribing, please quote: TUN2013

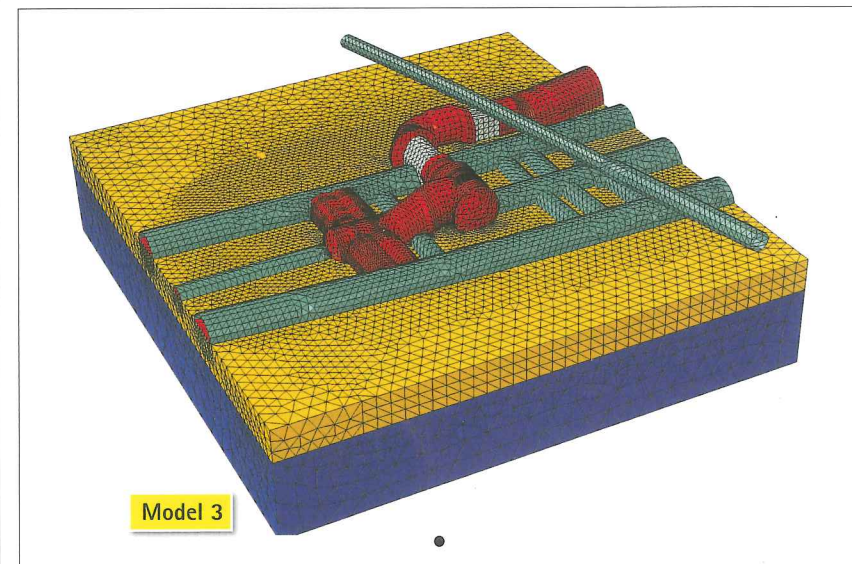
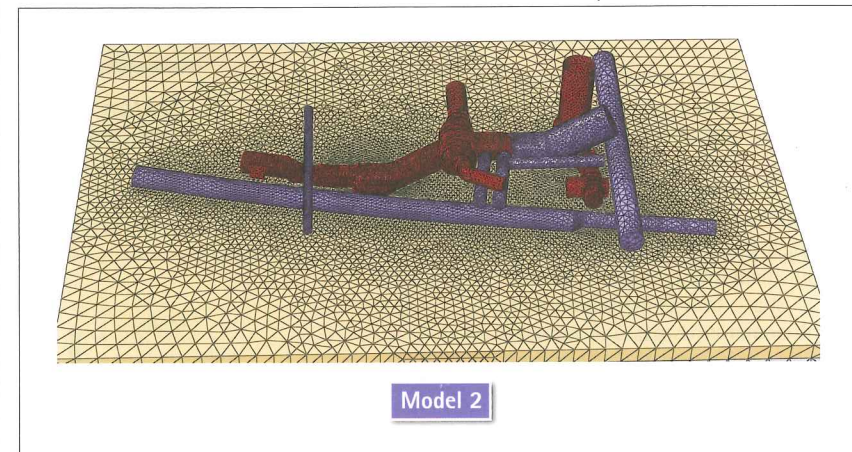
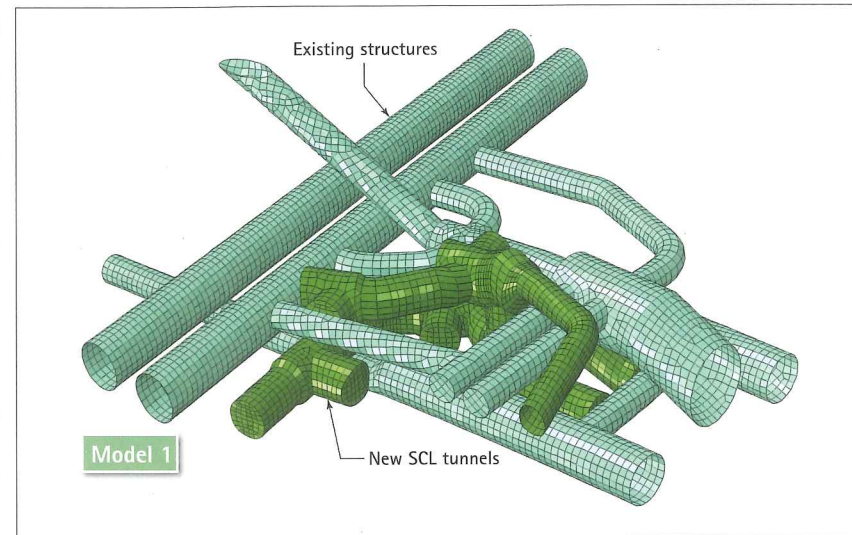
station and is very all-encompassing which makes the tube system even more complex. Due to hardware requirements, creating a large model covering all new tunnels in a single 3D-FE model was not feasible. Therefore three separate large FE models, FEM1, FEM2 and FEM3 whose boundaries are shown in Figure 1 were considered.

The five typical London subsoil layers, made ground (2m), river terrace deposits (6m), London Clay A3 (11m), London Clay A2 (11m), Upper and Lower Lambeth Group (20m) build up the ground model according to the information provided in the final Geotechnical Interpretative Report (GIR). The water table stands 6m below ground surface. The majority of the SCL tunnels are located within the London Clay stratum with a very low permeability. Therefore undrained soil parameters are considered for the analysis of tunnel excavation stages and the primary lining installation. The primary lining is designed only to carry temporary loads and the final lining to sustain the probable long term loads, assuming that the primary lining deteriorates in time.

A general purpose FE software, ABAQUS 6.10, was used to build and analyse the models. The Mohr-Coulomb material model was adopted for the soil layers. Models FEM1, FEM2 and FEM3 contain approximately 450,000, 600,000 and 1M solid tetrahedral linear elements.

Excavation is simulated mostly as full face, and in parts where a temporary invert was required, the excavation is divided into top-heading and bench-invert sequences. The overburden ranges from 11m to 33m. Sprayed concrete is modelled using three-noded triangular shell elements. Models FEM1, FEM2 and FEM3 contain 238, 255 and 178 calculation steps respectively.

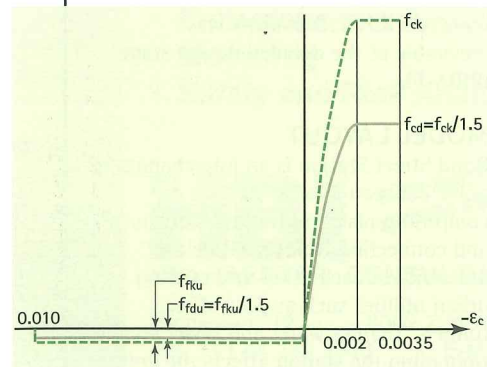
In these large FE models it has been tried to emphasise on the detailed excavation sequences, extent of the model, and FE mesh density rather than employing advanced constitutive models. Dr Sauer & Partners' experience



Above: Figure 2, Illustrations of FE model mesh

Left: Figure 3, stress strain of fibre reinforced concrete

has shown that in such ground conditions, the Mohr-coulomb material model is able to yield reasonable results and successful predictions for ground and tunnel structures if FE analysis is carried out with total stress analysis under undrained material conditions [4]. In addition, the consideration of the linear increase of both undrained shear strength ( $C_u$ ) and Young modulus ( $E_u$ ) of London Clay stratum with depth improves the precision of the model.



### MODELLING APPROACH

The numerical analyses have been undertaken on the basis of a total stress analysis and no water pressure is produced during the analysis. However the hydrostatic water pressure is applied normal to the secondary lining subsequent to degrading the primary lining. Based on the interpretation from the GIR report [5] the water table is assumed to be 6m below ground surface.

Prior to activating the secondary lining in the model, the primary lining becomes sacrificial by setting its stiffness to one per cent of the original value, hence the loads undertaken by primary lining become negligible and the loads are transferred to the secondary lining.

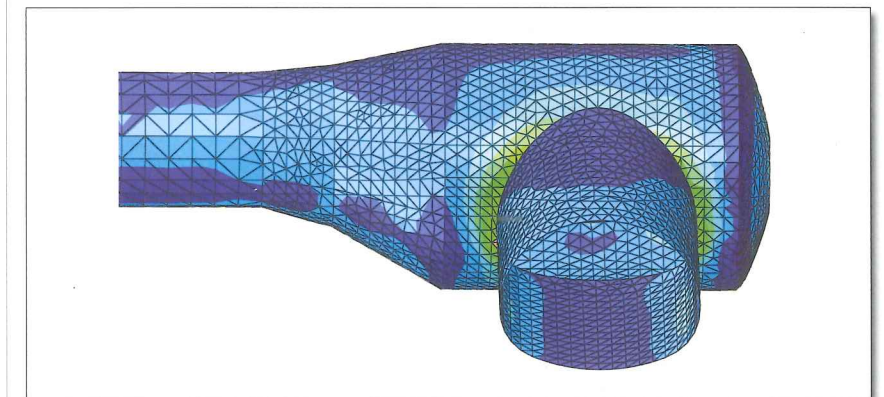
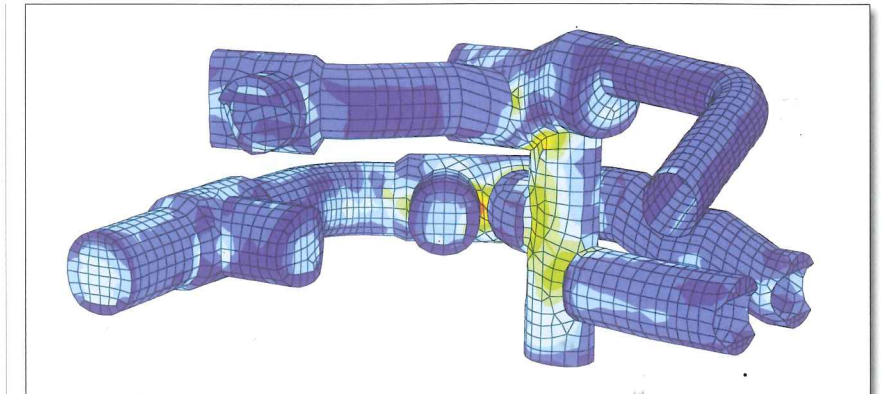
For the purpose of the primary SCL design no groundwater pressure was applied in the analysis since the primary lining is not considered to be watertight. Undrained soil parameters were taken for the analysis in order to account for the 'fast' construction in comparison to the time required for consolidation in London Clay.

The excavation and lining installation of one advance is performed in two steps; i.e., the soil is removed in the first step and the lining installed in the second step. The advancing sequential excavation was modelled using multiple analysis steps summarised as follows.

- In-situ 'free field' condition
- Excavation and installation of existing structures
- Excavation and installation of the SCL structures according to the design at stage RIBA E
- Installation of the secondary lining & degrading primary lining
- Applying long term conditions (including surcharge load on the ground surface and water pressure).

The SCL tunnel construction in the model commences after the simplified modelling of pre existing structures. This was modelled through a stiffness reduction of 50 per cent for elements originally located within the pre existing structures and the subsequent element removal and cast iron/brick and mortar lining installation.

The existing cast iron structures are modelled using structural shell elements. The shell elements used in the model are characterised by the cross sectional area to achieve the same bending stiffness as the reduced bending stiffness calculated according to LU standard 1-055 to take account for segment connections and imperfections [6].



Above: Figure 4, Contour plot of (top) maximum compressive stresses in FEM1 and (bottom) maximum compressive strains in upper machine chamber

### LINING SYSTEM AND DESIGN CONCEPT

The lining system for the SCL tunnels at BSSU consists of a primary lining, a sprayed waterproofing layer and a secondary lining. Both primary and the secondary lining are sprayed concrete reinforced with steel fibres. The lining system is designed using a primary lining system to provide stability during the excavation phase and a final lining system supporting all permanent loads. However, the invert of the secondary linings will be cast.

