

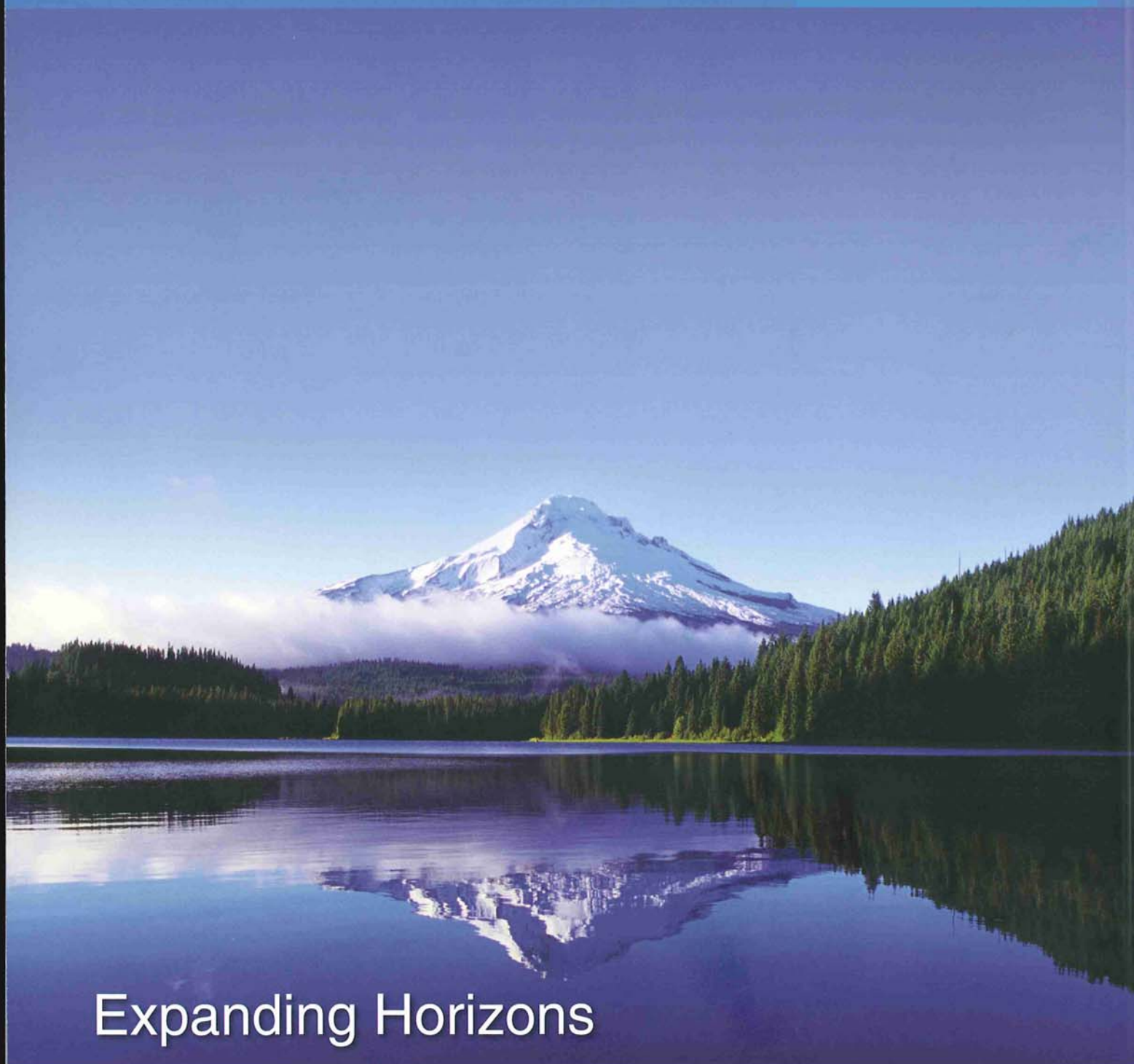
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# tunnels & tunnelling

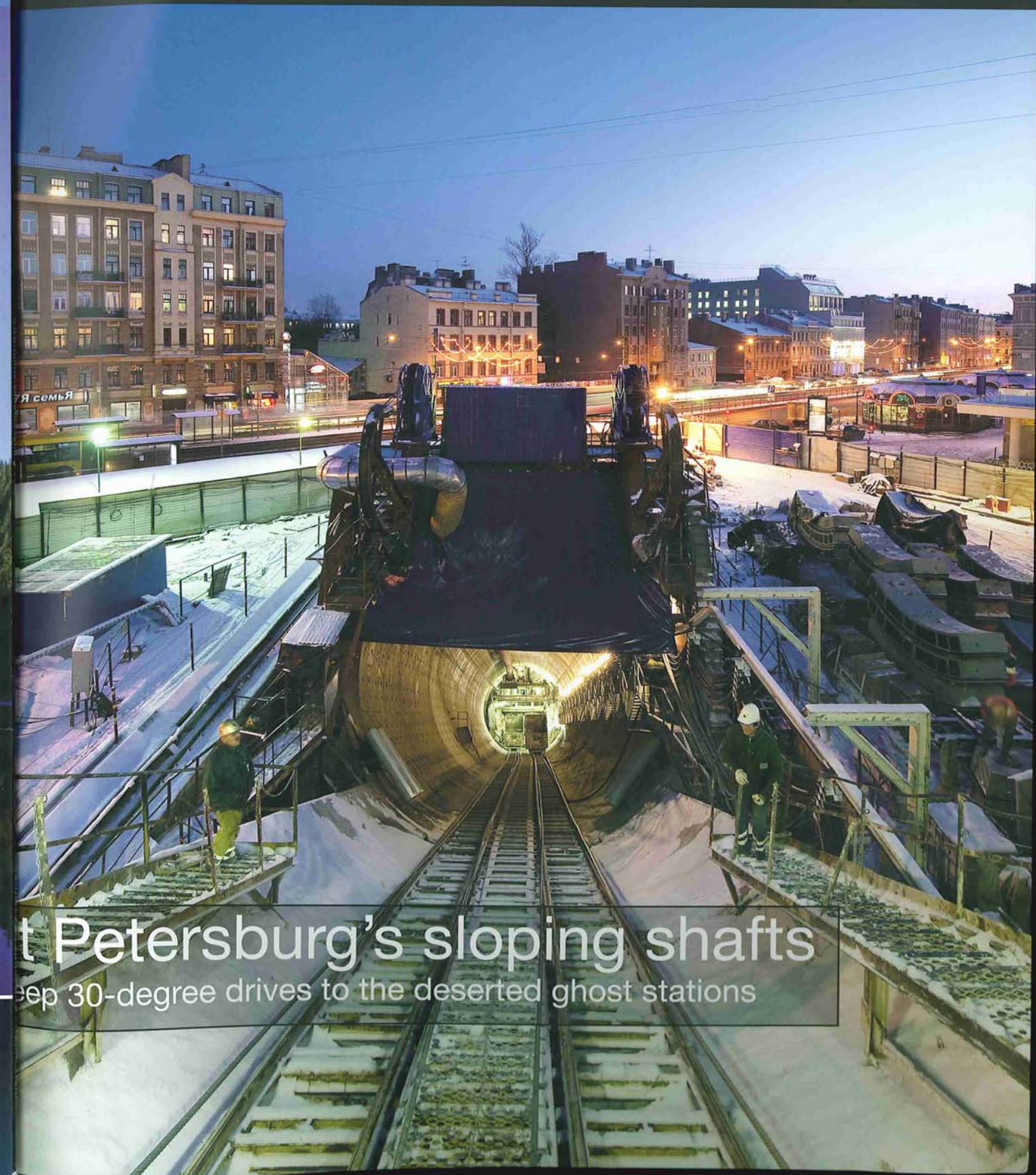
INTERNATIONAL



**T&T Asia focus: China**  
Challenging works underway in China

**Technical:**  
**Geotechnical instrumentation**  
Risk, responsibility and back to basics

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**St Petersburg's sloping shafts**  
Deep 30-degree drives to the deserted ghost stations



## SINGAPORE: METRO TUNNELLING IN THE LION CITY.

Singapore has experienced an enormous economic growth over the last few years. The requirements placed on the transportation infrastructure of this 5 million inhabitants metropolis city have risen as well. The Land Transport Authority has set its target by doubling the existing metro network to a total of 278km by 2020.

For the Downtown Line Phase 2 mega project, Herrenknecht will deliver 10 tunnel boring machines (4x Mixshield, 6x EPB Shield) for a total of 10 kilometers. The expected mixed ground condition poses different problems and challenges. To avoid any clogging in the challenging heterogeneous ground and at the same time break the hard Bukit Timah granite, the Herrenknecht designers have opted for an extremely open cutting wheel geometry and edging done with a large number of disc cutters. For the Mixshield TBMs, Herrenknecht will deliver two efficient separation plants.

Singapore's tunnelling specialists are relying on Herrenknecht technology when forging ahead the city state's metro system since the late 1990s. With the completion of the Downtown Line Phase 2, 23 machines will have driven a total of 37 metro tunnel kilometers.

### SINGAPORE

PROJECT DATA	CONTRACTOR
 Downtown Line Phase 2 4x Mixshield 6x EPB Shield Diameter: 6,660m Total length: 10,387m	Alpine Bau GmbH, McConnell Dowell South East Asia Pte. Ltd., Sembawang Engineers and Constructors Pte. Ltd., Ssangyong Engineering & Construction Co. Ltd.



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### comment

## India: Now or never

Passing through the congested streets of Mumbai last month on the way to the Bauma India construction trade show it was immediately obvious the challenge and potential in this city. With a population of 14M squeezed into narrow streets gradually being overrun by market stalls, it is in desperate need of a metro.

Dig a little beneath the surface and it is clear that transportation is not the only public service failing to meet the needs of this mega city. Water, power, sewage and drainage are all suffering. And the story is the same across all of India, from the largest cities to the most remote dwellings.

But India is moving. The country has the fastest growing GDP in the world and the success of the Delhi Metro project in the Indian capital has led every city to call for an underground network and utility services.

Across India there is tunnelling afoot. And there are more projects planned with money filtering down from central government. Manufacturers and equipment suppliers have taken up camp; contractors and consultants have entered into joint ventures with local firms.

But for western outfits there is just a short window of opportunity.

A foreign contractor cannot bid for a project in India unless in partnership with a local firm. Currently there are lots of Indian firms looking for foreign JV partners as there is not a great deal of tunnelling experience amongst local firms – certainly not enough to meet the prequalification requirements.

An Indian firm bidding for a USD 2bn tunnelling contract, for example, needs to demonstrate USD 2bn of past tunnelling experience. If it can't then it will have to join forces with a foreign outfit that can. If the local contractor in the JV goes on to successfully complete the USD 2bn project then it will gain a 50 per cent share of the credit, adding USD 1bn of experience to its credentials. Do this twice and the Indian contractor will now have enough experience to bid for the jobs alone.

It is vital that contractors wanting to join this booming tunnelling market act now, become part of a joint venture and use the time to establish their own Indian outfit. It will not be long before Indian companies can go it alone.

On page 37, Robbins country manager for India highlights the massive surge in TBM orders as part of our Asia focus this month. Also worth noting in the technical pages is the new How It Works section, launched this month to give a more fundamental look at processes or equipment readers should know about. The launch article looks at vibrating wire instruments on page 69.