The idea of using steel fibre reinforced sprayed concrete (SFRC) is to reduce additional bar reinforcement. Sprayed concrete without bar reinforcement has benefits including:

- A. Uniform and homogenous lining - Spraying concrete around bar reinforcement brings about shadow voids or poor consolidation behind steel reinforcement, therefore bond strength issues.
- B. Time saving - As no bar reinforcement needs to be installed for each final lining section.
- C. Cost saving - As final lining reinforcement does not need to be erected in a separate work sequence.
- D. Lining durability - The uniform distribution of steel fibre reinforcement in the final concrete lining ensures uniform micro-crack distribution in the lining and reduces the crack width of these cracks.
- E. Safety improvement - Avoiding working at height required for bar reinforcement installation.

SFRC will provide considerable post-crack load bearing capacity. On the other hand, a high level of indeterminacy is inherent in tunnel structures, which allows stresses to redistribute within the shell. Therefore as long as the predicted strains in the linings are within allowable limits, post-crack capacity may be exploited to reduce the amount of bar reinforcement required in the linings. Bar reinforcement will only be required where strains exceed allowable limits

**450**

The approximate total metres of tunnels required for the BSSUP

Figure 3 illustrates the idealised material behaviour of steel fibre reinforced concrete in terms of Stress-Strain relationship. The compressive part of the curve is very similar to normal concrete. However, the tensile part exhibits a considerable ductile behaviour with a constant residual post-crack load bearing capacity. In order to model the effect of steel fibres in a concrete section under bending, the Austrian Guideline for fibre reinforced concrete [6] will be used. The behaviour of concrete under compression follows EC2 [1].

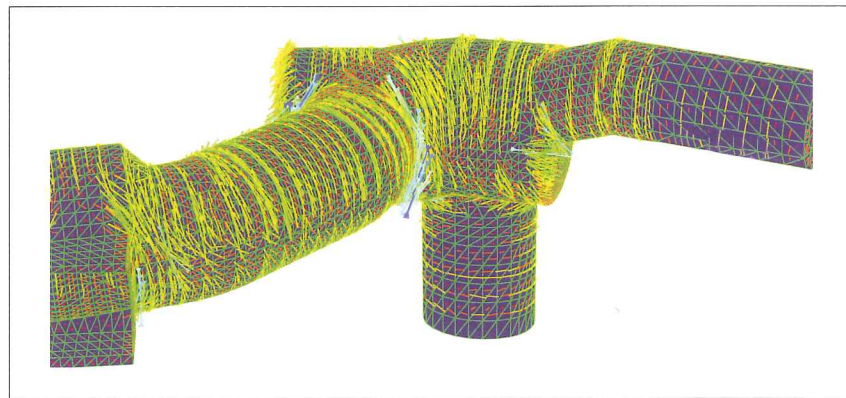
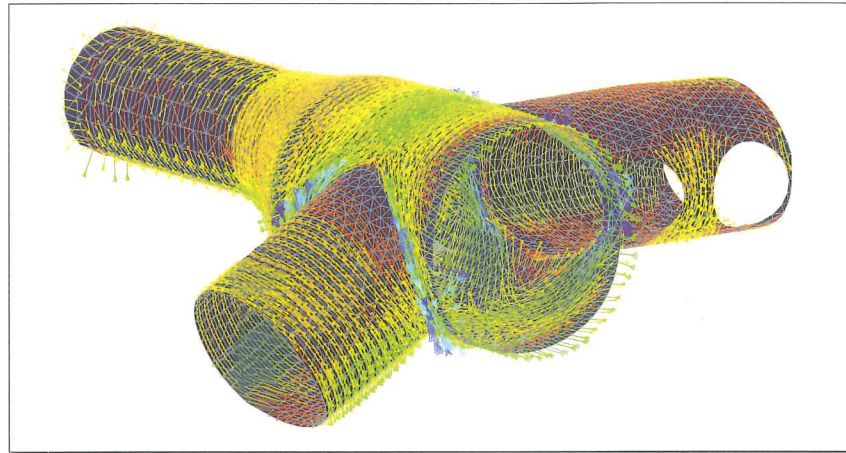
The residual strengths in tension will be calculated using the model stated in the Austrian Guideline. To ensure sufficient ductility is attained, flexural testing is required to demonstrate that at crack mouth openings of 0.5mm and 3.5mm, sufficient residual flexural strength is maintained [7]. This corresponds to an extreme fibre tensile strain of 2.5 per cent, which is the equivalent to that of reinforced concrete at ultimate limit state (ULS). That is, the SFRC must be able to withstand similar deflections to reinforced concrete without collapse; however the load carrying capacity of the fibres is conservatively truncated at one per cent tensile strain for the ULS.

Sprayed concrete is modelled as elastic-plastic material. The reaction of the material is ideally elastic as long as the peak values of compressive and tensile strength have not been reached. Residual strength parameters were considered in a post failure condition of the material. For instance, tension cut-off 0.4MPa is considered for the tunnel linings based on the sprayed concrete grade and the SFRC beam test specifications provided in the Design Statement. The 'concrete damaged plasticity model' was therefore employed in the model to satisfy this material behaviour [2]. It is a damage material model for concrete which assumes that the main two material failure mechanisms are tensile cracking and compressive crushing.

**SERVICEABILITY LIMIT CHECK**

In addition to enhancing toughness and ductility, steel fibres can provide post-crack load-carrying capacity as:

- The randomly distributed fibres in the concrete intercept micro-cracks as they form, inhibiting the tendency for larger cracks to form.
- After cracking, the fibres that span the crack will provide residual load-carrying capacity providing the potential for Elasto-plastic properties



Above: Figure 5, Plot of principal stresses around the openings in large chambers

Opposite page: Figure 6, Vertical displays in models 1, 2 and 3 from top

to be considered in the design.

- Also the fibres can reduce the formation of cracks due to drying and early age thermal cracking.

To satisfy serviceability criteria for the secondary lining, the strains obtained from the 3D FE model can be used to predict crack widths. As per the German guideline [3] for fibre reinforced concrete without steel bar reinforcement the crack width can be calculated as follows:

$$w_k = \epsilon_{ct} \times s_w$$

$$s_w = 0.14m$$

$$\epsilon_{ct} = \text{tensile strain of the fibre reinforced concrete.}$$

Requirements for using this equation are an indeterminate structural system and/or a system with a permanent compression zone.

Using the spacing  $s_w$  we can limit the strains in tension to achieve a required calculated crack width  $w_k$  to:

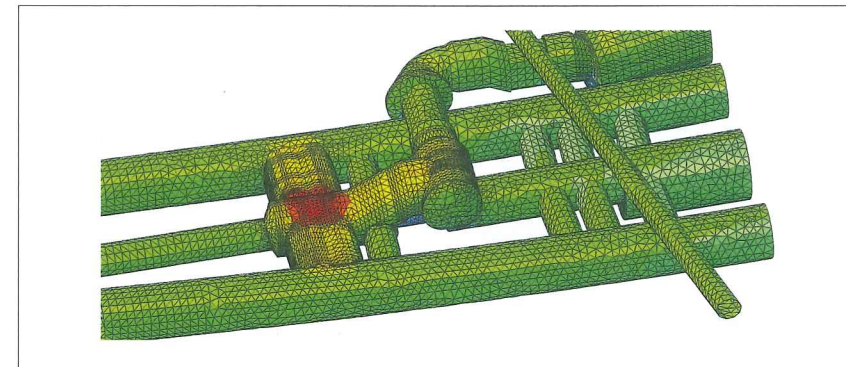
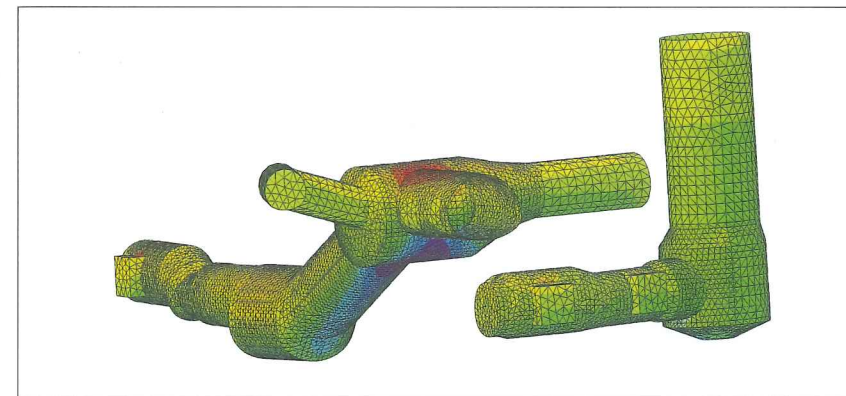
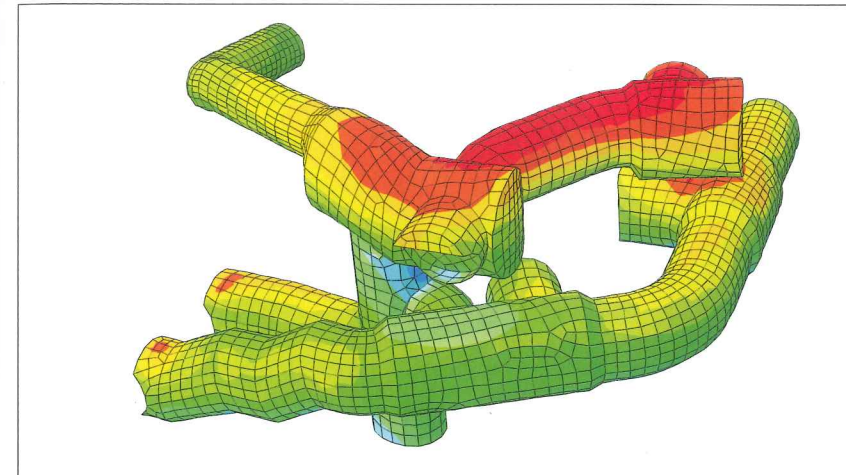
$$\epsilon_{ct} = \frac{w_k}{s_w}$$

For example, with a crack width of 0.3mm, tensile strains in the secondary lining would be limited to 0.21 per cent. Bar reinforcement and/or thickening is required where compressive strains predicted by the models exceed allowable strains.

**RESULTS**

For each individual model, necessary calculation steps have been set up in accordance with the actual construction sequences. Calculation of all excavation phases has been completed and the model has reached equilibrium and stability at each individual construction phase. Nonlinear analysis of the tunnel linings were performed using concrete damage plasticity

**6** Metres below ground the GIR assumed the water table was located



constitutive model. In the non-linear analysis, it is preferred that plasticity is allowed only for tensile stresses, and in compression the material remains elastic. The reason is that plastic section analyses require rotation capacity check based on EC2 which is a significant amount of work for a complex structure. Furthermore, the SCL failure mode in compression is brittle and unwanted. Tensile stress in the lining is limited to the allowable flexural strength (herein, 0.4MPa) in order to take the most advantage of steel fibres. When the FE calculation is completed and it reaches equilibrium, it implies that the lining is fine in terms of tensile stresses. However, the allowable strains should be checked by the designer.

ABAQUS post-processor enables us to check the strains at intrados and extrados of the shell elements where the maximum strains are expected. Sprayed concrete grades C30/37 and C40/50 are used for the primary and secondary lining respectively, which allows for a maximum compressive stress of 15MPa for primary lining and 16.8MPa for the final lining. Since the section forces of the lining extracted from the model are unfactored, for design check purposes the concrete strength capacity is factored by both material and load partial factors (1.35x1.5). In the calculation of allowable compressive stresses in the final lining, the long-term factor  $\alpha_{cc} = 0.85$ , based on the British Appendix in EC2, has been considered [1].

Over-stressed lining around the breakouts can be readily identified in the 3D model. Figure 5 depicts the principal stresses in large chambers with several openings. Based on the tensile and compressive capacities of the sprayed concrete, linings have been thickened around the large openings accordingly.