Jon Young



### On the cover

St Petersburg's steep 30 degrees dives (see page 26)

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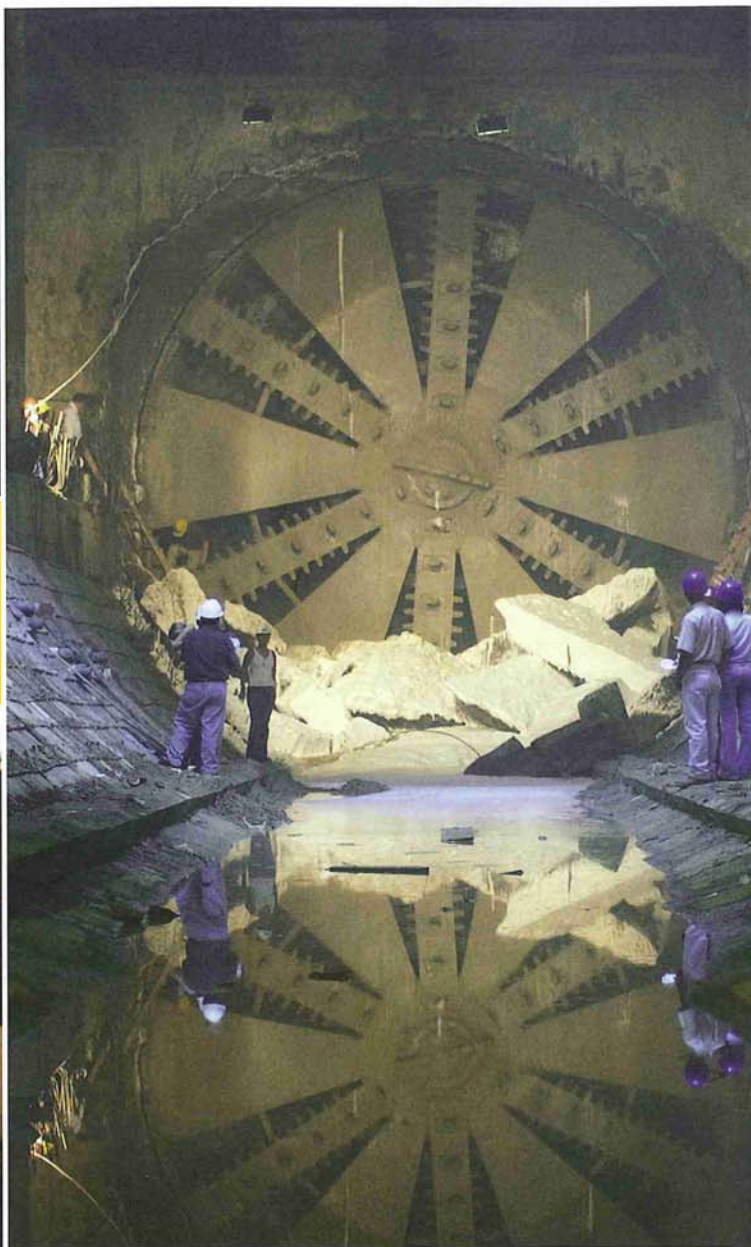
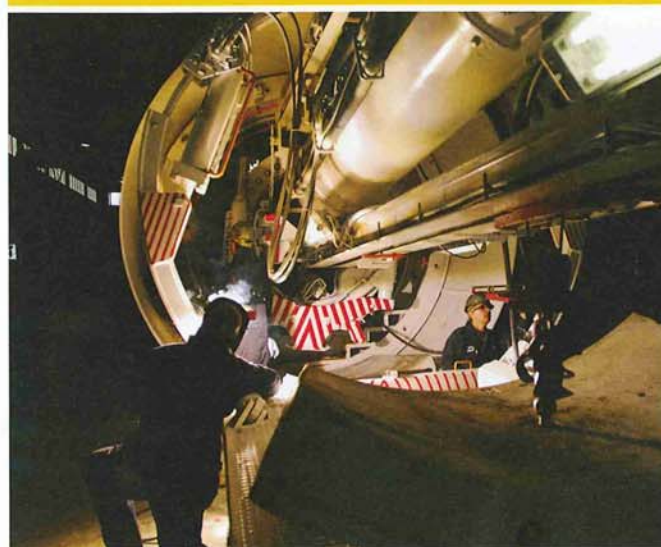
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## White House announces USD 53bn high-speed rail

USA

Vice President Joe Biden revealed a comprehensive USD 53bn plan to place high-speed rail on 'equal footing' with other surface transportation programmes last month in Philadelphia.

Funding would be distributed over six years to continue construction of a national high-speed rail and intercity passenger rail network.

"As President Obama said in his State of the Union, there are key places where we cannot afford to sacrifice as a nation—one of which is infrastructure," Biden said. "As a long time Amtrak rider and

advocate, I understand the need to invest in a modern rail system that will help connect communities, reduce congestion and create quality, skilled manufacturing jobs that cannot be outsourced. This plan will help us to do that, while also increasing access to convenient high speed rail for more Americans."

As part of the plan, the president's budget for the coming fiscal year would invest USD 8bn to develop or improve 'Core Express' corridors that would form the backbone of the high-speed rail network (125-250mph); 'Regional' corridors (90-125mph) that would be readied for future high-speed service and

"Emerging" rail corridors (90mph) that would provide access to the larger high-speed and intercity passenger rail network.

This system will allow the Department of Transportation (DOT)—in partnership with states, freight rail, and private companies—to identify corridors for high-speed rail, while raising speeds on existing rail lines and providing planning and resources to communities who want to join the high-speed rail network, according to the vice president.

The White House has already devoted USD 8bn of Recovery Act funds and USD 2.5bn from the 2010 budget to a national high-speed rail system.

## Cross River Rail stuck

AUSTRALIA

The Cross River Rail project in Brisbane, Australia has had construction work pushed back a further two years due to heavy flooding in Queensland.

In January the Queensland Government announced flood reconstruction assessments for the Queensland area would not affect the detailed feasibility phase, which was ongoing as T&T went to press.

The final business case and environmental impact statement have not begun. When the detailed feasibility phase has been completed, the government will decide how and when to proceed with the project.

## Second Avenue Subway west tunnel completed

USA

The TBM that has been progressing down Second Avenue has completed its first run of approx. 7,200-feet (2,195m). Completion of the west tunnel marks significant progress for phase 1 of Metropolitan Transportation Authority's (MTA) Second Avenue Subway construction project. Mining began in May 2010 and scheduled to complete by December 2016.

Reconditioned in Newark, New Jersey, this 485-ton, 450-foot (137.2m) long machine is now to be disassembled and returned to 92nd Street to embark on its second run to excavate the east tunnel in spring. Originally manufactured in the late 1970's by Robbins, it was first used to dig MTA's 63rd Street tunnel and at least four more projects since; most recently the Fall River CSO Project in Massachusetts.

MTA hopes that Phase 1 of the Second Avenue Subway will reduce overcrowding on the adjacent Lexington Avenue Line by up to 13 per cent, or 23,500 passengers on an average



Above: Completion of the West tunnel was a significant milestone

weekday. It will serve more than 200,000 people a day, reduce travel times by up to ten minutes and restore a transit link that was lost in 1942 with the takeover of the Second Avenue Elevated. The TBM that has been progressing down Second Avenue has completed its first run of approx. 7,200-feet (2,195m). Completion of the west tunnel marks significant progress for phase 1 of Metropolitan Transportation

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Latest news & archive - [www.tunnelsand tunnelling.com](http://www.tunnelsand tunnelling.com)

## News in brief

#### ▼ Cavico secures tunnelling contract for Vietnam hydropower plant

Vietnamese company Cavico has been awarded the contract for the Song Giang 1 Hydropower plant. With a 10.5-foot (3.2m) diameter and tunnels running for 3,505m underneath the Khanh Vinh District, it will be the largest hydropower project in Khanh Hoa Province. The twin-unit plant is to be funded by Song Giang Hydropower Joint Stock Company, investing an anticipated USD 23.2M.

#### ▼ Poyry granted Swiss assistance role

Poyry has been awarded a EUR 1.2M (USD 1.7M) contract to provide environmental consultancy and assistance services to the Swiss Federal Roads Office on an 8km stretch of road that included a 6km tunnel. The aim of the technical works was to adapt the road to the latest requirements. The project started last month to last until 2018. Construction was scheduled to take five years.

#### ▼ Niagara milestone

The TBM excavating the Niagara Falls project, 'Big Becky', has broken through to a small grout tunnel. Some 300m remained to be driven as T&T went to press. Final breakthrough was scheduled for late March to early April.

## Blanka tunnel costs to pass USD 2bn mark

### CZECH REPUBLIC

New Prague Mayor Bohuslav Svoboda has said that the 6.3km-long Blanka tunnel project will cost an extra CZK 10bn (USD 561.51M), raising the total to CZK 37bn (USD 2.08bn).

The responsibility for the overruns is a subject of debate. "The cost of Blanka is going up by roughly CZK 10bn, a huge sum, and we have to analyse how this happened," Svoboda said. He added, "We are analysing the original plans to find out where costs went up and why and to what extent they are justified. We also have to meet with the developer to discuss the whole problem. The jump from the original cost is so high that there is no way the city can pay it."

Metrostav is the main contractor on the project and responsible for all construction works. Metrostav project director Ermin Stehlik told T&T, "Metrostav is working according to the valid agreement, which is based on the International Federation of Consulting Engineers' (FIDIC's) 'Red Book'. This means that a 'measurement' contract is applied, with the originally estimated total costs for construction, and electrical and mechanical parts, and also for the client's part in land acquisition, engineering and design, geological investigation

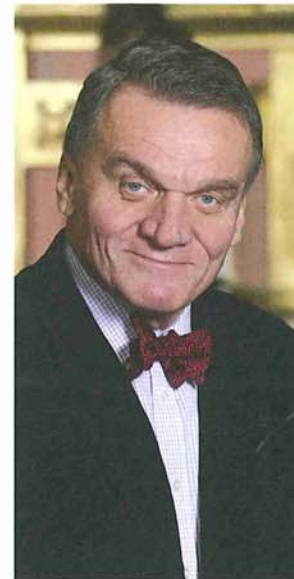
and geotechnical monitoring.

"The newly estimated costs are in the same structure as above, which includes all completed works accepted by the client and estimates of works needed for completion [of the project], including the increase due to the time extension as a result of insufficient funding."

As T&T went to press investigations and negotiations were ongoing between contractors and clients. The Prague Magistrate is verifying the agreement, which comprises over 4000 pages including addendums, as ordered by the Mayor.

With the change in the city administration, and even before, the project became a political football.

The previous administration had assured the public that the tunnel construction would be finished on time and within budget. Local media have claimed that the large cost increase was due to Prague City Hall violating its own rules, including a directive requirement to discuss cost increases of over 10 per cent in large construction projects. According to the Hospodarske Noviny daily newspaper, members of the previous controllers of City Hall (ODS party), including deputy mayors, blamed the previous mayor Pavel Bem and the



Above: Mayor Svoboda has attempted to calm Blanka spending

investment department for the increase in project costs, claiming they knew nothing about it. The head of the investment department, Jiri Toman, was recently dismissed from post. Bem, however, blames the new administration that took over in December.

Construction has been progressing steadily with section breakthroughs recently reported, following the stop on work ordered by safety authorities following the most recent, third collapse last July.