**CONCLUSION**

Through the constant advance of reliable software and powerful computer processors, 3D FE analyses are more frequently used in the design of complex tunnels. One of the great merits of a 3D model is to avoid applying subjective assumptions about the 3D effects of excavation sequencing and tunnel geometries. Comprehensive 3D analysis is now often demanded not only from the designer's side but also from the client's standpoint. Large 3D models can tackle the design challenges of complex SFRC tunnel linings and assist in drawing realistic conclusions on the necessity of steel bar use in the lining; face stability; adequacy of ground support; and ground movement

**References**

[1] British Standard, Eurocode 2, Design of concrete structures – Part 1-1: General rules and rules for buildings, BS EN 1992-1-1:2004, 2008.  
 [2] Dassault Systemes Simulia, ABAQUS Analysis User's Manual, Version 6.10-EF, 2010.  
 [3] DAFStb-Richtlinie Stahlfaserbeton, German Guideline for steel fibre concrete, Deutscher Ausschuss Fur Stahlbeton, March 2010.  
 [4] Deformation comparison at Green Park, A. Feiersinger; T. Mitsch, Tunnelling Journal, issue December 2010 / January 2011.  
 [5] London Underground, Bond Street Station Upgrade Project, Final Geotechnical Interpretative Report (GIR). ATK-C125-8799-TUN-R-30109, Rev. 3, April 2011.  
 [6] London Underground, Standard, Civil engineering – Deep Tube Tunnels and Shafts, 1-055, October 2007.  
 [7] Richtlinie Faserbeton, Austrian Guideline for steel fibre concrete, Österreichische Vereinigung für Beton- und Bautechnik, July 2008 edition.  
 [8] Testing sprayed concrete, BS EN 14488-5:2006. Determination of energy absorption capacity of fibre reinforced slab specimens.



Partners for new perspectives

jaegerbau.com

# WE THINK DEEPER.

Technical excellence. Flexibility. Experience. Reliability.

These are some of the factors for our success in this business.

What really sets us apart however, is the way we think.

Our mission is to continuously move forward and find innovative approaches in order to meet your requirements.

For new perspectives in underground engineering.

Forward.co



## Easy to handle, Difficult to imitate.

### GUIDANCE & LOGGING system for TUNNEL

from Kyoto/Japan to the World.

ENZAN KOUBOU CO., LTD. ([www.enzan-k.com/index-e.html](http://www.enzan-k.com/index-e.html))



**OSTU**  **STEEL AND FORMWORK**  
**STETTIN** [www.tunnelschalung.at](http://www.tunnelschalung.at)

**OSTU**  **STEEL AND FORMWORK**  
**STETTIN** [www.tunnelschalung.at](http://www.tunnelschalung.at)

CONSTRUCTION UNLIMITED

OSTU - STETTIN Hoch- und Tiefbau GmbH  
 Münzenbergstraße 38 / A - 8700 Leoben  
 Tel.: ++43 (38 42) 4 25 23  
 Fax: ++43 (38 42) 4 25 23 - 142  
 E-Mail: [schalungsbau@oestu-stettin.at](mailto:schalungsbau@oestu-stettin.at)



# GIERTSEN Tunnel



**WG Tunnel Sealing**  
 Tunnel & Rock Cavern  
 waterproofing solutions

Effective and inexpensive method to provide permanent sealing of humid rock walls and ceilings

## [www.tunnelsealing.com](http://www.tunnelsealing.com)

Underground parking in Skien - Norway

WTC 2013<sup>in</sup> Geneva  
 May 31 - June 07  
 Visit us at stand no G62



## Mastermind - and stay waterless.

As pioneers in waterproofing-engineering, we develop products for highest demands - the absolute dryness for your tunnelling projects - because dryness stands for safeness. Problem-oriented and customised remedial or preventive sealing concepts guarantee success! **RASCOR - Pioneers in waterproofing.**

**Rascor International Ltd**  
Gewerbstrasse 4  
CH-8162 Steinmaur/Switzerland  
Telefon +41 (0) 44 857 11 11  
Telefax +41 (0) 44 857 11 00  
info@rascor.com

CONSTRUCTION ENERGY MINING

OSSA,  
OVER **60** YEARS OPENING THE WAY  
UNDERGROUND

*OSSA is a leading international underground specialist contractor with over 60 years experience in major tunneling and mining projects. Over the years our focus has been to meet our clients demands by specializing and improving our core strengths in the underground sector. Our projects range from the most complex metro, railway, roadway and hydraulic tunnels to large mining galleries, caverns and shafts.*

OBRAS SUBTERRANEAS

T. +34 902 678 808 | T. +34 917 823 400 | [www.ossaint.com](http://www.ossaint.com)  
Street Aragoneses 2-A, 3<sup>rd</sup> floor. Pol. Industrial Alcobendas  
28108 Alcobendas, Madrid, Spain

*The Reliable Tunnelling Partner*

# GENEVA CONVENTION

The international tunnelling community heads to the Lake Geneva shoreline as the World Tunnel Congress enters Switzerland's metropolitan heart

WTC

31 May - 7 June, 2013  
Centre International de Conférences  
Geneva, Switzerland  
[www.wtc2013.ch](http://www.wtc2013.ch)

**T**HE PEDIGREE Switzerland has for hosting international events and institutions in Geneva will be furthered in May as tunnellers gather for WTC 2013. The annual conference is a highlight of the technical calendar for underground construction and builds on the success last year of the conference in Bangkok, Thailand. Aside from the scientific achievements in the area such as the confirmation of the Higgs-Boson particle at the CERN laboratory, the country is surrounded by some of the most impressive offerings, and future visions of the tunnelling industry. Nestled in the Alps, titanic local projects have included the Gotthard base tunnel, the longest transport tunnel in the world, and will see future world-beaters such as Brenner take the crown in years to come. Welcome to Switzerland

### Welcome

Switzerland and the Swiss Tunnelling Society feel honored and take pride in hosting the World Tunnel Congress 2013 and the 39th General Assembly of the International Tunnelling and Underground Space Association in Geneva between the 31st May and 7th June 2013.

After the successful completion of the two long base tunnels through the Swiss mountains, the WTC offers a unique opportunity to present the lessons learnt to a worldwide auditorium. In the so called Swiss Session a full half day will be dedicated to this topic. This specific session will not be the only highlight at the WTC.

The organizing committee has put a lot of effort and creativity into making the World Tunnel Congress 2013 an outstanding event in many aspects. There are various new functions introduced, such as the ITA committee innovation session, where the new developed guidelines and the activities of this committee will be presented, the so called presentation forum inside the exhibition for lecturers and presentations of exhibitors, a special session dedicated to students giving them a podium to present their semester or diploma thesis etc etc

Much attention also was dedicated to all the other non-technical functions of the World Tunnel Congress 2013.

Beside the traditionally held social events such as the welcome reception and the banquet Wednesday evening, which will take place on old steam cruise ships on the lake of Geneva, also smaller cultural events and activities are planned during the congress which all will add the special Swiss flavor to the WTC 2013 and which hopefully will make it to an enjoyable and unforgettable event for all of us.

We all are looking forward to welcoming you in Geneva. Be our guests at the WTC 2013!

Felix Amberg  
Chairman of the Organizing Committee  
WTC 2013



Above, Scenic Lake Geneva in Switzerland

## Swiss success

On behalf of the Swiss Tunnelling Society, I would like to invite you to attend the 2013 ITA-AITES World Tunnel Congress and 39th General Assembly in Geneva, Switzerland, from May 31 to June 7, 2013.

Switzerland is renowned for its natural beauty as well as its excellent infrastructure and transportation system. The structural engineering exhibited by many of Switzerland's 2,500 tunnels testifies to the country's tremendous capacity for innovation and its pioneering spirit, as well as to the fact that Switzerland has always been in the technological vanguard of the tunnelling industry.

One of the prime examples of Swiss tunnelling expertise is the 57km-long Gotthard tunnel, which is also the world's longest railway tunnel. Such tunnels are vital for Switzerland due to our mountainous topography and the massive number of trucks and trains that transit through Swiss territory. Also, the demand of Switzerland's densely populated cities for transportation infrastructure is growing, and in view of the limited space available these structures have to be built underground under daunting above and below ground geological and environmental conditions. Examples of such projects include Zurich Cross Rail and the CEVA project in Geneva.

Switzerland has always extended a warm welcome to visitors interested in discovering our cultural life, our expertise, and the country's natural scenic beauty, and we invite you to do likewise. Geneva is known as the "capital of peace" thanks to its congenial and cosmopolitan atmosphere, and the fact that the European headquarters of the UN is located here, as are the headquarters of the Red Cross.

I very much look forward to seeing you in Geneva.

**Martin Bosshard**  
President of the Swiss Tunnelling Society

## Geneva

The French-speaking city of Geneva is located between nearby Alpine peaks and the hilly terrain of the Jura on the bay where the Rhone River flows into Lake Geneva.

Geneva is known as the capital of peace thanks to its congenial and cosmopolitan atmosphere, and the fact that the European headquarters of the UN is located here, as are the headquarters of the Red Cross.

Geneva is one of Switzerland's most visited cities. For many years Geneva was also Switzerland's most populous urban area, but since 1870 has been the country's second most populous city, behind Zurich. Geneva is a highly multinational and multicultural city, with foreign nationals representing around 45 per cent of the city's population. Geneva canton is located in French-speaking Switzerland and shares a 107.5km border with France.

Geneva is home of the International Committee of the Red Cross (ICRC), the World Health Organisation (WHO), the International Standards Organization (ISO), the UN High Commissioner for Refugees (UNHCR), and the European headquarters of the United Nations.

Geneva was also the birthplace, in 1991, of the World Wide Web, which was initiated by researchers from CERN, which is also the site of the 26 kilometre long Large Hadron Collider, among other advanced physics research installations.

### Area and population

Geneva: 16 sq.km, 192,000  
Geneva canton: 282sq.km, 467,000

## Spare a Franc?

CHF (Swiss Franc) 1 =  
USD 1.06 = GBP 0.7 = EUR 0.82

Inexpensive restaurant meal: CHF 25  
Mid range three course meal: CHF 50  
Fast food meal: CHF 13

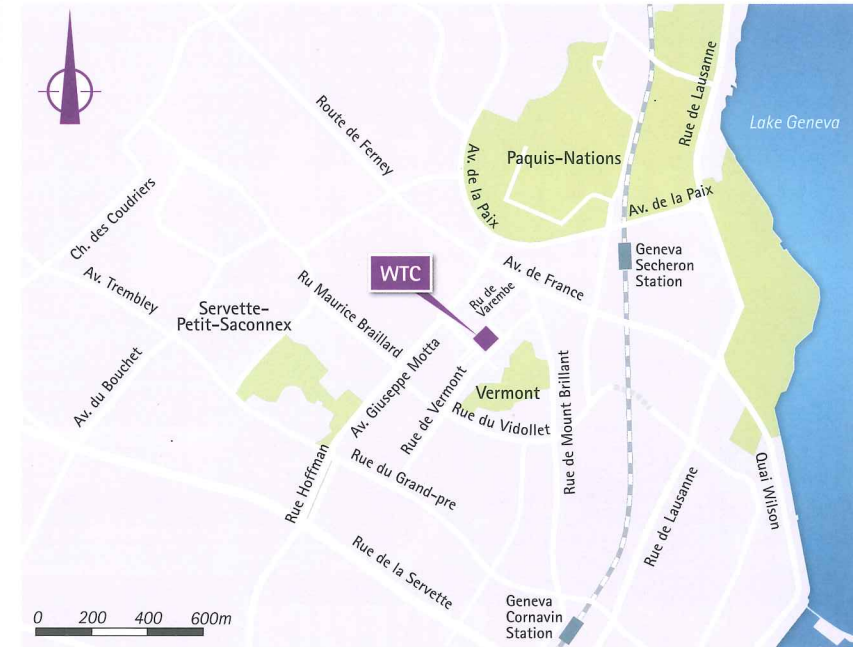
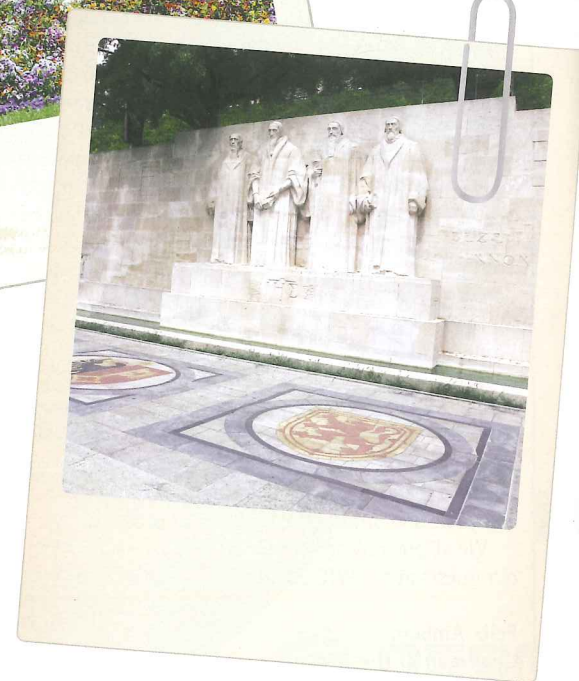
Water bottle: CHF 3  
Beer: CHF 5  
Coke: CHF 3  
Coffee: CHF 4  
Cigarettes: CHF 8

Transport (single): CHF 4  
Taxi (1km): CHF 10  
Cinema: CHF 20

Source: Numbeo.com (March 2013)

## Sights to see

- The Flower Clock in the English Garden
- Place Bourg du Four
- Grand Theatre de Geneve
- Reformation Wall
- The Molard Tower



## Centre International de Conférences Genève

The conference centre is conveniently located only minutes from the Geneva airport, major highways, the railway station and international sites, and is near Lake Geneva and the historic Old Town. It is near the Place des Nations, where a number of major international organisations and permanent missions are located.