## Gateway tunnels proposed to replace ARC

### USA

Amtrak has proposed spending USD 50M to begin preliminary engineering and design on two new trans-Hudson rail tunnels from New Jersey to New York City.

Amtrak said it expedited its plans to build new rail tunnels following cancellation of the ARC tunnel by New Jersey governor Chris Christie in 2010. Its CEO, Joseph Boardman, and board member Tony Coscia, with New Jersey senators Frank

Lautenberg and Robert Menendez (both democrats), announced the Gateway Project at Penn Station in Newark, New Jersey, on 7 February.

"Intercity and commuter rail passengers in New York and New Jersey are in need of increased rail capacity," Coscia said. "The two new trans-Hudson tunnels envisioned under this plan will provide long-sought peak-period operational capacity and is an investment that will improve transportation flexibility and

reliability for decades to come."

Tunnels for the Gateway Project would connect New Jersey from Penn Station in Newark to an expansion of existing Penn Station in Manhattan.

There would also be significant infrastructure improvements in New Jersey including increasing track capacity from two to four, and replacing the 100-year-old Portal Bridge across the Hackensack River.

According to projections by Amtrak, the entire Gateway

Project could be completed in 2020 at an estimated cost of USD 13.5bn.

Amtrak said it will take the lead in finding ways to pay for the new tunnels, including seeking potential contributions from local, regional and state governments including New Jersey, New York State, New York City, the Port Authority of New York and New Jersey and New York's Metropolitan Transportation Authority (MTA), as well as private investors.

## Tension as Alaskan Way tunnel moves forward

### USA

Seattle mayor Mike McGinn vetoed the City Council's agreements with the Washington State Department of Transportation (WSDOT) outlining their partnership on the Alaskan Way Viaduct bored tunnel, including support with utilities and right-of-way issues.

In a letter to the council last month, McGinn said he was protecting the city from "the unacceptable risks of this project," and "the likelihood of unaffordable cost overruns on the tunnel."

The City Council had approved the measure 8-1 last month. Prior to this vote the mayor announced his veto intentions.

Council president Richard Conlin released a same-day statement in response to the mayor, announcing efforts to override the veto. "Working with our regional partners including Gov. Gregoire, King County and the Port of Seattle, we are moving forward with this approved solution," he said.

WSDOT crews started demolition work on the Viaduct the following day.

Earlier in the month, 'Seattle Citizens Against the Tunnel,' or SCAT, submitted a petition to stop tunnel construction. The group secured more than 27,000 signatures for its I-101 Stop the Tunnel initiative, which would put preventing the city from using right-of-way for building the



Above: The planned replacement for the Alaskan Way Viaduct (pictured) has been controversial

tunnel to a public vote.

Only 20,629 signatures were needed to qualify, and SCAT had hoped I-101 would be on a May election ballot, but it will be unlikely the county's election

officials will have enough time to validate the all signatures. This could be problematic for the anti-tunnel group with the election in autumn, and the groundbreaking scheduled for August.

## Breakthrough for Australia's two largest TBMs

### AUSTRALIA

The second of two EPB machines excavating the Brisbane Airport Link project broke through to a purpose-built cavern earlier this month.

The first, nicknamed 'Rocky', reached the halfway cavern last month. It and its twin 'Sandy' were

the two largest machines ever used in Australia at 12.48m in diameter, 195 metres in length and weighing 3600 tonnes. They reached a maximum depth of 55m on the project.

"The tunnelling teams have achieved good progress, with the TBMs travelling underneath streets and parklands between Clayfield

and Woolloowin," said Gordon Ralph, Thiess John Holland project director. "Once tunnelling is complete the cutterheads for the massive TBMs will be buried underneath the tunnels."

"The two TBMs were custom built for the Airport Link and this solution will reduce the complexity in removing the cutterheads, while

avoiding the need for additional surface work in the Lutwyche area," he said. "The last 180 metres of each machine will be removed after the front ends are concreted into the burial pits."

The project has been part of a AUD 4.8bn (USD 4.9bn) infrastructure investment on Brisbane's Northside.

## Samsung C&T to build Abu Dhabi sewer

### UAE

South Korean trading and construction company Samsung C&T has been awarded a USD 270M contract for construction of a deep sewage tunnel in Abu Dhabi.

The contract was part of the

larger 41-km programme of deep-tunnel sewers from Abu Dhabi island to Al-Wathba.

Three tunnel packages were planned for the 'Strategic Tunnel Enhance Programme', with two similar contracts already awarded to Italian contractor Impregilo.

Samsung C&T announced that

it had been chosen to build the 4m-diameter, 16.1km tunnel by the Abu Dhabi Sewerage Services Company on 14 February.

The project will link the industrial satellite town of Mussafah with central Abu Dhabi, the capital of the UAE and should be completed in 43 months, said Samsung C&T.

## News in brief

▼ Marti's exploratory tunnel Marti was chosen to construct the 3.7km tunnel in southern Germany to examine geological conditions for the main Kramer tunnel. The contract value was approximately CHF 29M (USD 31.3M).

# Denmark supports Fehmarnbelt tunnel

## DENMARK

Danish MPs last month approved tunnel plans for the Fehmarnbelt link, said state-owned planning body Femern.

The 18.1km link between Denmark and Germany was recommended late last year by Danish statutory body Femern, which said it favoured the immersed tunnel option over a cable-stayed bridge because it would entail fewer risks, in construction and operation.

The EUR 5.1bn (USD 7.04bn) project would comprise a combined motorway and rail tunnel under the Fehmarnbelt between Rodbyhavn in Denmark and Puttgarden in Germany.

"We welcome the political support for our recommendation that the future link be designed as an immersed tunnel," said Leo Larsen, CEO of Femern. "As our conceptual design projects are based on an extremely thorough, technical foundation we can now focus on ensuring that the authorities approve the project,



Above: Artist's conception of the Denmark portal of the Fehmarnbelt tunnel

including from an environmental perspective."

Over the coming year, Femern will prepare an Environmental Impact Statement to be considered by the authorities in Denmark and Germany in accordance with national regulations.

Femern expects to submit an application to the German authorities during the first six months of 2012. A construction bill will then be submitted to the Danish parliament in 2013. This

more or less coincides with the timetable for the German authorities' approval of the project.

"The aim is to build and operate one of Europe's safest and most modern tunnels for both trains and cars, which will bring Northern Europe and Scandinavia even closer together," said Larsen. "As a result we'll create opportunities for increased growth and prosperity for more than 10 million residents in the Fehmarnbelt Region."

Construction should commence in 2014.

## News in brief

### Civil engineers Croatia meet

The 6th Annual Meeting of Chartered Civil Engineers of Croatia and Chamber Convention is being held in Opatja, Croatia, on 15-18 June 2011. The specific seminar topics, all in the civil engineering sector, include tunnels in urban areas, geotechnics and project management.

### Kiev metro to issue bonds to fund a new line

Kiev Metropolitan, the company that operates the metro infrastructure in the Ukrainian capital, is raising funds to add another line, to the Trojevshina district. The estimated cost, including rolling stock, is UAH 12bn (USD 1.51bn). Several funding options are being considered.

### Tunnel under Red River

A four-lane road tunnel to link Hoan Kiem District with Long Bien District in Hanoi has been agreed by delegates. The 1.5km tunnel would be the first under North Vietnam's longest river.

## Calgary airport tunnel gets green light

### USA

The City Council of Calgary voted 8-7 last month to build the CAD 295M (USD 298M) underpass beneath the city airport's new runway.

A report from the Transportation Department found that building the underpass in addition to the new runway would be the city's cheapest option. Cost estimates found that building a bored tunnel later would cost CAD 1.5bn to 1.6bn (USD 1.54bn to 1.64bn).

In April, Barlow Trail will be closed for the Calgary Airport

Authority to construct a fourth runway. The city has been exploring options for a road connection, particularly under the runway.

A third option, abandoning the airport link, was considered as well. This would eventually require a series of improvements in the surrounding road network, estimated to cost CAD 325M to 425M (USD 328M to 429M).

The tunnel design has been reduced from 720 to 615m, with a recommendation for six lanes to accommodate future conversion from bus to rail-based transit.

## Leighton Asia reaches water transfer milestone

### HONG KONG

The 2.35km Lai Chi Kok branch tunnel, part of the Lai Chi Kok Transfer Scheme in Hong Kong has been completed after 11 months of construction.

Excavation of the main tunnel by Leighton Asia, a subsidiary of Leighton Holdings, will commence at the end of April, with possible delays until the start of May. As T&T went to press, the project was awaiting a VMT navigation system for hard rock machines to arrive at the end of the branch tunnel to guide the

TBM through the main tunnel.

The main tunnel will run for 1.14km and will have an internal diameter of 4.9m.

The tunnel was designed to negate flooding in Lai Chi Kok city, Hong Kong. Under the plan, rainwater from the west Kowlook hillside would be absorbed by intakes leading to the branch tunnel, which would then feed the main tunnel to transport the water to Victoria Harbour.

The contract also required six intake shafts, a stilling basin, an outfall structure and around 270 metres of 3m id connection adits.



WHEN  
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SELI  
starts to fight

Veligonda Project, India



## San Vicente tunnel opens

USA

The San Vicente Pipeline Tunnel has been completed and opened on 19 January in San Diego County, California, USA.

Jacobs was prime design consultant for this part of the USD 1.5bn Emergency Storage Project, which was carried out by the San Diego County Water Authority (SDCWA).

The 17km long, 2.6m diameter pipeline drive stretched from

Lakeside to Mira Mesa and connected the San Vicente Reservoir to the Water Authority's Second Aqueduct. The intention was that this 757,000-litre per minute capacity pipe would help the county's emergency water distribution in the event of a disaster.

Tunnelling began in 2005 and required three access shafts and one portal along the route. Three TBMs – one hard rock machine and two digger shields – were

engaged around the clock on different sections of the drive. The last breakthrough occurred in September 2009.

Following excavation, the construction teams placed 1,145 of the 15m, 15.4-tonne steel pipe sections into the tunnel and encased them in cellular concrete on the outside for structural protection and lined the inside with cement mortar to resist corrosion.

Testing in December revealed

the pipeline to be fit for service.

"One unique operational aspect of the pipeline is that it provides SDCWA with a bidirectional flow capability. When imported water is available, the pipeline can convey water from west to east to fill San Vicente Reservoir.

"It can also be used to convey water from the reservoir to the west when emergency conditions require the stored water," said Jacobs.

## Longest Hong Kong drain breakthrough

HONG KONG

Hong Kong secretary for development Carrie Lam led a breakthrough ceremony for the Hong Kong West Drainage Tunnel last month.

The 6.25-7.25m diameter, 11km-long tunnel featured the first use in Hong Kong of raise boring and reverse circulation drilling to construct dropshafts.