Centre International de Conférences Genève  
Rue de Varembe 15,  
1202 Geneva,  
Switzerland  
Tel: +41 22 791 91 11

## Swiss sessions

Every year in June, the Swiss Tunnelling Society holds the Swiss Tunnel Congress in Lucerne. The Swiss Tunnel Congress has gained high reputation as an outstanding event where top-quality papers are presented and the unique surrounding of the KKL creates an atmosphere that facilitates networking and socialising. In 2013, the Swiss Tunnel Congress will be transferred to Geneva and be integrated into the WTC as the "Swiss Session."

The 'Swiss Session' will convey the spirit of the Swiss Tunnel Congress to Geneva and unfold it in a manner much like in Lucerne: Tuesday afternoon, the traditional Swiss Tunnel Colloquium will be held followed on Wednesday by carefully selected papers and presenters. In 2013, the Swiss Session will center around the lessons learned from the construction of the Lötschberg and Gotthard tunnels through the Alps and make it available to the international underground community.

As has traditionally been the case, papers will be presented in German, French, Italian or English with simultaneous translation into English and German.

Wednesday evening after the Swiss Session, the traditional aperitif will be offered by the Swiss Tunnelling Society. In Geneva, the aperitif will be combined with the Young Swiss Tunnellers poster presentation and the Farewell cocktail.

The participants of the WTC 2013 have access to the Swiss Session and are heartily invited to get some personal impressions.

A portion of the Swiss Session will be given over to the presentation of the work of Swiss Student Tunnellers, who must meet one of the following sets of eligibility requirements: must be a Masters candidate, (or hold a Master's degree), from a Swiss institution or must be a doctoral candidate discussing doctoral thesis research.

## Technical excursions

The technical excursions will take place after the congress.

### The Swiss Alps (2 days)

Visit of the Nant de Drance site in the Swiss Alps (pump-storage hydropower scheme) linked with a train ride over the Golden Pass.

### The world's longest railway tunnel (2 days)

Train ride on the famous Glacier Express from Brig to Andermatt, visit of a cheese manufacturer and visit to the south portal of the Gotthard Base tunnel and the intermediate attack of the Ceneri Base tunnel.

### Nant de Drance and Chillon Castle (1 day)

Visit of Nant de Drance (pump-storage hydropower scheme) and guided tour through the Chillon Castle, a medieval fortress at the shore of Lake Geneva.

### Simplon Tunnel Rehabilitation and Aletsch Glacier (1 day)

After a disastrous tunnel fire, a part of the roughly 100-year-old Simplon railway tunnel is under rehabilitation. The visit of this site in the middle of the tunnel is combined with a trip to the Eggishorn, which offers a splendid view of the longest glacier in the Alps.

### A16 Transjurane and visit of the Omega Museum (1 day)

The A16 motorway links Switzerland and France through difficult terrain (Jura formations). The visits to different sites are combined with a visit to the Omega Museum, one of the leading brands of Swiss watches.

## Photo Competition

Don't forget to enter the Tunnels and Tunnelling Photo Competition if you think you have what it takes to claim the latest in digital camera technology as your prize.

The closing date for entries is 1 July and the short listed entrants will be announced in the September issue of *Tunnels*. The winners will be announced in the Tunnels Awards supplement in the December issue of *Tunnels*.  
[awards@tunnelsonline.info](mailto:awards@tunnelsonline.info)

GOLD SPONSOR

**WTC 2013**  
Switzerland - Geneva  
May 31 - June 07, 2013

**CIFA** TUNNELLING

**UNDERGROUND EXPERIENCE**

CIFA S.p.A. Via Stati Uniti d'America, 26 » 20030 SENAGO (MI) » Tel. +39 02 990 131 » Fax +39 02 998 1157 » www.cifa.com » e-mail: cifa@cifa.com

# NORRA LAENKEN'S NOVEL LINING



tunnelsoft

**TPC** **TPC**

Quality Management Real-time Connection

www.tunnelsoft.com

Tunnel engineering Advanced Company

**TAC Corporation**  
Aiming to the Engineering Team of Favorability No.1!  
http://www.tac-co.com e-mail tac@tac-co.com

*TAC is ready to provide a total solution for TBM construction*

3.5th Generation (Setting into the tail body) Simultaneous Backfill Grout Injection Pipe

Backfill Grout Mixing Plant

Design & Supply for Backfill Grout Injection Material

Foam, Additive & the Other Injection Material

Automatic Additive, Foam Injection System

Automatic Backfill Grouting System

In the January BTS meeting, technical and risk manager **Andreas Raedle**, construction manager **Jörg Steppuhn** and site manager **Felix Lenzen**, all of Hochtief Solutions, presented on the Norra Laenken road tunnel project in Stockholm, Sweden. This article gives an overview of both the design and construction for the Lot NL 35 project, including the pre-grouting works, the drill and blast operations and a new concept for inner lining

LOT NL 35 of the 'Norra Laenken' project in Stockholm forms part of the northern link of the City's inner ring road. The project comprises the construction of approximately 2.6km of tunnels in hard rock with features specific to that of tunnel construction in Sweden. These include large cross sections, pre-injection grouting of the rock and tunnel advance lengths up to 6m during drill and blast excavation works.

In addition, a new concept for the tunnel inner lining structure has been utilised on this project which comprises the use of precast elements, a suspended shell structure and a shotcrete lining. The primary function of the inner lining is to protect the traffic against ice, dripping water, fire and explosion.

**INTRODUCTION**

A dramatically increasing amount of traffic in the city of Stockholm in the mid-20th century led to a plan for a ring road around Stockholm's inner city, to relieve the centre from most traffic. The first section of this ring road, called 'Essingeleden', was completed in the late 1960s and runs through the area's western suburbs.

Further enhancements were opened for traffic only half a century later with a first section of the northern link - Norra Länken - followed by the southern link - Södra Länken.

The implementation of the remaining part of Norra Länken, scheduled for completion in 2015, will connect two major motorways coming from the north as well as two important ports in the northeast of the city with the already existing parts of the ring road.

As most of the 5km long 'Norra Laenken' will lead through areas with existing buildings, as well as the world's first urban national park, the majority of Norra Länken will be underground. The excavation of in total about 11km of tunnel has mainly already been carried out in 10 major construction lots.

Figure 1 illustrates an overview of the entire awarded 'Norra Länken' project. From the entire 10 main construction lots the Hochtief Solutions was together with its JV partner Oden awarded with the construction contracts NL 35 and NL 51 in the eastern project area.

The lot NL 35 has a total length of about 1,100m and consists of two



Above: Figure 1, the Norra Laenken portion of the ring road around Stockholm

Right: Pregrouting works on the tunnel project



parallel main tunnels as well as two approximately 200m long connecting tunnels. Exemplarily a typical tunnel cross section is illustrated in figure 2, overleaf.

A new concept for the tunnel inner lining structure has been utilised on this project which comprises the use of precast elements, a suspended shell structure and also a sprayed concrete lining. The primary function of the inner lining is to protect the traffic against ice, dripping water, fire and the force of an explosion.

**EXCAVATION AND SUPPORT WORKS DURING DRILL AND BLAST TUNNELLING**

The resulting total tunnel length of approximately 2,600m has been excavated by using conventional drilling and blasting methods. The cross section of the tunnels varied between approximately 80 to 340m<sup>2</sup>, with an average of 160m<sup>2</sup>, while the stroke (advance) length remained constant at about 6m during excavation.

Steel fibre reinforced shotcrete and rock bolts have been used in various thicknesses (0 to 150mm) and lengths (4 to 6m) depending on the rock conditions to support the rock around the excavated tunnels.

As usual for hard rock conditions in Scandinavia the Q-Value classification system from Grimstad/Barton has been used to determine the appropriate support measures (i.e., shotcrete thickness, bolt length, spacing).

*Andreas Raedle*

Andreas Raedle is technical and risk manager for Hochtief Solutions. He presented with his co-speakers in January

*Jörg Steppuhn*

Jörg Steppuhn is construction manager for Hochtief Solutions. He was previously project manager at Norra Laenken

*Felix Lenzen*

Felix Lenzen is site manager for Hochtief Solutions. The talk was held on 17 January 2013

The tunnel heading works were in the regular tunnel cross sections executed with full face heading. The advance lengths of up to 6m lead to very high advance rates for conventional tunnelling techniques. On the other hand this leads to irregularities during blasting such as over excavation profiles and enormous overbreak especially in case of unfavourable dipping of the rock joints.

The tunnels are located within the Stockholm granite and granite gneiss which is characterised by vertical dipping joints/fissures and horizontal layering. Nevertheless, due to the suspended inner lining system, the resulting overbreak does not have to be compensated and backfilled with shotcrete.

In order to achieve the demands concerning the low groundwater inflow (underpassing of an urban national park) into the tunnels (about 4 litres/min per 100m of tunnel length), overlapping grout curtains were positioned around the tunnels prior excavation. Each curtain had a length of about 25m and an overlapping length of 7m.

The actual injection has been carried out by using microfine cementitious grout and a maximum pressure of 50 bar. Lugeon tests were carried out in controlled drillings through the temporary face to confirm the success of the grouting works.

**DESIGN AND WORKS PREPARATION OF THE INNER LINING SYSTEM**

The primary function of the inner lining system is to protect the traffic against ice, dripping water and fire. Additionally it provides the facing of the tunnels traffic space.

**160**

Square metres on average for the tunnel cross section

**6**

Metre lengths at most allowed for very high advance rates for tunnelling

The tunnel lining system consists of precast concrete wall elements that are placed on both sides of the road and the suspended shell structure installed in the tunnel crown between these walls.

The shell is formed by a combination of a tunnel sealing membrane, suspended with a minimum distance of 500mm to the rock, and a 100mm thick shotcrete lining that is applied in a second step towards this membrane.

The main advantage of the suspended lining system is that in long frost periods in winter time no blasting development due to pressure can be formed because a stressless ice layer can be developed between the rock surface and the lining. A minimum distance of 500mm was considered within the design and construction.

In the past major damages in existing road and railway tunnels in Sweden occurred due to ice pressure. This led to additional remedial works to be executed associated with additional costs.