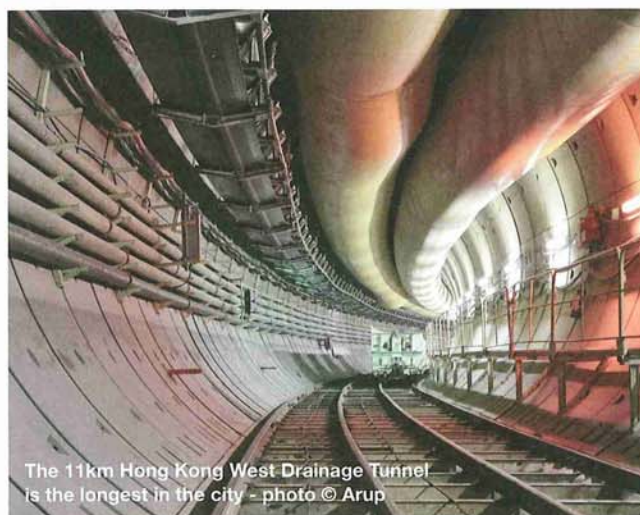
Consulting supervisor Arup said, "The logistics for delivery of explosives, removal of spoil generated by both TBMs and blasting operations, and arrangement of working and supervisory staff inside the tunnel, was one of the most complicated processes ever for

the Hong Kong construction industry."

Breakthrough occurred in January beneath Stubbs Road, Wan Chai and marked entry to the final phase. Construction began under the Dragages-Nishimatsu JV in 2007 and will be completed in 2012.

"The HKD 3bn (USD 385.4bn) project is the biggest flood prevention project implemented by the Drainage Services Department so far," said Chan Chi-Chiu, Hong Kong director of drainage services.

The project involved 34 intakes and eight 1km adits, constructed by drill and blast, to connect intakes to the main drainage tunnel. Two TBMs excavated the



The 11km Hong Kong West Drainage Tunnel is the longest in the city - photo © Arup

tunnel from either end simultaneously to shorten construction time.

"The government is implementing various flood prevention and sewerage infrastructure projects with a total cost of HKD 36.6bn (USD 4.7bn),

in order to create a quality living environment in Hong Kong," said Lam. "Other major projects with a total value of HKD 20.6bn (USD 2.65bn) are also under planning."

When finished, the tunnel will divert 30 per cent of stormwater from northern Hong Kong.

## Afcons bags Chennai contracts

INDIA

An Afcons and Transtunnel JV has won two contracts worth a total of INR 25.98bn (USD 567.43M) on the Chennai metro project in India.

The contracts covered construction of 8.6km of tunnels and nine underground stations. The first contract, UAA01 was valued at INR 15.67bn (USD

344.02) and covered works from Washermenpet to Egmore Station. The second, UAA05, was valued at INR 10.31bn (USD 226.35) and covered works from Shenoy Nagar to Thurmangalam Station.

Construction was scheduled to begin in mid-February with completion in April 2015.

"We have been one of the key partners in Delhi Metro having

done seven jobs for them," said Ramakrishna V Ramanan, director of transportation for Afcons Infrastructure. He added, "Similarly we are currently executing the first underwater metro tunnel below Hoogly River in Kolkata for the Kolkata Metro. Now we are very proud and privileged to have such an important association with Chennai Metro."

## News in brief

**TBM launching ceremony in Wilhelmshaven**  
A formal TBM launching ceremony was held on 6 January at the site of a new pipeline tunnel for the a coal-fired power plant under construction at Rustersieler Groden, northern Germany. The 800MW power plant will go on line in 2012.

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## Crossrail appointments

### GREAT BRITAIN

Crossrail has made two non-executive appointments to its board, it announced on 25 February.

Former Hong Kong MTR Managing Director Phil Gaffney and former managing director of TfL London Rail Ian Brown will join the board on 1 April.

Crossrail Chairman Terry Morgan said:

"I'm delighted that Phil Gaffney and Ian Brown will be joining the

Crossrail Board. Crossrail continues to make excellent progress and these two new appointments will bring considerable railway operations experience and help inform future decisions about signalling, timetabling and the integration of Crossrail services with the existing National Rail and Tube networks.

"Phil Gaffney has a wealth of experience from overseeing the operation of the Hong Kong MTR, one of the world's busiest metro systems, and has extensive

knowledge of delivering major infrastructure improvements and procuring new rail signalling technology.

"Ian Brown has vast railway experience and has successfully overseen the major upgrade and expansion of the Docklands Light Railway and London Overground including the GBP 1bn (USD 1.61bn) transformation of the East London Line. His knowledge of railway operations in London and the south east is unparalleled."

## Scottish Government to announce changes to hydro planning

### GREAT BRITAIN

The Scottish Government has announced that the planning process for hydroelectric schemes in the country is set to become simpler and quicker from June 2011, with new applications up to 50MW to be determined by councils rather than Ministers.

Currently, applications for hydro schemes over 1MW are decided by ministers. The changes, announced yesterday, will bring hydro into line with the thresholds for determining wind farms.

"Scotland has a long tradition of hydro development and today's vibrant sector is putting forward plans for new, mainly small scale schemes all the time," said Energy Minister Jim Mather. "At the moment planning authorities already consider hydro applications, sometimes at

committee, before responding to Ministers. Rather than making a recommendation, councils will now apply local knowledge to make local decisions on hydro applications up to 50MW, cutting out another layer of bureaucracy. Developers have welcomed these changes to simplify and streamline the process.

"Our tough target to determine energy applications within nine months has made a noticeable difference to the speed of decision making. While every application has its own characteristics, planning authorities are experienced in hydro schemes and I expect developers will now get even quicker decisions and be able to contribute further to Scotland's low carbon economy."

The planning process shake-up follows a consultation carried out between September and December 2010.



Above: Scottish energy Minister Jim Mather

An order to change the threshold back to its original level has been laid in Parliament.

Applications submitted to Scottish Ministers before 1 June will continue to be determined by Scottish Ministers.

## RiverCity Motorways in receivership

### AUSTRALIA

The Cem7 tunnel operator in Brisbane, Australia announced last month that it had gone into receivership.

KordaMentha partners Martin

Madden and David Merryweather were appointed as receivers and managers to RiverCity Motorways.

KordaMentha had successfully worked as a receiver for other complex infrastructure projects in Australia, including the Lane Cove

and Cross City tunnels in Sydney.

"We must secure a sustainable business for this valuable asset in Brisbane's road network," said Madden. "Operationally, Cem7 is performing well. We do not intend to make any significant changes."

## News in brief

### Geokon sales up

Geotechnical instrumentation specialist Geokon reported an increase in sales of 35 per cent in 2010 over the previous, record, year. The increase was attributed to several large international civil engineering projects. Geokon also completed its fourth premises expansion last year.

### Milan metro contract award

Earlier this month the Coestra/Boncinari/ACMAR di Firenze JV secured the EUR 61.05M (USD 84.05M) contract for design and equipment of the 1.8 km-long Line 1 metro extension from Sesto FS to Monza in Milan.

### Invitation to tender for nuclear waste disposal tunnel in Upper Normandy, France

Negotiated invitation to tender for the construction of two shafts and a 1 km-long, 5m-diameter tunnel for Penly 3, a European Pressurised Reactor. Contract duration 65 months. Closing Date: 21 March. Further information: Mickael Fauvet at EDF, tel +33 2183751-34, email: mickael.fauvet@edf.fr.

### Norway road tunnel tender prior notice

Proposed improvement of 3.15km of County Road 51 from Lovraeidet to Tysingvatnet will involve construction of a new 950m-long tunnel. Contract duration 16 months. Scheduled start of award procedures 25 May. Contact: Knut Utaaker at Statens vegvesen Region vest in Leikanger, tel: +47 51911456, e-mail: knut.utaaker@vegvesen.no

### Franco-Spanish cable tunnel award

Inelife awarded the consortium Eiffage/ACS/Setec/Arcadis/Sener the EUR 105 million (USD 144.56M) contract to build an 8.5km-long, 3.5m-diameter cable tunnel between Spain and France last month.

## Mapei Korea takes on former Henkel products

### SOUTH KOREA

Mapei has completed the acquisition of all activities regarding adhesives and other construction products carried out by Henkel in South Korea, under the Ceresit and Thomsit trademarks.

This has been carried out

through the new Mapei Korea company with headquarters in Seoul. The production unit is only 100 km away from the capital city region Chungcheonbuk-do (Mapei's 58th plant), which will supply the North Pacific zone.

The plant will produce Mapei's other products as well as the Ceresit and Thomsit ranges

that will be maintained for up to three years.

The Ceresit range includes waterproofing materials for tanks and renovation, plus mortars.

Mapei has invested more than EUR 200M (USD 270.7M) into the Asia-Pacific region with its headquarters in Singapore led by Marcel Smit.

## Geocomp's move to extend...

### USA

An international leader in geo-engineering, the Geocomp Corporation has moved its headquarters to larger premises at 125 Nagog Park, Acton, Massachusetts, United States, in order to accommodate expected growth.

"We have an ambitious five-year growth strategy and we're delighted to have found an ideal space that will expand our capacity in consulting,

laboratory services and products manufacturing," said Dr Allen Marr, Geocomp president and CEO.

Geocomp has had main roles in projects such as the Boston 'Big Dig'/CA-T, the New York Eastside Access project, the World Trade Center and 2nd Avenue subway, and the Athens Metro.

Geocomp integrates its web-based, real-time, monitoring platform called 'iSite Central' into its 'Active Risk Management'

protocols, to reduce risk over the entire project life cycle. This is coupled with predictive modelling, expertise in innovative construction materials, and foundation and earth support system design.

Approximately 24,000ft<sup>2</sup> (2230m<sup>2</sup>) of office space is available for lease by tenants at Geocomp's new premises.

Other Geocomp locations include New York, Atlanta and San Francisco in the US, plus Peru.

## ... and boss elected to Academy of Engineering

### USA

The founder of geotechnical specialist Geocomp Corp, and also its president and CEO, W. Allen Marr, has been elected to the US National Academy of Engineering.

He was selected for his 'innovative applications of numerical methods, risk analysis, advanced laboratory techniques, and field instrumentation to geotechnical engineering and construction'.

The National Academy of Engineering (NAE), together with the National Academy of Sciences, the Institute of

Medicine and the National Research Council, make up the National Academies who advise the US on issue in science, engineering and medicine. The mission of the NAE is to promote the technological welfare of the country by marshalling the knowledge and insights of eminent members of the engineering profession.

Marr is presently working on the reconstruction of the World Trade Center in New York City, and the construction of the new twin tunnels to carry commuters between Queens and the Grand Central Terminal in Manhattan (the Eastside Access project).



Above: Geocomp CEO, W. Allen Marr

Most of his current work focuses on helping clients determine what factors threaten a project's cost and schedule, and how to manage those factors to deliver projects on time and within budget.

## News in brief

### Ostfeld Court bottleneck relief - invitation to tender

Invitation to tender using restricted procedure for engineering design of the Gamlebyen-Langhus tunnel section of the new 22 km-long twin-track Follo line Oslo-Ski. Langhus tunnel will be twin-tube and will become the longest rail tunnel in Norway. Deadline set for 21 March. Contact Per Fahlen at Jernbaneverket in Oslo, tel +47 97832327, e-mail xfahper@jbnv.no. Register interest at: www.doffin.no

### Treviso tunnel contract

Last month the Eureka Consorzio Stabile/Accisa/So.Co.Gen JV secured the contract for design and construction of Lot 1 La Sega-Rindola of the Vittorio Veneto bypass on SS51 di Alemagna in Treviso province. The 2.35 km-long section included the 1.5km rock tunnel, Sant Augusta, and the cut and cover tunnel Via Carso.