The novel inner lining system was applied the first time, therefore innovative, economic and practical

Your Reliable Partner in Tunnelling Separation Technology Worldwide



Schaenburg MAB GmbH • Weseler Str. 35 • 45478 Mülheim a. d. Ruhr / Germany  
 website: www.schaenburg-mab.com • e-mail: hwm@hwm-engineering.de  
 phone: +49 (0)208 - 9991 - 0 • fax: +49 (0)208 - 59 24 09

SCHAENBURG MAB

solutions amongst others for design details were required during the design and works preparation phase.

A close cooperation and early continuous communication between client, JV, designer and membrane supplier was a key element for the success of the project. In the calculations for the inner lining and precast concrete elements the following load cases were taken into account:

- Dead load of membrane and lining
- Creep and shrinkage
- Loads resulting from ice formation
- Temperature loads (+20 °C to -15 °C)
- Pressure and suction loads caused by traffic
- Falling stones
- Impact load on vertical walls caused by traffic
- Exceptional accidental loads
- Loss of a rock bolt
- Explosion
- Fire

A practical full scale load test for the lining system for proof of the load case explosion was developed and executed which demonstrated the omission of a collapse of the lining ('falling down') in case of explosion within tunnel.

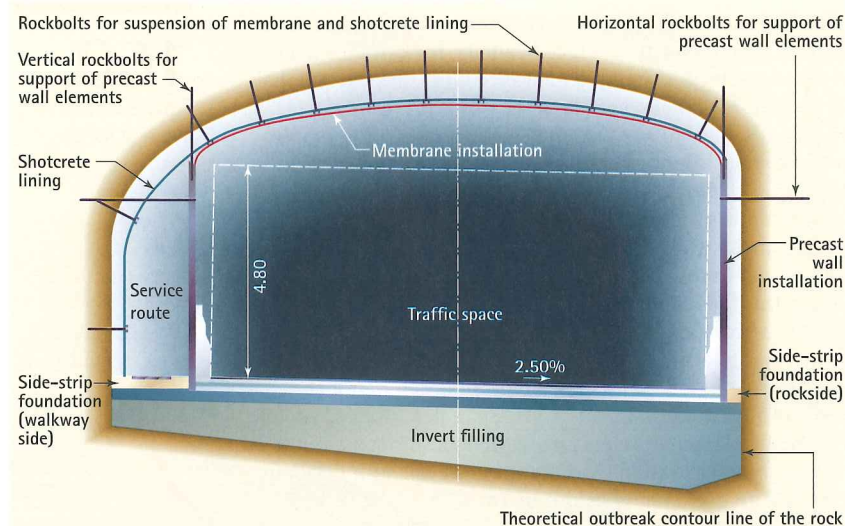
### CONSTRUCTION SEQUENCE FOR THE INNER LINING

The construction sequence was broken into eight stages:

#### Foundation for ventilation fans

The foundations for the ventilation fans were planned in the contract as two single foundations for a pair of fans as in-situ concrete.

To optimise the installation process the foundations were re-designed as one large pre-cast block, which holds the pair of fans. The foundations are hoisted up to the ceiling with the help of chain blocks and fixed to an already levelled ceiling and installed rock bolts. The gap was subsequently contact grouted.



Above: Figure 2, A typical tunnel cross section

Below: The skyline of the Stockholm city centre

The installation takes only half the time of conventionally cast foundations and the tunnel is less blocked because of it. Six pieces of acid resistant stainless-steel rock bolts M24 are used per foundation.

#### Concrete curbs and side-strip foundations

The outline for the side strips is formed with concrete curbs, which are acting as 'kickers' for the wall foot. The curbs are produced by a diesel driven curb former (commonly used in the US or in Americas for road construction or e.g. CFRP dam concrete blinding).

The curb shape is custom made to take into account the different slopes of the road in the tunnel and to be installed on the same filling layer and supporting the wall foot. An installation performance of 120m per shift has been achieved.

Once the curb is installed the side strips can be completed.

The side strip for the culvert is used as a walkway. To lead the forces from the walls into the rock, unreinforced beams are casted between rock and curb with a common distance of 3m at the wall joints. In between the beams, 0-4mm graded crushed rock is filled and compacted to form the walkway. Behind the culvert membrane the water is able to drain into the tunnel invert.

On the opposite 'rock'-side, the relative small distance between curb and rock is filled with drainage concrete which allows for transferring loads and draining of water.

#### Drilling and installing rock bolts

A drill rig with a twin drill boom (c/c 1.20 for the main pattern of bolts) is used.

The double drill on the machine is mounted on an 8m long

rail allowing longitudinal movement of rock bolts. The arm for the double drill moves in radial direction. The positioning is computer aided and the lining outline and bolt positions are programmed.

Once the rig is set up and the laser positioned it finds the hole positions with the help of the system. Furthermore the distance from the lining outline to the actual rock surface for each hole is recorded. The drill depths are then suited to bolt lengths staggering 200mm allowing for the pre-defined minimum drill depth of 600mm.

An installation list is produced which indicates the appropriate rock bolt length for each hole position. This method simplifies the installation process and furthermore avoids the cutting of bolts, which are double corrosion protected (hot-dip galvanised and epoxy coated).

The system enables drilling within a tolerance of plus or minus 50mm.

Therefore the wall bolts need to be drilled 'manually' with surveyor assistance to achieve greater accuracy. The suspended sections for the wall elements only allow for a tolerance of plus or minus 30mm.

The bolt installation is carried out from a truck mounted mobile platform with a size of 3m by 5m.

Cement grout is used (w/c ratio continuously checked by mud-balance method) to ensure additional corrosion protection. Spacers ensure that the bolt centres in the hole. Any epoxy type resin was not allowed due to a design life of 80 years.

The drilling performance for membrane bolts was 500 holes

**500**

Holes per shift were drilled for membrane bolts

**400**

The number of bolts per shift that were installed

per working shift, and bolt installation performance was about 400 bolts per working shift.

#### Membrane installation

The 1.5mm strong LDPE membrane had to fulfill defined features from Trafikverket regarding fire resistance. Certain flashover time and smoke mass were defined.

The installation is carried out from a purpose made working platform, which enables workers to roll down the membrane and tighten it in radial and longitudinal direction to get a proper base. This is important for the sprayed concrete application.

The radial moving arm equipped with platform and membrane roll dispenser is sitting on a four-leg construction. The frame is driven on caterpillars and the legs can be adjusted in height to allow traffic to pass underneath.

Usually the membrane is installed in 3.75m wide lanes (250mm welding overlap) starting at the rock side.

The rolls are pre-confectioned with a certain length suited for the tunnel sections minimising the cutting waste.





**STATE OF THE ART EXPERTISE**

- Tunnel design
- Tunnel installations
- Immersed tunnels
- Traffic Management
- Bored tunnels
- Operation and Maintenance
- Cut & cover tunnels
- Risk management and value engineering
- Special techniques

Tunnel Engineering Consultants (TEC), established in 1988, is a permanent Joint Venture of DHV, Royal Haskoning and Witteveen+Bos.

TEC combines the knowledge, expertise and experience of the three mother companies (of 9000 professionals) within the field of large underground infrastructural projects. The permanent collaboration guarantees continuity and comprehensive specialized knowledge of tunnel design and construction. This enables TEC to solve nowadays complicated underground mobility challenges through an integral, innovative and sustainable project approach.

TEC is involved in challenging international projects such as Busan Gyeongje Fixed Link in South Korea (recently opened to traffic), the Coatzacoalcos tunnel in Mexico. The 19 km long FehmernBelt Fixed Link between Denmark and Germany and the 30 km long Hong Kong Zhuhai Macao Fixed Link in China.

Postbus 108  
6500 AC Nijmegen  
Barbarossastraat 35  
6522 DK Nijmegen  
T: +31 (0)24 3820430  
E: info@TEC-tunnel.com  
www.TEC-tunnel.com



Manufacturer for injection technology

## Injection systems

- Mining
- Tunneling
- Civil engineering
- Special civil engineering



Hydraulic packer



2K Pneumatic reciprocating pump

DESOI GmbH Phone: +49 6655 9636-0  
Gewerbestraße 16 info@desoi.de | www.desoi.de  
D-36148 Kalbach



Videos

To advertise here call Tom Willard on +44 20 7406 6599 or email [twillard@tunnelsonline.info](mailto:twillard@tunnelsonline.info)

The installation performance was 900m<sup>2</sup> per shift.

**Fixation parts for wall elements**

As Trafikverket needs to access any pipes or drains lying in the tunnel invert without influencing the lining construction, the walls are hung from the tunnel ceiling rather than based on foundations. Therefore suspension frames had to be developed that are able to take up the tolerances from the bolt installation.

For the vertical fixation gallow-like hangers with slotted holes and a turnable head plate with a slotted hole were developed. To fix the hangers to the wall the slotted holes allow for longitudinal tolerances. The turning plate to fix the hanger to the vertical bolt allows for combined latitudinal and longitudinal adjustments.

For horizontal fixation a plate with big bores and suitable washers was designed to adjust the walls.

A turnbuckle type adapter between fixing plate and horizontal bolt makes it possible to do adjustments in a latitudinal direction.

**Wall installation**

The wall elements are delivered to the site on racks on special trailers.

To get a good performance for mounting the wall elements an installation system consisting of a 24t tunnel excavator equipped with a fully articulated vacuum plate has been developed. The challenge here was the rough surface which had to match the sprayed concrete surface of the ceiling.

Whereas the roughness is not a problem for a vacuum system with regard to holding the sucking force as long as the pump is running, it is more difficult to hold the vacuum if the pump fails for any reason while it is lifting an element. For this case a safety period of 20 minutes to either secure the area and/or mechanically fix the wall element was agreed upon.

Coordination of the wall producer as well as the vacuum plate manufacturer was necessary. The solution was a combination of a homogenous formed rough surface by means of a form inlay and special sealing rubber on the vacuum plates.

Before lifting and installing the walls they are equipped with an EPDM rubber to seal the element's joints. The EPDM sealing fulfills the necessary fire resistance proven by Hochtief's earlier research on EPDM sealed segmental lining (tubbings) for TBM tunnels carried out at the University of Brunswick.

The walls are brought into rough position by one operator in the machine's cabin. A second operator with a remote control for the vacuum plate carries out the final adjustment and placement. The wall is now fixed to the rock bolts via the fixation parts.

**Reinforcement mesh installation**

Before installing the reinforcement mesh the membrane needs to be prepared for the sprayed concrete with all built in parts. All necessary cable ducts are installed.

The dilatation joints every 22 to 30m need to be fire resistant and are prepared with a fire resistant cloth and a PE profile to get a controlled crack.

Now the mesh (Ø6mm at 150mm) is installed. The mesh for the elliptical sides is custom made and pre bent, the middle part is standard mesh.

The installation is carried out by a truck mounted crane and a working platform.

Additionally, the mesh is cut into pieces with a maximum weight of 30kg to ensure also manual installation. Most important here are the spacers, which are glued to the membrane and hooked in to the mesh. The result is a sturdy and stiff base necessary for a good result when applying the sprayed concrete.

**Sprayed concrete application**

A 'Meyco Potenza Maxima' shotcrete robot is used. The machine was developed for the Scandinavian market to reach for the long rounds.

It is equipped with a long arm with less articulation features, e.g., a robojet arm, and enables to spray areas of 15m length and 20m width without repositioning the machine. Additionally an automatic movement either in longitudinal direction or circumferential direction can be preset.

The shotcrete is applied in three layers. The first layer, about 10 to 20mm, stabilises the membrane. A lower pressure and flow of shotcrete is used here to reduce rebound as the membrane acts like a drum skin.

When the first layer has hardened (usually by the next day/shift), the second layer is applied and filled behind the mesh. Now the concrete spraying works 'as usual', since the first layer gives a sturdy base.

The final layer (mesh to final outline) can be applied after four to five hours. The average spraying performance was 5m<sup>3</sup> per hour. The final contour is checked by 3D laser scanning.

**SUMMARY AND OUTLOOK**

Typical techniques, equipment and materials from conventional tunnelling (NATM/SEM) and mechanised tunnelling have been used such as:

- Rock bolts, shotcrete, grouting
- Sprayed concrete units, rock drills, working platforms; excavator, vacuum system

A combination of two mechanised construction operations for future tunnel projects in hard rock conditions could be possible by application on a gantry system or after runner of a hard rock gripper TBM.

Also potential application of the developed lining system is under consideration of the client Trafikverket for future tunnel projects in Sweden.

The system at NL 35 was built within budget and planned time frame with a very satisfying quality product for the client - also because of our main modification to use precast walls on both sides

www.tunnelsonline.info

A world of information fully archived and searchable at the click of a mouse



CHEMICALS

**BASF**  
The Chemical Company

**MEYCO**  
Expanding Horizons Underground

[www.meyco.basf.com](http://www.meyco.basf.com)

CUTTER TOOLS

**PALMIERI** TUNNELLING - DRILLING

CUSTOM-MADE CUTTERHEADS FOR TBMs MICROTUNNELLING AND VERTICAL OR DIRECTIONAL DRILLING MACHINES.

BACK UP AND MUCK HAULAGE SYSTEMS.

ROLLING STOCK AND SPECIAL TUNNELLING RELATED EQUIPMENT

T: +39 0534 32511 F: +39 0534 32501  
E: [info@palmierigroup.com](mailto:info@palmierigroup.com) W: [www.palmierigroup.com](http://www.palmierigroup.com)

Agents wanted in selected countries. Please apply to: [a.tasselli@palmierigroup.com](mailto:a.tasselli@palmierigroup.com)

**T.B.M. CUTTERS Ltd.**  
DESIGN AND MANUFACTURE OF TBM CUTTING TOOLS AND WEARPARTS CUTTER HEADS MANUFACTURED & MODIFIED

TEL. +44 (0) 1430 427954  
FAX. +44 (0) 1430 427955  
EMAIL. [office@tbmcutters.com](mailto:office@tbmcutters.com)  
[www.tbmcutters.com](http://www.tbmcutters.com)

DIRECTIONAL DRILLING

**devico**

DIRECTIONAL CORE DRILLING & BOREHOLE SURVEYING INSTRUMENTS

Contact us [devico@devico.no](mailto:devico@devico.no) [www.devico.com](http://www.devico.com)

DRILL and BLAST

**OSSA**  
OBRAS SUBTERRANEAS

1952 - 2012

Polígono Industrial Alcobendas.  
28108 Alcobendas (Madrid)  
T. +34 902 678 808 | F. +34 915 618 894  
[www.ossaint.com](http://www.ossaint.com)

ENGINEERING CONSULTANTS

Your Trustworthy Tunneling Consultant Since 1962

CONSULTING ENGINEERS  
**SAANIO & RIEKKOLA OY**  
Laulukuja 4, FI-00420 Helsinki, Finland  
tel. +358 9 530 6540, [www.sroy.fi](http://www.sroy.fi)

**TONY RIDLEY HYPERBARIC ASSOCIATES LTD**  
Consultancy, Expertise and Personnel  
Specialist Tunnelling Services

Compressed Air - TBM Intervention - Safety - Rescue - Occupational Health

Tel +44 (0) 1508 538 838 Fax +44 (0) 1508 538 938  
Email [info@hyperbaric-tunnelling.com](mailto:info@hyperbaric-tunnelling.com)  
[www.hyperbaric-tunnelling.com](http://www.hyperbaric-tunnelling.com)

ENGINEERING CONSULTANTS

31 años 1982-2013

**GEOCONTROL**  
BRASIL | CHILE | ESPAÑA | PERÚ

GEOTECHNICAL SERVICES  
DESIGN OF TUNNELS  
SAFETY EQUIPMENT DESIGN  
ROCK MECHANICS APPLIED TO MINING  
ON-SITE TECHNICAL ASSISTANCE

[www.geocontrol.es](http://www.geocontrol.es)

Cristóbal Bordiú, 19-21, 5ª - 28003 Madrid (SP)  
T: +34 91 553 17 63 | F: +34 91 554 93 96  
[geocontrol@geocontrol.es](mailto:geocontrol@geocontrol.es)

**Alan Auld**  
GROUP LTD

TUNNEL AND SHAFT DESIGN SPECIALISTS

Telephone +44 (0) 1302 329911  
Fax +44 (0) 1302 329922  
Email [mail@alanauld.co.uk](mailto:mail@alanauld.co.uk)  
Website [www.alanauld.co.uk](http://www.alanauld.co.uk)

Tunnels · Caverns Foundations · Slopes

Consultants in Rock Engineering

**GEO-DESIGN**  
[www.geo-design.co.uk](http://www.geo-design.co.uk)

EQUIPMENT

The one-stop source for the tunnelling industry.

**tunneltrade.com**  
your tunnel internet portal

**METAX**  
CIMA GROUP

29122 Piacenza - Italy - Via Orsino, 33  
Tel. +39 0523 0103 Fax +39 0523 593106  
[www.metax.it](http://www.metax.it) - [info@metax.it](mailto:info@metax.it)

Jet Grout, Mud, Slurry Pumps  
Batching Plants - Injection Plants  
Drilling Rods - Ancillary Parts

**GJERSTAD**

Our side dumping bucket is the most efficient tool for underground, limited space, work. Mucking out time is reduced by a minimum of 25% compared with other methods. Tyre wear and fuel consumption is also significantly reduced, adding an environmental advantage. More than 90% of tunnel contractors in Norway use Gjerstad side dumping buckets - we deliver all over the world to our customers satisfaction.

**Rock Solid Solutions** [www.gjerstad.com](http://www.gjerstad.com)

To advertise here call Tom Willard on +44 20 7406 6599 or email [twillard@tunnelsonline.info](mailto:twillard@tunnelsonline.info)

EQUIPMENT

**Sp SPECIALIST PLANT**  
**TUNNELLING EQUIPMENT HIRE & SUPPLY**  
 Specialist Plant Associates Ltd  
 Agents for **CIFA**  
 Tel: +44 (0) 1234 781 882  
 Email: [info@specialistplant.co.uk](mailto:info@specialistplant.co.uk)  
[www.specialistplant.co.uk](http://www.specialistplant.co.uk)

FUEL TANKS

**WESTERN** **ABBI**  
 YOUR PERFECT REFUELLING PARTNER  
  
 T +44 (0) 1454 227 522  
[www.western-global.co.uk](http://www.western-global.co.uk)

FABRICATION

**TUNNEL STEELWORK SPECIALISTS**  
 Cable & pipe brackets, walkways, sleepers and steel fabrications  
  
**F TRANSFORGE UK LTD**  
[www.transforge.co.uk](http://www.transforge.co.uk)  
 +44 (0)1733 249260  
[info@transforge.co.uk](mailto:info@transforge.co.uk)

RAIL and ROLLING STOCK

Maschinen Stahlbau **MSD** Dresden  
 Branch of Herbolzsch AG  
 For whatever reason you're tunnelling MSD - your reliable partner for special tunnelling equipment.  
[www.msd-dresden.de](http://www.msd-dresden.de)

**VALENTE**  
 TUNNELLING EQUIPMENT  
 ROLLING STOCK - TURNOUTS  
 LOCOMOTIVES  
 WAGGONS  
 Via Don Minzoni, 06 Phone: +390293799212  
 20020 Lainate (MI) ITALY Fax: +390293799349  
[www.valente.it](http://www.valente.it) [info@valente.it](mailto:info@valente.it)

VENTILATION

**AMCO PLASTICS LIMITED**  
 Wire Reinforced & Layflat Tunnel Ducting  
 Tel: + 44 (0)1709 872574  
 Fax: + 44 (0)1709 879020  
 Email: [info@amco-plastics.co.uk](mailto:info@amco-plastics.co.uk)  
[www.amco-plastics.co.uk](http://www.amco-plastics.co.uk)

**SCHAUBURG TUNNEL-VENTILATION GMBH**  
 Flexible Ventilation Ducting  
[www.tunnel-ventilation.de](http://www.tunnel-ventilation.de)  
 Phone: +49 208 8827610  
 Fax: +49 208 8827615

FIBRE REINFORCEMENT

**MACCAFERRI**  
 Engineering a Better Solution  
 Fibre reinforcement | Tunnel drainage | Fibreglass reinforcement  
 Self-drilling anchors | Steel arches | Ceramic linings  
[www.maccaferri.com](http://www.maccaferri.com)

GROUND CONTROL

DYWIDAG-SYSTEMS INTERNATIONAL **DSI**  
**ALWAG SYSTEMS**  
 GROUND CONTROL SOLUTIONS  
**DSI UNDERGROUND SYSTEMS INC.**  
[www.dsi-tunneling.com](http://www.dsi-tunneling.com)

**hw** hoelscher dewatering  
 • dewatering  
 • groundwater control  
 • water treatment  
[www.hw-dewatering.com](http://www.hw-dewatering.com)

SEGMENT FITTINGS

**TTTC**  
 TECHNICAL TUNNELLING COMPONENTS  
 PLASTIC COMPONENTS FOR SEGMENT CONNECTION  
 BUILDING AND GROUTING SYSTEMS  
[WWW.TTCLTD.ORG](http://WWW.TTCLTD.ORG)  
 +44(0)1455 234401

RECRUITMENT

**Hunter Personnel**  
 Recruiting For Your Industry  
 Specialists in Tunnelling and Infrastructure Recruitment  
**VIEW CURRENT VACANCIES ONLINE AT:**  
[www.tunnelsandtunnelling.com](http://www.tunnelsandtunnelling.com)  
 Contact: David Kellett  
 T: +44 (0) 1202 298322 E: [tt@hunterpersonnel.com](mailto:tt@hunterpersonnel.com)  
 For more information please go to: [www.hunterpersonnel.com](http://www.hunterpersonnel.com)

MICROTUNNELLING

**WHEN THE GOING GETS TOUGH...**  
 ...Iseki microtunnelling machines come smiling through!  
 Microtunnelling equipment - for hire or sale  
  
**ISEKI MICROTUNNELLING**  
 Iseki Microtunnelling  
 Wellingborough UK  
 +44(0)1234 781166  
[www.isekimicro.com](http://www.isekimicro.com)

MONITORING EQUIPMENT

Tunnel Atmosphere Monitoring  
  
 Carbon Monoxide  
 Nitric Oxide  
 Nitrogen Dioxide  
 Visibility  
 Air Flow & Direction  
 Low cost high precision tunnel sensors proven over 20 years  
**CODEL International Ltd**  
 World leaders in tunnel atmosphere monitoring  
 +44 (0) 1629 814351  
[sales@codel.co.uk](mailto:sales@codel.co.uk)  
[www.codel.co.uk](http://www.codel.co.uk)

SURVEYING and MONITORING

**AMBERG TECHNOLOGIES**  
 Tunnel Surveying  
 Tunnel Seismics  
[www.amberg.ch/at](http://www.amberg.ch/at)

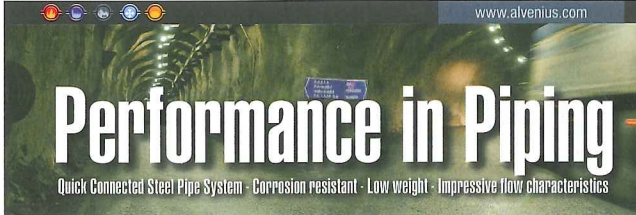
TBM's

**CATERPILLAR**  
 Caterpillar Tunneling Canada Corporation  
[www.cattunnelboring.com](http://www.cattunnelboring.com)  
 +1 416 675 3293


MONITORING EQUIPMENT

**TUNNEL SENSORS**  
 Monitoring Solutions for Tunnels  
 Manufacturer of atmospheric monitoring equipment designed specifically for the tunnel market.  
  