### Romanian tunnel rehabilitation tender

Open invitation to tender with a deadline of 11 April for rehabilitation of Lot 1: SRCF Brasov tunnel and Lot 2: SRCF Timisoara tunnel. The contract durations will be 12 months. Contact Ion Preda at CFR in Bucharest, tel: +40 213192433, e-mail ion.preda@cfr.ro

### Consulting contract for Romanian metro

Last month a Metroul/Systra JV won the EUR 1.4M (USD 1.93M) contract for consultative engineering and construction services the new Universitate-Pantelimon section of Line 5 on the Bucharest underground.

### Balfour Beatty record-breaking end of year report

Order book record increase of USD 1.1bn to USD 15.2bn (8 per cent) and pre tax profit up 20 per cent to USD 319M.

# Cowi checks for widest tunnel

RUSSIA

The joint owners of the planned 19-m diameter Orlovski Tunnel in St Petersburg have selected Denmark-based Cowi as engineer for the project to conduct an independent design assessment. The tunnel it is currently destined to become the world's largest diameter TBM driven tunnel. The project is being operated as a public-private partnership (PPP) scheme according to Russian government decree. The estimated costs total RUB 44.7bn (USD 1.51bn).

A specially designed TBM will bore the record-breaking structure over one kilometre long, and project construction is scheduled to begin late this year.

The client for the project is a partnership between Nevskaya Concession Co (NCC) and the City of Petersburg (as the Western High Speed Diameter – WHSD – JSC).

Herrenknecht is currently preparing a Mixshield to tackle the generally soft ground and to meet the preliminary design.

Orlovski Tunnel, which has been planned for several years, is intended to relieve a special traffic congestion problem in St Petersburg. Known as 'The Venice of the North', St Petersburg has a multitude of weaving waterways. In summer months the city's 22 elevating bridges are raised every night so that ships have non-stop passage to Moscow along the River Neva. This is an 'issue of federal significance', to increase traffic along the Volga-Baltic Waterway (VBW). However, this causes a major traffic nuisance for road traffic in the city as it is restricted to just a few crossings, with no permanent link between the right and left banks of the Neva in the city centre. The existing alternative bridges are said to have exhausted their capacity, and traffic level increases are expected.

The Orlovski Tunnel will allow traffic to flow freely, as well to increase the opening time of the bridges. The expected daily traffic

load in 2016, on opening, is 60 000 vehicle per hour on its two decks between Piskarevski Avenue and Smolnaya Embankment. The concessionaire will operate the crossing with mechanical tolls under the proviso that no queues are allowed to form.

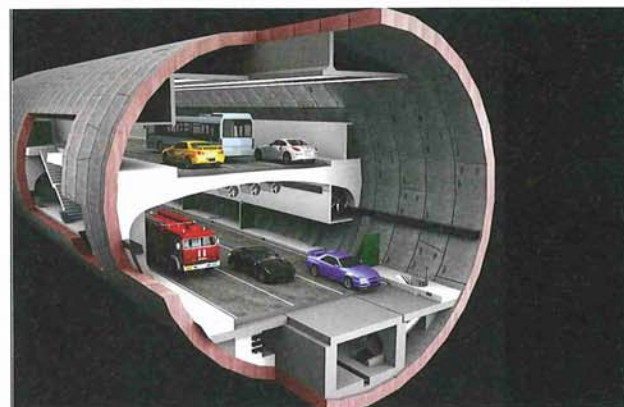
Cowi's project manager is Morten Faurshou. He said Cowi's specialists are already conducting the engineering review, commenting on geological and hydrosurvey findings as well as conducting independent structural calculations and verifying designs for the tunnel's ventilation system. Cowi works jointly for NCC and the City. In the event of any technical dispute between these two parties, Cowi will also act as arbitrator.

The soft-to-very soft ground on the planned bore alignment includes lake and marine sediments, diluvium (fluvioglacial deposits), and Quaternary strata. Therefore layers of fine sand, sandy loam, gravelly moraine are expected. Below these there is older, stiff clay that may be encountered by the tunnel drive at its lowest points.

In addition to the bored tunnel other structures required include TBM launch and retrieval shafts, and cut-and-cover for portals and approaches at depths of 15-50m. These are also included in Cowi's design verification work.

According to Faurshou, by the end of this month (March), Cowi will have examined the construction documentation and conducted an analysis to ensure compliance with the concession agreement. "If all goes to plan, construction will begin by the end of the year," he said. This will necessitate state authority approval of the project subject to Cowi's findings.

The project is understood to be on schedule, due partially to the compression of some preliminary activities. The contractor has not yet been appointed but NCC's project technical manager, Mikhail Ryjevski, told T&T that they are currently selecting a potential



Above: Artist's impression of Orlovski tunnel section

contractor, with Russian and foreign companies participating in the tender process. The final decision will be made in June.

Main design work is being carried out by JSC Institute 'Stroyproekt' of St Petersburg under the direction of NCC and works checking by NCC specialist. It is understood that PSP Consulting Engineers of Germany, carrying out segmental lining design, is one of several design subcontractors. Mechanical and electrical design has not been commissioned yet but a Russian company has been appointed for ventilation design with Poyry of Finland and Switzerland working direct for NCC.

It appears that Herrenknecht will get the order for the monster TBM, although a spokesperson for Herrenknecht said that a feasibility and design study order had not yet been received. If all goes well the TBM will be a brand new machine of 19m diameter (built at Schwanau) reported Ryjevski. "This tunnel boring machine will be specially made for Orlovsky Tunnel," he said, "on the assumption of difficult geological conditions and tunnel design peculiarities."

Herrenknecht said that TBM manufacture will start on receipt of the final order. It recently played host to the governor of St Petersburg, Valentina Ivanovna Matvienko and other high-ranking representatives of the city and the

Duma of the Russian Federation. Former German Federal Chancellor Dr Gerhard Schroder also attended. The party saw the current world's largest TBM, the 15.62m-diameter shield machine that was awaiting acceptance inspection by its Italian customer. "The technology is very impressive," said Matvienko.

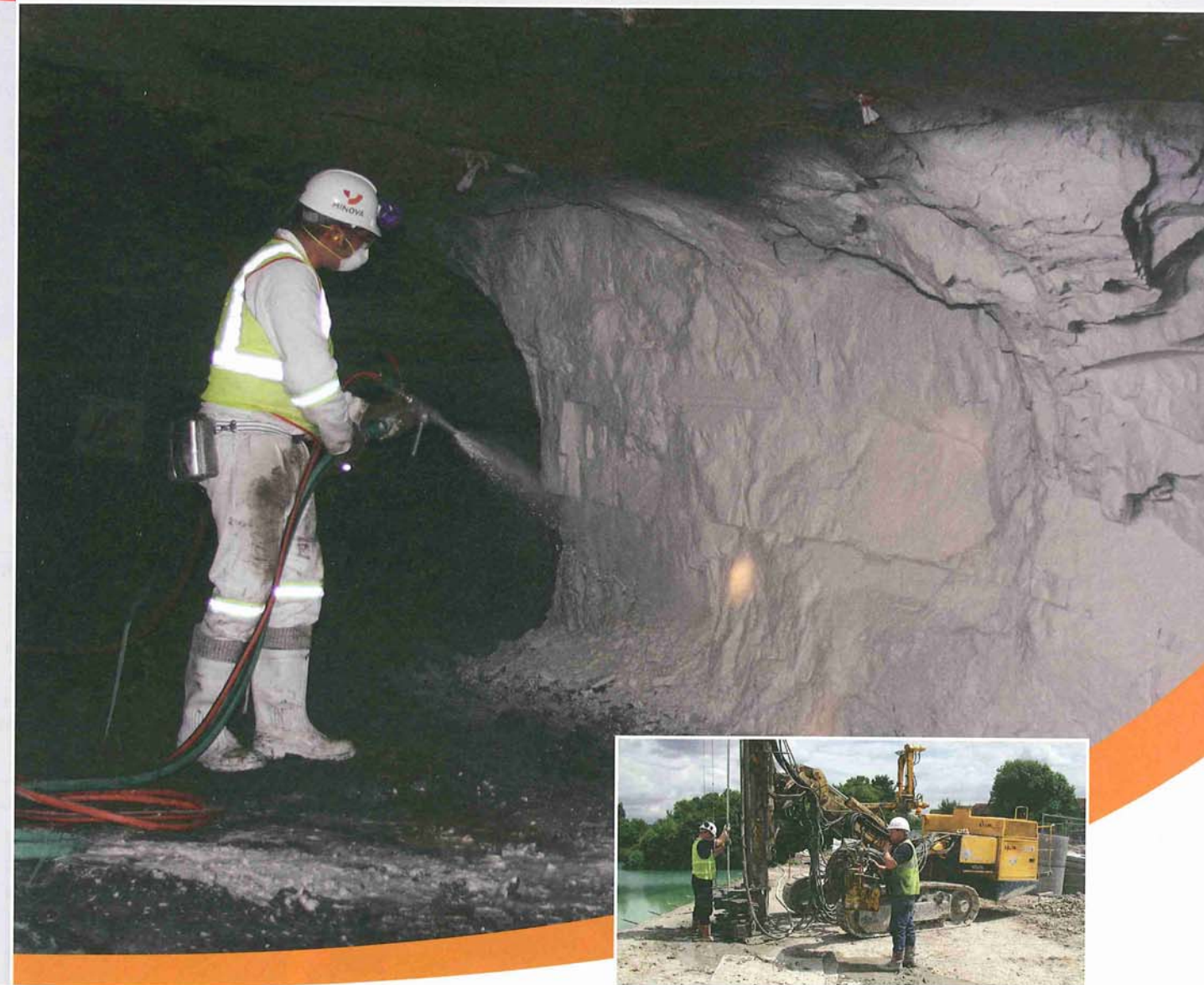
The World Bank supports the project with strategic and financial advice, and letters of in-principle interest have been received from the European Bank for Reconstruction and Development, the International Finance Corporation, Vnesheconombank, the Eurasian Development Bank and the European Investment Bank. The Orlovski Tunnel is just one of several PPP projects in Russia, and especially St Petersburg, in which the World Bank is carrying out a consultancy and support role. Russia has planned a USD 1000bn investment programme in infrastructure over a 10-year period, representing eight per cent of its GDP each year. PPP is expected to play a significant role in this programme.

A project brief on the tunnel was presented in September 2007 with participation by the World Bank, Mott MacDonald, international law firm and PPP specialists Freshfields Brukhaus Deringer, and the Russian Research and Design Institute of Regional Development and Transportation.

Maurice Jones

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# Photo competition heats up

First entries are in for the T&T 2011 photo competition, don't miss your chance to enter!

The daunting task of capturing the perfect photo in a dark, confined space has not deterred the first entrants to the revived T&T photo competition. The first entries are in and the competition is heating up. It is time to dust off your SLR or power up your digital and get snapping.

Capture the moment that defines a tunnel project. Be it contractors knee deep in mud

and concrete or the glossy finish of a newly laid segment. We are looking for the photo that can reveal the true nature of tunnelling.

The judges will be scoring on the technical quality of the shot and the moment it captures.

The closing date for entries is 1 July and the three short listed entrants will be announced in the August issue of T&T.

## Win

The winner of the T&T 2011 photo competition will receive a digital SLR camera with a range of accessories. Full details to follow.

The final three short listed by the judges will win free passes to the T&T Conference and Exhibition being held in Germany in the Autumn and will win seats at the T&T table at the Awards dinner.