 Call: +44 (0)1280 850521 Email: [sales@tunnelsensors.com](mailto:sales@tunnelsensors.com) Visit: [www.tunnelsensors.com](http://www.tunnelsensors.com)

PIPES and COUPLINGS

**Performance in Piping**  
 Quick Connected Steel Pipe System - Corrosion resistant - Low weight - Impressive flow characteristics  
  
**ALVENIUS**  
 Performance in Piping  
[www.alvenius.com](http://www.alvenius.com)

TUNNELLING SUPPLIES

**Robit ROCKTOOLS**  
 Reliable tunnelling tools from Finland  
  
 Please see our web pages for more details:  
 tel. +358 3 3149 3400 • [www.robif.fi](http://www.robif.fi)

PIPES and COUPLINGS

**SVEBRA**  
 LIGHTWEIGHT PIPING  
 Quick Coupling Pipes And Fittings  
 Strandvägen 25 | 686 30 Sunne, Sweden | T: + 46 565 689410 | F: + 46 565 711215  
[www.svebra.se](http://www.svebra.se)

RAIL and ROLLING STOCK

**Clayton** World Leading Locomotives & Haulage Solutions...  
 ...for Mining, Tunnelling & Surface Transport  
  
**Clayton Equipment Ltd**  
[www.claytonequipment.co.uk](http://www.claytonequipment.co.uk) Tel: +44 (0) 870 112 9191

TUNNELLING SUPPLIES

**TA Tunnelling Accessories**  
 EPDM GASKETS  
 PLASTIC SEGMENT FITTINGS  
 FOAMS & POLYMERS  
 HYDROPHILIC RUBBER  
 BOLTS  
 PACKERS  
 LIFTING EQUIPMENT  
 BULLFLEX  
 SEALING STRIPS  
 SECONDARY SEALS  
 TBM LAUNCH SEALS  
 LUBRICANTS  
 ROLLING STOCK  
 +44 (0) 1424 854112  
[info@tunnellingaccessories.co.uk](mailto:info@tunnellingaccessories.co.uk)  
[www.tunnellingaccessories.co.uk](http://www.tunnellingaccessories.co.uk)

**Global Tunnelling Experts.**  
 Bringing the best together.  
  
 Global Tunnelling Experts is your teamwork partner for the best human resource solutions on your tunnel construction site. We supply personnel for all jobs throughout all the construction phases - including operational job profiles for all aspects of mechanized tunnelling operations and the equipment they involve. **Choose the right experts and contact us now.**  
**Global Tunnelling Experts**  
 +31 (0) 10 266 94 44  
[clients@global-tunnelling-experts.com](mailto:clients@global-tunnelling-experts.com)  
[www.global-tunnelling-experts.com](http://www.global-tunnelling-experts.com)  
 The Netherlands | Germany | United Kingdom  
 Panama | Denmark | Australia  


To advertise here call Tom Willard on +44 20 7406 6599 or email [twillard@tunnelsonline.info](mailto:twillard@tunnelsonline.info)



This is not the full list of British Tunnelling Society Corporate Members | To see a full list of all members visit: [www.britishtunnelling.org.uk](http://www.britishtunnelling.org.uk)

Applied Industrial Systems Ltd

Tunnel Control & SCADA  
[www.tunnelautomation.com](http://www.tunnelautomation.com)

**ARUP**

T: +44 (0)20 7636 1531  
E: [london@arup.com](mailto:london@arup.com)  
W: [www.arup.com](http://www.arup.com)

**ATKINS**

[www.atkinsglobal.com](http://www.atkinsglobal.com)

**Balfour Beatty**  
Civil Engineering

+44 (0)1737 785 000  
[enquiries@bbcel.co.uk](mailto:enquiries@bbcel.co.uk)  
[www.bbcel.co.uk](http://www.bbcel.co.uk)



If you wish to become a British Tunnelling Society Corporate Member please email: [bts@britishtunnelling.org.uk](mailto:bts@britishtunnelling.org.uk)

**Joseph Gallagher Ltd**  
Tel: +44 (0)1375 672070  
Fax: +44 (0)1375 672073  
Email: [headoffice@josephgallagher.co.uk](mailto:headoffice@josephgallagher.co.uk)

**LONDON BRIDGE ASSOCIATES LTD.**  
[www.lbassoc.co.uk](http://www.lbassoc.co.uk)  
Delivering value across the construction cycle.

**MINOVA**  
[www.minovainternational.com](http://www.minovainternational.com)

**MORGAN SINDALL**

01788 534 500  
[morgansindall.com](http://morgansindall.com)

**BASF**  
The Chemical Company

**MEYCO**  
Expanding Horizons Underground  
[www.meyco.basf.com](http://www.meyco.basf.com)

part of the Enterprise Group  
UK Tunnelling Specialist & Hire.  
Tunnelling & Underground Construction.  
[www.byzak.co.uk](http://www.byzak.co.uk)  
Plant Yard: +44 (0)1704 896888  
Head Office: +44 (0)161 746 3200  
Email: [enquiries@byzak.co.uk](mailto:enquiries@byzak.co.uk)

**Cooper & Turner**  
Manufacturers and suppliers of connection and embedded items for segment lined tunnels worldwide  
[www.cooperandturner.co.uk](http://www.cooperandturner.co.uk)

**DANNY SULLIVAN GROUP**  
[enquiries@dannysullivan.co.uk](mailto:enquiries@dannysullivan.co.uk)  
+44 (0)20 8961 1900  
[www.dannysullivan.co.uk](http://www.dannysullivan.co.uk)

**Mark Leggett**  
T: +44 (0)20 8774 2758  
E: [mark.leggett@mottmac.com](mailto:mark.leggett@mottmac.com)  
[www.tunnels.mottmac.com](http://www.tunnels.mottmac.com)

**Natural Cement**  
[www.naturalcement.co.uk](http://www.naturalcement.co.uk)

**normet**  
FOR TOUGH JOBS  
CHEMICALS EQUIPMENT SUPPORT  
[www.normet.com](http://www.normet.com)  
[www.taminternational.com](http://www.taminternational.com)

**otb**  
CONSULTING, DESIGN, SUPERVISION  
+44 (0)20 7099 2608  
[enquiries@otbeng.com](mailto:enquiries@otbeng.com)  
[www.otbeng.com](http://www.otbeng.com)

**DONALDSON ASSOCIATES**  
[www.donaldsonassociates.com](http://www.donaldsonassociates.com)

[www.dr-sauer.com](http://www.dr-sauer.com)  
[london@dr-sauer.com](mailto:london@dr-sauer.com)

**Gall Zeidler CONSULTANTS**  
GEOTECHNICS | TUNNEL DESIGN | ENGINEERING  
[www.gzconsultants.com](http://www.gzconsultants.com)

**GRACE de neef**  
Leader in injection and waterproofing products  
[www.deneef.com](http://www.deneef.com)

Global consultants | Designers  
Engineers | Programme managers

**PARSONS BRINCKERHOFF**  
[www.pbworld.com](http://www.pbworld.com)  
[services@pbworld.com](mailto:services@pbworld.com)

**Rutherford global power**  
TEMPORARY ELECTRICAL EQUIPMENT & CABLES FOR TUNNELLING & CONSTRUCTION  
TEL: +44 (0)1206 596 100  
[info@rutherfordpower.co.uk](mailto:info@rutherfordpower.co.uk)  
[www.rutherfordglobalpower.com](http://www.rutherfordglobalpower.com)

**stirling lloyd**  
THE TECHNOLOGY OF PROTECTION  
SEAMLESS WATERPROOFING TO CREATE WATERTIGHT TUNNELS  
01565 633111  
[marketing@stirlinglloyd.com](mailto:marketing@stirlinglloyd.com)  
[www.tunnelwaterproofing.com](http://www.tunnelwaterproofing.com)

**TROLEX**  
[www.trolex.com](http://www.trolex.com)  
T: +44 (0)161 483 1435

**HALFEN**  
YOUR BEST CONNECTIONS  
01582 470300  
[WWW.HALFEN.CO.UK](http://WWW.HALFEN.CO.UK)

**HERRENKNECHT**  
Tunnelling Systems  
[www.herrenknecht.com](http://www.herrenknecht.com)

**Hunter Personnel**  
Recruiting For Your Industry

Specialists in Tunnelling and Infrastructure Recruitment  
[www.hunterpersonnel.com](http://www.hunterpersonnel.com)

**itmsoil**  
t: +44 (0) 1825 765044 e: [info@itmsoil.com](mailto:info@itmsoil.com)  
f: +44 (0) 1825 744398 w: [www.itmsoil.com](http://www.itmsoil.com)

**URS**  
Multidisciplinary engineering consultancy  
+44 (0)121 212 3035  
[uktunnelling@urs.com](mailto:uktunnelling@urs.com)  
[ursglobal.com](http://ursglobal.com)

**VINCI CONSTRUCTION** | GRANDS PROJETS

Tunnelling works:  
world class innovative solutions  
[www.vinci-construction-projects.com/british-isles](http://www.vinci-construction-projects.com/british-isles)

**Mechanical & Electrical Engineering**  
tel +44 (0)1268 711845 | fax +44 (0)1268 711846  
[www.vvb-eng.com](http://www.vvb-eng.com)

PROJECT LOGISTICS

**W&W** | **ALS**  
WALLENIUS WILHELMSEN LOGISTICS | ABNORMAL LOAD SERVICES

Tel: +44 (0) 1482 796214  
[info.tunnelling@als-europe.com](mailto:info.tunnelling@als-europe.com)  
[www.abnormal-loads.com](http://www.abnormal-loads.com)



This is not the full list of British Tunnelling Society Corporate Members To see a full list of all members visit: [www.britishtunnelling.org.uk](http://www.britishtunnelling.org.uk)



If you wish to become a British Tunnelling Society Corporate Member please email: [bts@britishtunnelling.org.uk](mailto:bts@britishtunnelling.org.uk)



The complete source of project, company, market and deal information for the global construction industry.



Quality Data. Deep Insight. Innovative Delivery

Global coverage giving access to:

- 35,000 mega projects
- \$21 trillion projects value
- 100,500 key industry contacts
- 250 market reports
- 7,500 company profiles
- 16,000 deals
- 115,000 news articles

Across the following sectors:

- Tunnelling
- Infrastructure
- Energy & Utilities
- Industrial
- Institutional
- Residential
- Commercial & Leisure



For more information on Construction Intelligence Centre visit [www.construction-ic.com](http://www.construction-ic.com) or email [sales@construction-ic.com](mailto:sales@construction-ic.com)

# What's on

## 2013

**World Tunnel Congress**  
31 May - 7 June 2013  
Geneva, Switzerland

The technical highlight of the conference calendar, the show includes WTC and the 39th ITA General Assembly.  
[wtc2013.ch](http://wtc2013.ch)

**Tunnel Safety & Fire Protection**  
4-5 June 2013  
Brisbane, Australia

This conference and networking event focuses on the need to optimise fire protection and safety for tunnel operators as tunnel developments boom across the Australasia region.  
[www.safetyintunnels.com](http://www.safetyintunnels.com)

**Construction Expo**  
5-8 June 2013  
Sao Paulo, Brazil

Dedicated to both construction and infrastructure, this trade show will represent such sectors as materials, services and equipment providers for industries including roadways, airports, seaports, bridges and metros.  
[www.constructionexpo.com.br](http://www.constructionexpo.com.br)

**Strait Crossings Conference**  
16-19 June 2013  
Bergen, Norway

Organised by the Norwegian Public Roads Administration, the focus is on extreme crossings and new technology.  
[www.sc2013.no](http://www.sc2013.no)

**RETC**

23-26 June 2013  
Washington D.C., USA  
The Rapid Excavation and Tunnelling Conference is the largest North American tunnelling show. This year Washington plays host to the show and is expected to attract nearly 2,000 tunnellers from around the country and overseas. Tunnels will have a stand at the show so be sure to find us there.  
[www.retc.org](http://www.retc.org)

**ISARC/WMC 2013**  
11-15 August 2013  
Montreal, Quebec, Canada

The 30th International Symposium on Automation and Robotics in Construction, Minig & Petroleum Industries (ISARC) is being held in

conjunction with the 23rd World Minig Congress (WMC). Both conferences will sponsor a joint trade show.  
[www.isarc2013.org](http://www.isarc2013.org)  
[www.wmc-expo2013.org](http://www.wmc-expo2013.org)

**18th ICSMGE**  
2-6 September 2013  
Paris, France

The 18th International Conference on Soil Mechanics and Geotechnical Engineering (ICSMGE) will have a new format with the first two days devoted to plenary sessions and the following days devoted to discussion of papers and workshops from the committees.  
[www.issmge2013.org](http://www.issmge2013.org)

**Bauma Africa**  
18-21 September 2013  
Johannesburgh, Africa

The massive construction show holds its first edition in Africa, focusing on all sectors of the construction industry.  
[www.bauma-africa.com](http://www.bauma-africa.com)

**ExpoTunnel**  
17-19 October 2013  
Bologna, Italy

The newly-established exhibition will also host the Italian Tunnelling Society congress entitled "Tunnelling and Underground Space for European Development."  
[www.expotunnel.it](http://www.expotunnel.it)

**Stuva Conference**  
27-29 November 2013  
Stuttgart, Germany

The bi-annual confereency of the Stuva organisation heads to Stuttgart.