Entry is free. Closing date is 1 July. Terms and conditions apply. Submit your entry to [photo2011@tunnelsandtunnelling.com](mailto:photo2011@tunnelsandtunnelling.com) and files should be no less than 2Mb and no more than 10Mb.

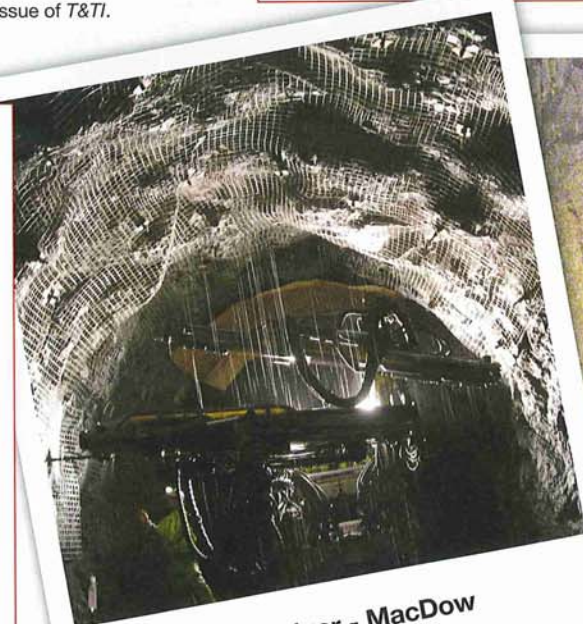
## The judges

**Nick Kozak** – Nick is an experienced photographer based in Toronto, Canada who specialises in disaster and construction photography and has recently returned from photographing the earthquakes and aftermath in Haiti.

**David Vintiner** – David is an accomplished photographer based in London, England. David's clean, understated images have been acquired and exhibited by the National Portrait Gallery.

**Henrik Williams** – Henrik is creative director at T&T publisher Progressive Media. He has more than 20 years' experience in publishing and is responsible for managing all aspects of art and design within Progressive.

**Jon Young** – As the editor of T&T Jon has to sift through hundreds of tunnel photos in an attempt to sort the wheat from the chaff.



Stan Schwalger - MacDow



Einar Broch - NTNU



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## GAUTRAIN SITE DEMOBILIZATION

Bombela Civils Joint Venture consortium (civil contractor to the Gautrain), consisting of Bouygues Civil Works, Murray & Roberts and the Strategic Partners Group (SPG) has reached the point of site demobilization. as a result the equipment / plant are available:



Refurbished PAUS Dumper 10000A 20t payload interchangeable with Concrete mixer CIFA



Refurbished Shotcrete Robot PUTZMEISTER: Model PM 407



Refurbished Shotcrete Robot PUTZMEISTER: Model PM 500



Refurbished NORMET Himec 9915 B.A

LIEBHERR Tower Cranes 280 EC-H 12

For more information please contact:  
Nilton Barreira (011 997 8414 / 078 804 3039)  
[nilton.barreira@bombelacjv.com](mailto:nilton.barreira@bombelacjv.com)



# Finishing Gotthard

Work is getting into full swing on the 15.4km long Ceneri tunnel that completes the Gotthard high-speed railway axis in Switzerland. Adrian Greeman visited the site

If it were not for the Gotthard base tunnel, the Ceneri would have been attracting more attention as one of Switzerland and Europe's larger tunnel projects. But the 57km length and enormous depth of its big brother to the north has left this 15.4km long sibling in the shade so far.

Things might change now that Gotthard has broken through and work is into its swing at Ceneri. After all, the twin bore drive is not only a major project in its own right, but also an important component in the overall Gotthard railway link.

The Gotthard axis is the biggest high-

speed railway tunnel project yet attempted, and one of the most significant in the world – a forerunner of a series of deep level mountain rail links that can be expected in the 21st century. It is one of four major Alpine connections, joining the shorter 34.6km-long Lotschberg tunnel already completed within Switzerland, the Brenner Pass base tunnel just starting between Austria and Italy and, eventually, the Lyons to Turin connection via the Frejus pass between France and Italy.

When complete, Ceneri and the Zimmerberg tunnel near Zurich will cut another ten minutes from the high-speed

train journey time between Zurich and Milan. It is a critical saving; together with the 50 minutes that the Gotthard cuts from journeys this makes a complete hour, giving much better connection with the hourly timetable structure of the growing European high-speed train network. From 2019 when Ceneri is due to open, the high-speed routes will be properly synchronised. Gotthard opens three years earlier (see *T&T Gotthard* November 2010).

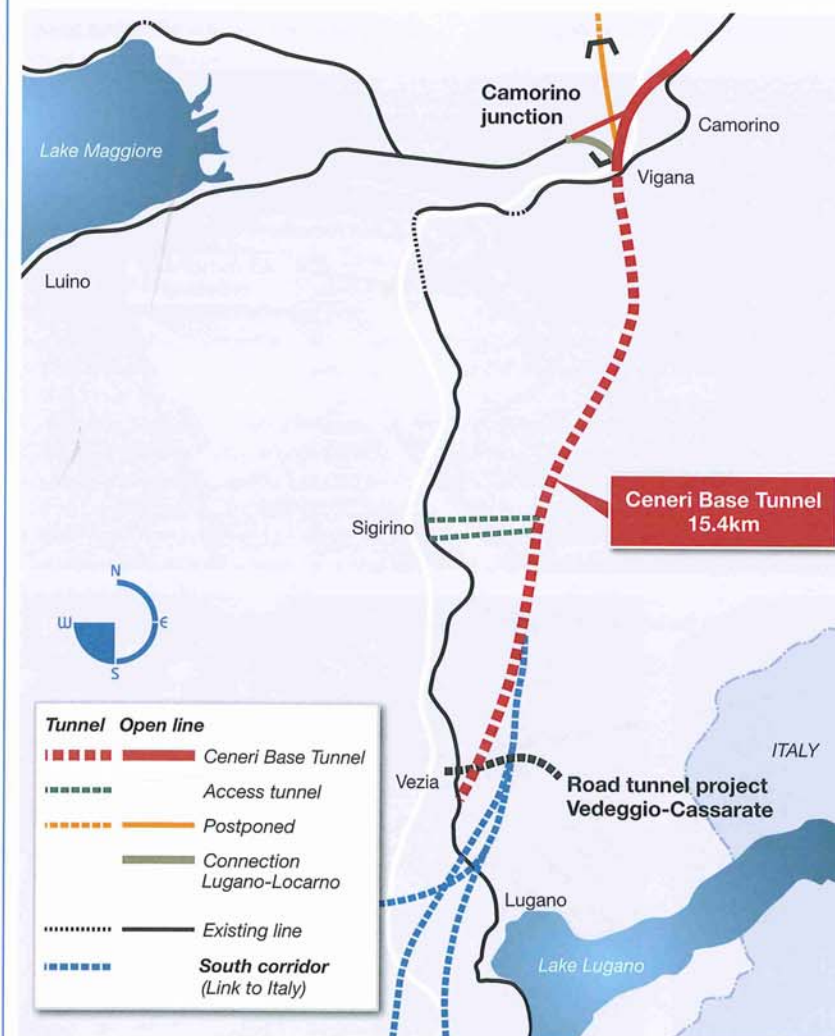
Ceneri will have gradients no greater than the Gotthard's 6.7 in a thousand, which means it can also cope with the 4000t capacity 160km/hour freight services which are an important part of the overall economic and environmental justification for construction of the route. Existing trains are 2000t and require several locomotives to make the high climbs.

The new tunnel lies on the south part of the route in Italian speaking Switzerland, passing under Monte Ceneri, which separates the border city of Lugano and its lake, from Locarno and Bellinzano to the north. The mountain rises to 1100m, less than half the 2500m of the high Alps but still a respectable rock mass to drive through. It is crossed at present by a winding railway route with a high tunnel at the peak.

"This is the southern edge of the Alpine block," says Paolo Vicentini, a site manager in client AlpTransit Gotthard's project team. AlpTransit is the special company set up by Swiss Federal Railways to oversee construction and commissioning of the entire axis.

"It is where the African tectonic plate crashes into Europe and is pushed down underneath."

Like the larger Gotthard, Ceneri will carry the high speed and heavy freight trains in two single-track tunnels, with minimum diameters of around 8.5m before, typically, a 250mm lining. These bores will be separated by 40m of rock with cross passages every 325m for emergency access, and for tunnel and signalling service locations. Each passage will be sealed with heavy pressure doors that can be opened by escaping passengers in the event of fire or other





disaster, allowing them through to the other bore where they will be picked up and carried to safety.

Unlike Gotthard however, the Ceneri does not require any of the big multifunction stations used for both escape purposes and additional ventilation. Its length means that many emergencies can be dealt with by trains continuing to the outside before stopping.

There will be a large cavern at the centre however; from this point the main drives have begun, two south and two northwards.

**Opting for drill and blast**

The tunnel is being constructed by drill and blast in both directions, the result of an alternative bid option offered to contractors. The client had thought perhaps part of the excavation could be driven by TBM on the southern section but the full length of the route was never going to be suitable for machine driving, in contrast to the mainly TBM drives of the Gotthard.

Boreholes were used to investigate the geology of the tunnel and an early 5.5m diameter exploratory bore from the village of Sigorino, which lies about half way along the route length. It was made in 1999 to 2002. Results indicated the rock to be mainly fairly hard orthogneiss and schists. There is also glacial Swiss molasse near the portals.

Cover is relatively high, but topping out at 1040m rather than the 2000m of the Gotthard; this means high temperature problems and squeezing ground are far less of an issue with a maximum of

**Right:** The northern portal passes just underneath the A2 motorway; **Below, left:** Jet grouted umbrella under motorway. All photos © Ceneri; **Below, right:** South portal approaches at Vetzia were close to residences

19 degrees C expected.

The exploratory tunnel was intended from the beginning to be part of the construction access, though a second larger side tunnel was bored alongside it between late 2007 and November 2008. The Consorzio Monte Ceneri, a joint venture of CSC and two other contractors, made the 9.7m diameter bore using a refurbished Robbins main beam TBM and completed the 2.4km long adit in just ten months. It is simply lined with shotcrete.

Robbins says that it is the first time 19-in disc cutters were used on AlpTransit and the additional pressures achievable significantly reduced cutter wear while speeding up advance rates to as much as 16m a day average. Maximum cover for the side tunnel was 600m.