## 2014

**CONEXPO**

4-8 March 2014  
Las Vegas, Nevada, USA  
Held every three years, the exposition showcases the latest construction equipment, products, services and technologies. The show will be held at the Las Vegas convention centre.  
[www.conexpoconagg.com](http://www.conexpoconagg.com)

**ISTSS**

12-14 March 2014  
Marseille, France  
The 6th International Symposium on Tunnel Safety and Security will discuss

current practice and emerging trends and research in the field of tunnel safety and security.  
[www.istss.se](http://www.istss.se)

**Samoter**  
8-11 May 2014  
Verona, Italy

Trade show dedicated to earth moving, site and construction machinery held every three years.  
[www.smaoter.it](http://www.smaoter.it)

**World Tunnel Congress**  
9-15 May 2014  
Iguassu Falls, Brazil

The show includes WTC and the 40th ITA General Assembly.  
[www.wtc2014.com.br](http://www.wtc2014.com.br)

## British Tunnelling Society

The BTS has a membership of almost 700 individual and 60 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. Events are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month.

**Preston project report**  
16 May 2013

A report on the construction details of this project in the north of England.

**Gotthard Base Tunnel**  
20 June 2013

After 10 years of tunneling, the two main breakthroughs were celebrated on 15.10.2010 in the eastern running tunnel and on 23.03.2011 in the western running tunnel, completing the two main tunnels of the 27 km long Bodio and Faido section. This report is presented by Rainer Rengshausen of Hochtief.

**Thames Tideway Tunnels**  
19 September 2013

The presentation will include background on the sewage problems and the proposed solution; an update on the project development and design for tender; progress on the development consent application; an outline of the technical challenges faced; the proposed delivery route for the construction; and the latest situation on procurement

## Contact us

Jon Young



### Editorial

**Editor**  
Jon Young  
Tel: +44 20 7406 6622  
[jyoung@tunnelsonline.info](mailto:jyoung@tunnelsonline.info)

Nicole Robinson



**Americas Editor**  
Nicole Robinson  
Tel: +1 612 940 2780  
[nrobinson@tunnelsonline.info](mailto:nrobinson@tunnelsonline.info)

Alex Conacher



**Features Editor**  
Alex Conacher  
Tel: +44 20 7406 6616  
[aconacher@tunnelsonline.info](mailto:aconacher@tunnelsonline.info)

**Regular Contributors**  
Maurice Jones, Adrian Greenman,  
Bernadette Ballantyne, Partick Reynolds,  
Rhian Owen

### Production

Jim Moore



**Design/Editorial Production**  
David Cooper

**Production Controller**  
Lorraine Lee  
Tel: +44 20 8269 7799  
Fax: +44 20 8269 7840  
[llee@progressivemediagroup.com](mailto:llee@progressivemediagroup.com)

**Technical Illustrator**  
Nick Stenning

### Sales

### Head Office

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

Tel: +44 20 7406 6622  
Fax: +44 20 7936 6813

[www.tunnelsonline.info](http://www.tunnelsonline.info)  
[editor@tunnelsonline.info](mailto:editor@tunnelsonline.info)

**Head of Sales**  
Jim Moore  
Tel: +44 20 7406 6584  
[jmoore@tunnelsonline.info](mailto:jmoore@tunnelsonline.info)

**European Sales**  
Randolf Krings  
Tel: +49 611 5324 416  
Fax: +49 611 5324 519  
[rkt@emcmedia.de](mailto:rkt@emcmedia.de)

**Classified & Recruitment**  
Tom Willard  
Tel: +44 20 7406 6599  
[twillard@tunnelsonline.info](mailto:twillard@tunnelsonline.info)

### BTS - Editorial Advisory Board

**Editorial Advisory Board Chairman:**  
Myles O'Reilly ME, PhD, CEng, FICE  
**Committee:** Keith Bowers MSc, PhD, CEng, FICE, MIMMM, FGS; David Court CEng, FICE; Ivor Thomas BEng, LLB, CEng, MICE; Roger Margerison BSc, CGeol, FGS; Barry M New MSc, PhD, CEng, MICE; Roger Bridge; Andrew Smith BSc, CEng, MICE; Ken Spiby BEng; Eddie Woods BSc, CEng, FICE; Petr Salak MSc, Eur Ing, CEng, MICE.

### Subscriptions & Reprints

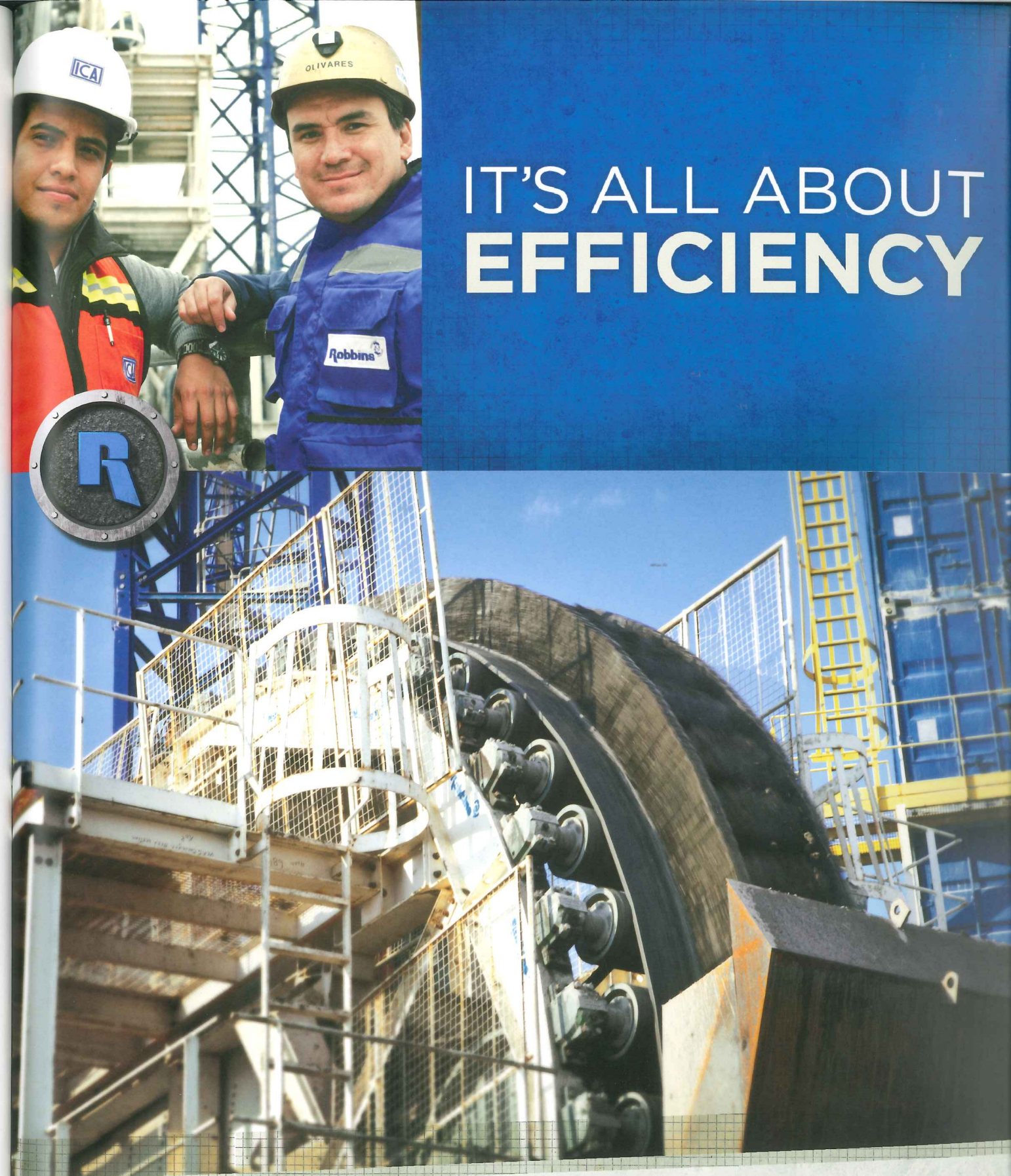
Subscription prices for 12 (24) months: Mailed anywhere in Europe €262.50 (€459), USA & Canada \$258 (\$258), UK £110 (£188), Rest of the world \$316 (\$553). Send subscription and back issue queries to Tunnels Customer Services. [cs@progressivemediagroup.com](mailto:cs@progressivemediagroup.com)

Tel: +44 (0) 845 155 1845 (local rate)  
Fax: +44 (0) 208 269 7277  
[subscriptions@progressivemediagroup.com](mailto:subscriptions@progressivemediagroup.com)  
Tunnels International Subscriptions,  
World Market Intelligence,  
Progressive House, 2 Maidstone Road,  
Foots Cray, Sidcup, DA14 5HZ.  
Subscribe online at [www.getthatmag.com](http://www.getthatmag.com)

The content of *Tunnels International* is subject to copyright. However, if you would like to obtain copies of an article for marketing purposes high-quality reprints can be supplied to your specification. Please contact the advertising team for full details of this service.

*Tunnels International* is printed at Stephens & George Print Group, Merthyr Tydfil.

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage or retrieval system, without the express prior written consent of the publisher. The contents of *Tunnels International* are subject to reproduction in information storage and retrieval systems. Contact: University of Microfilms International, 300 N. Zeeb Road, Ann Arbor, Michigan 48106, US. *Tunnels International* ISSN 1369-3999 is published monthly by Global Trade Media, John Carpenter House, John Carpenter Street, London EC4Y 0AN, UK. The 2012 US annual subscription price is \$ 226 Airfreight and mailing in the USA by agent named Air Business, C/O WorldNet Shipping Inc, 156-15, 146th Avenue, 2nd Floor, Jamaica, New York NY11434 USA. Periodicals postage pending at Jamaica NY 11431. US Postmaster: Send address changes to Hotel Management International C/O Air Business, C/O WorldNet Shipping Inc, 156-15, 146th Avenue, 2nd Floor, Jamaica, New York NY 11434 USA. Subscription records are maintained at Global Trade Media, John Carpenter House, John Carpenter Street, London EC4Y 0AN, UK. Air Business Ltd is acting as our mailing agent. *Tunnels International* and its Editorial Board accept no responsibility for the accuracy of statements or opinion given within the Magazine that is not the expressly designated opinion of the Magazine or its Editorial Board. Those opinions expressed in areas other than editorial comment may not be taken as being the opinion of the Magazine or its staff, and the aforementioned accept no responsibility or liability for actions that arise therefrom.



# IT'S ALL ABOUT EFFICIENCY

**Robbins**  
RELIABLE | RESPONSIVE

THEROBBINSCOMPANY.COM

### ROBBINS CONVEYORS SET THE PACE

High speed tunneling demands high speed muck removal—with maximum capacity, minimal hands-on labor, and controlled operating costs.

Robbins builds the most efficient conveyor systems available today. Our continuously advancing conveyors simplify any site's logistics, moving thousands of tons of muck per hour off the jobsite.

We keep you moving.