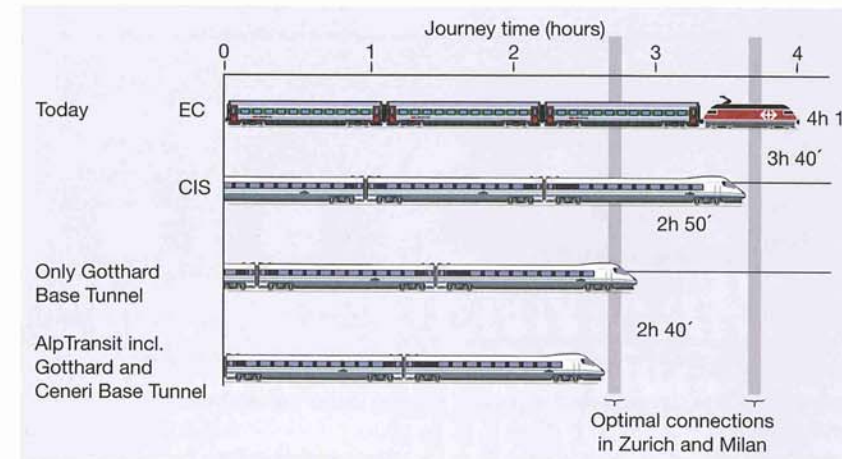
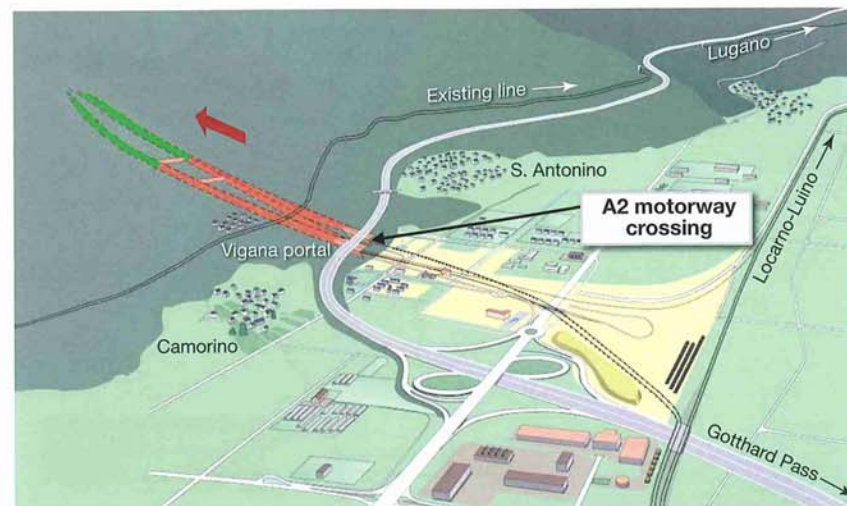
The two parallel adits are now the key access point for much of the work on the tunnel which is being driven in four main drives from a large central cavern. Two other smaller contracts are also underway for difficult portal work at either end, in one case on the north side passing underneath a busy highway and at the other end

forming an access cutting in a relatively crowded residential area.

Preparation work for the drives under an early contract has been underway since 2006, creating site facilities, canteens and offices, a small road network and installing some crushing and spoil sorting plant at the access tunnel entrances and in a small tight area around it. Such are the space constraints that a railway loading and unloading point has to be sited about 1km away. "A conveyor links the railhead with the immediate portal," says Vicentini.

The plant is being used to screen and divide spoil into three categories, A for use in aggregate, B for clean waste which is being disposed of close by, and C for material that has to be removed for alternate disposal.

Unfortunately, says Vicentini, most of the rock is not expected to be good enough for aggregate and there is therefore a need to import material for concrete making. Around 60-80 per cent of the aggregate needs will be supplied from outside, mostly brought in by rail, and conveyed from the offloading point



**Left:** Ceneri and Gotthard together will save one hour on journey times

while the two northward drives are 8.1km. Around 760m more is driven in from the northern portals under a separate contract and another 340m in the south. A 220m long cut and cover artificial tunnel completes the southern end of the project.

So far 11km or just over 28 per cent of the overall 39.8km of tunnel has been driven, mostly on the main drives and including the two Sigorino accesses.

**Early setback**

Unfortunately the early work has brought a tragedy, with a sudden rockfall in September during rockbolting operations. One worker was struck by a large block which fell around 8m from the tunnel roof and despite first aid, he died later in hospital.

No more details have been released as the incident is being investigated by the local Ticino Canton public attorney. AlpTransit says it is not clear yet how it happened.

The southern drives must take a curving path at the end. This is because the tunnel will at first exit to the west of Lugano at Vezia, to link into the existing Swiss-Italian border rail crossing. New high-speed rail links through Lugano will eventually allow a direct connection into the tunnel and for this two blind stub ends for the straight tunnel line will be excavated and left ready for eventual connection.

"Finance has not been agreed for that yet," says Vicentini.

Breakthrough on the southern drives is scheduled for 2016, and somewhat earlier on the northern drives.

Meanwhile, complex work at the portals had already begun before the start of the main drives. Most difficult is the northern portal where the tunnel alignment carries it

to the Sigorino worksite and then into the tunnel. Trucks will bring in cement for concrete mixing inside the tunnel.

To cope with the constraints and for logistical reasons, much of the tunnel material supply, and some spoil crushing, will be done inside the mountain. "It saves space and is better too for delivery," says Vicentini, "because the concrete has less distance to travel and less danger of going off."

Concrete batching plants have been installed in two parallel 20m high caverns, each with a 265m<sup>2</sup> cross-section and interconnected with cross passages.

The passages link the large central caverns in a connected square on plan, for plant movement and to serve also as a central ventilation distribution ring. It is fed by large fans at the end of ducts in the first exploratory tunnel, while the main service tunnel is the exhaust path. Individual tunnel drives draw their air from the central ring.

Forming the caverns was final task for CMC during the construction of the adit, to make way for the Consorzio Condotte Cossi consortium, a joint venture of Condotte D'Acqua and Cossi, which won the main contract for the work in spring last year for CHF 987M (USD 1.05bn).

**Hanging platforms**

When T&T was on site early last autumn the caverns were complete and much of the plant was installed and being commissioned in the caverns.

A first of four Rowa hanging platform support trains was complete for the drill and blast operations on the four drives.

The increasingly widely used Rowa platforms make good sense, says Vicentini, keeping fixed plant like fans and conveyors out of the way in the tunnel's upper section while mobile equipment like loaders, excavators, the explosives transport tanker and drill machines can move freely.

The contractor is using brand new Sandvik 1300 three-boom rigs for the face work and smaller two-boom BT 820 rigs for the cross passages and other incidental work, with spoil crushed and then transport by conveyor. Spoil is moved out by conveyors along the service tunnel.

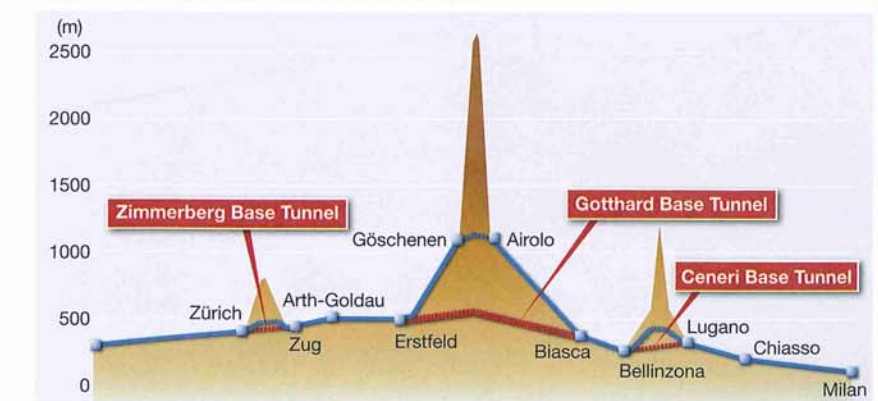
Three of the Rowa platforms were complete in February and a fourth was being bolted into place for the second of the northern drives, bringing the tunnel excavation work to full production level. The heavy duty steel frames can move along suspended rail, supported on chains bolted into the rock wall of the tunnels.

"The two southern drives were set up first because they are on the critical path," says Vicentini "They are not the longest drives at just 6km but there are some anticipated rock difficulties." Environmental constraints under low cover in the southern section will also restrict blasting times, particularly under residential zones, and this will slow progress at the end of the drives.

Two fault zones are expected in the metamorphic gneiss, one fairly early on this year and another later.

The southern drives are each 6km long

**Below:** Cover on Ceneri is up to just over 1km





at a shallow depth underneath the important A2 motorway running along the northern face of the mountain. It is the main autostrada from Gotthard to Lugano and on to Italy.

The contract for the first 760m of each bore is also complicated by an addition to the project. This was made at the insistence of the local canton, which wanted a connection to Locarno for the local trains.

At present they run on the existing mountain line and this traverses the north face on a steep incline which heads towards Bellinzona. The local trains must run on there before taking a connection back to Locarno.

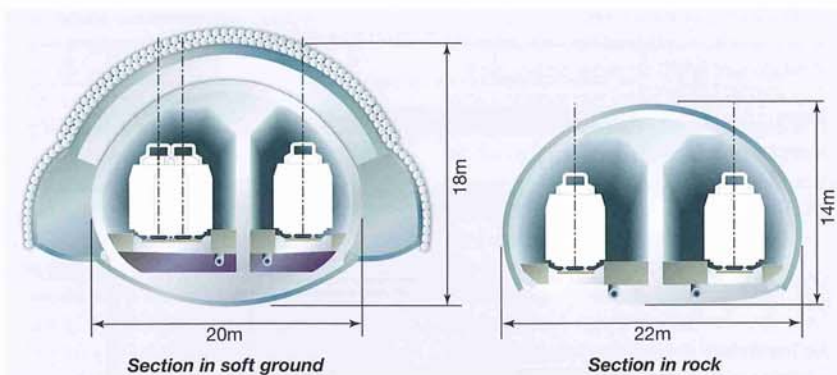
Because of its lower exit level, a curved link can be included outside the Ceneri exit, which allows trains to head directly on to the Locarno route. The additional line enters the new tunnel in one of the two portals, which is doubled up to allow it; the two tracks through the arched entrance are separated by a partition.

Inside the mountain there is also a crossover tunnel between the two bores connecting into a wider cavern area on the other side.

#### Coping with soft ground

Much of the work is in hard rock and can be done by straightforward drill and blast but Contractor Consorzio Matro Sud faced a difficult task getting through first 50m of soft glacial ground when it began in October 2008. It had to drive the two portals just 8m underneath the motorway, an especially difficult job for the wider twin track entrance.

Extensive checks and monitoring were needed for movement on the motorway, which could not be shut down while the tunnel was driven. "The controls were more stringent than normal at the



Above: A very thick lining is needed when passing under the motorway

insistence of the national motorway administration," says Vicentini.

To do the job, the consortium has used a horizontal jetgrouting system to create an arch 'umbrella' in the ground. A double row of 600mm diameter grouted cylinders forms the main arch and this is continued at the side with a single row over the abutment sections.

Within the single row 'umbrella' small side drifts were excavated 6m high and 4m wide at the bottom, with a shotcrete lining. Much of this space was then filled with reinforced concrete to make massive side abutments from which the tunnel's main arch could spring later.

With those made a top heading could be excavated to the level of the abutments using an excavator. To stabilise the face it was reinforced with drilled and grouted passive anchor rods that were then excavated out along with the glacial material.

"With the excavation made it was possible to fit steel reinforcement arches and concrete the thick arch section," says Vicentini. A thinner concrete arch invert completes the excavated section that will finally be given an inner tunnel lining.

Work on the first 30m long section has been done in three overlapping phases. A further 18m section passes through a firmer weathered rock transition zone before the harder gneiss of the mountain. Here grouted steel tubes were sufficient to make the umbrella arch.

There has been some settlement on the motorway during the work, a maximum of 140mm, which has triggered repair work for the carriageway. "The threshold was 120mm," says Vicentini.

Currently the drives are complete in the soft ground and work is proceeding with the rock drives to form the main bores, the crossover passage and the wider cavern sections needed at each end of the crossover (see 3d representation).

Meanwhile in the south, work is complete on forming approach cuttings for the portals and the underground excavation of the first 340m of tunnel has just begun. Apart from a curving alignment this is straightforward enough, but there are severe local community and environmental constraints. The area is part of the well-off Lugano suburbs and sensitivities to vibration are high, which means tight limits on blasting levels and timing for contractor the Consorzio Portale Vezia, which comprises contractors CSC Lugano and Pizzarotti Bellinoza. Work has also had to avoid damage to a classical villa nearby.

Lining work will complete the two portal sections.

Attention is mainly on the central drives however, which will all be in full production by spring on a timetable break through in 2016.

Lining work on the southern drives will begin in 2013 while tunnelling continues but in the northern drives it will wait until excavation is complete in around 2014.

After that comes fit-out of electrical and signalling equipment. But that will be decided later. ■

Above: Central access cavern from which main drives begin



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# Solving Russia's sloping shaft challenge

Tunnels with gradients of 30 degrees used to be uncharted territory for TBM design engineers. But Metrostroy, the company that operates St. Petersburg's subway system was looking for new ways to finally access the deep, so-called 'ghost stations' that were built with no connection to the world on the surface, Herrenknecht presents this report

**S**t. Petersburg is the most northerly city with more than a million inhabitants in the world. Located at the eastern end of the Baltic Sea, on the mouth of the River Neva, its 18 city districts cover an area of 1,431sqkm. It has 300 bridges, 80 museums and 3,500 listed buildings and monuments—enough to earn it a place on the UNESCO list of world heritage sites. But the city is not just one big museum; it is home to over 4.5M people and every day more than half of them use the subway system.

The metro itself is a sight to be seen. Its 63 stations, designed in a wide range of styles, are considered architecturally to be among the most beautiful in the world. The metro is also the world's deepest subway system, lying more than 100m beneath the surface in parts. This is because Russia's second largest city,

established by Tsar Peter the Great in 1703, was built on a swamp.

Tsar Peter's motivation was geopolitical—he wanted to give Russia access to the Baltic Sea. The ground beneath the 42 islands on which St. Petersburg now stands is still challenging for construction projects. Its unstable nature means subway constructors have to build tunnels on the solid mudstone bedrock beneath the city. This is why the five metro lines are located at an average depth of 50 to 75m. This situation not only poses challenges for tunnel construction but also presents unusual problems for the shafts connecting stations to the surface. Three escalators next to each other also make considerable shaft diameters necessary. However the biggest challenge is to install a straight tube with a gradient of 30 degrees in the mainly soft clay ground of the swamp area beneath St. Petersburg.

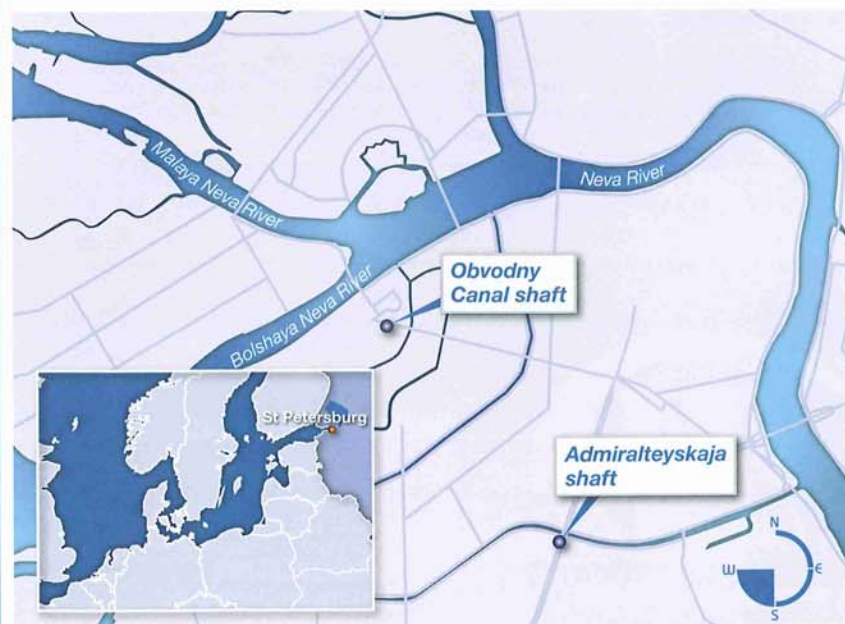
The fact that some of St. Petersburg's metro stations remained without a connection to the surface for years after they had been completed shows the extent of this construction challenge. Conventional construction techniques such as gradual excavation by temporarily freezing the soft ground and the subsequent concrete lining of the tunnel tubes are time consuming and therefore expensive. Such freezing involves considerable risks. One major problem in densely built-up urban areas is that the ground can be subject to heave when it is frozen and subsidence when it thaws. Before now, TBMs able to cope with these very particular conditions were not available.

The new inclined shaft machine, the Herrenknecht-supplied S-441, took just over two months to work its way along a 105m stretch down to the Obvodny Kanal station at a depth of 65m. This station on Line 5 is one of the 'sleeping' stations; people in St. Petersburg have been waiting for it to open for some time. The new canal-side station now finally connects the city's bus station to the metro system. Until now, passengers have had to walk for 20 minutes through the Obvodny Kanal district to reach the Ligovskiy Prospekt metro station, some 1.5km away. This journey time will be considerably reduced following the project.

From the front, this machine looks deceptively like a normal EPB Shield with a diameter of 10.7m. EPB Shields are in their element in cohesive and incohesive soils with high clay and silt content and low water permeability.

However, this new and very specific job required an innovative design engineering

**Left:** The two shaft locations in St Petersburg



approach. The first issue was the comparatively short tunnel route meant the TBM had to be shortened to just 35m, less than a third of the usual length of an EPB Shield with this kind of diameter.



**Above:** A new escalator shaft in the heart of St. Petersburg

approach. The first issue was the comparatively short tunnel route meant the TBM had to be shortened to just 35m, less than a third of the usual length of an EPB Shield with this kind of diameter.

First and foremost, the back-up housing all the internal logistics for everything from the removal of excavated material to the lining of the tunnel had to be completely redesigned. The gradient meant stairs and platforms had to be added for the use of the operating personnel. Plus, the 30-degree gradient caused a particular problem.

Since the centre of gravity of the machine with cutting wheel and drive unit is located towards the front, great downward forces result. To ward off an uncontrolled sinking of the machine or a

## Magnificent metro

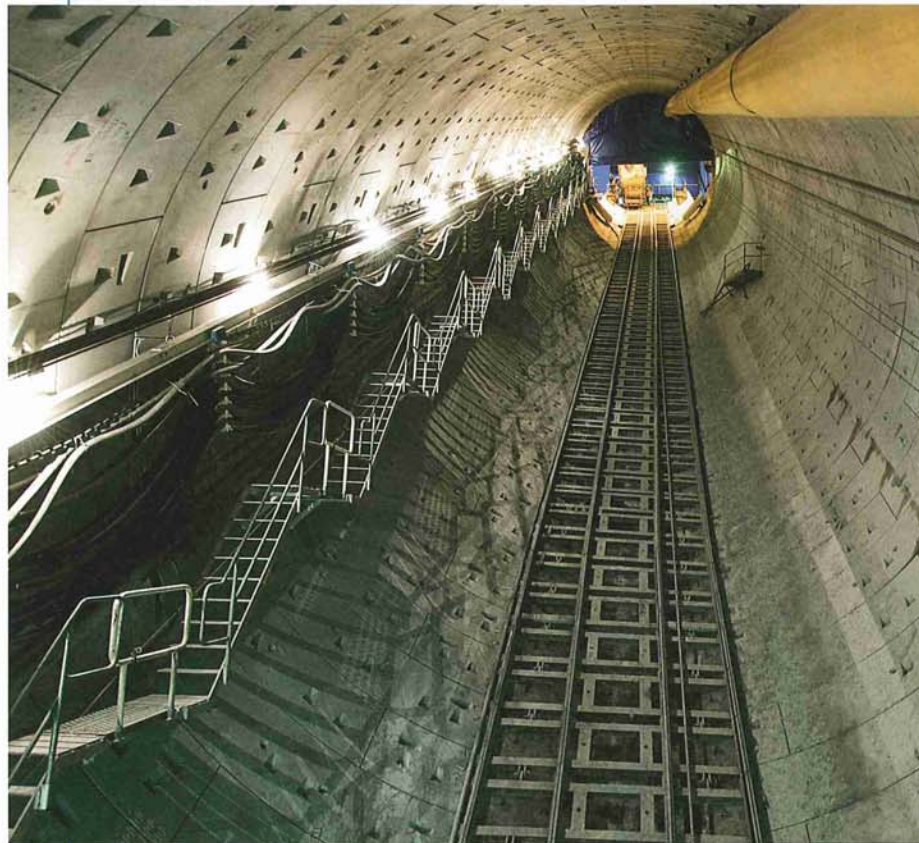
The subway forms the backbone of St. Petersburg's public transport system. Its first line was opened in 1955. Since then, the subway network has grown continuously, although the clayey and swampy ground beneath the city is anything but easy terrain for tunnel constructors. Further subway lines went into operation in 1961, 1967, 1985 and 2008. The relatively long delay in opening the newest line was caused by a simple reason. The dissolution of the Soviet Union and the economic woes that followed meant no funds were available to finance this project. Today, the metro has five lines with a total length of almost 110 km and 63 stations. More than one billion people travel on it every year. St. Petersburg's metro stations are among the most impressive in the world. Their architectural styles range from tsarist grandeur and Art Nouveau to modernist minimalism. Only Moscow's metro stations can compete with them for ostentatious splendor. Tunnel boring machines are currently connecting the 'ghost stations', which passengers currently see as they travel through them without the train stopping.

deviation of its route, a system of traction ropes and hydraulic cylinders was developed to keep the machine on course. Also, the usual conveyor systems for the removal of the excavated material—belts and spoil cars—were completely insufficient. This was solved using winches to raise two rail-bound cars along

controlled routes. On the downward journey, these cars transported the lining segments to the lining segment erector. The lining segments were produced using mould systems supplied by Herrenknecht Formwork.

Starting the machine on a gradient of 30 degrees also required a new approach.





**Left:** The pulling forces had to be calculated precisely and then dealt with: the TBM was pulled downwards by a total of 900 tonnes; **Left, below:** Herrenknecht EPB Shield S-441 constructed for the sloping shaft project in St Petersburg

A shield cradle was used to assemble the TBM at the jobsite in a horizontal position at first. Four hydraulic cylinders were then used to tilt the machine into its 30-degree gradient position. However, since the machine was still 'up in the air' in this position, it needed a number of blind ring supports to push off from until the first lining segments had been installed.

Tunnelling went smoothly with the innovative Schwabau-built machine in the hands of the Metrostroy specialists, achieving rates of up to 4m a day. The machine drove the 105m long tunnel route at an average speed of 1.5 lining rings of 1m each per day. This eclipses the performance of all previously employed procedures and machines.

The final rings were installed before Christmas 2009, after more than two months of tunnelling. The machine had then been dismantled so that it could be reassembled at a new jobsite in St. Petersburg. Only the S-441's shield, with a length of around 8m, remained underground as a final element of the tunnel construction.

A replacement for a new 'sloping' mission has already been delivered and installed. Its next jobsite is in a prominent location—not far from the western end of St. Petersburg's famous shopping street, Nevsky Prospekt. There, below the ground, the completed Admiralteyskaya metro station has been waiting to go into operation for several years. This is where the machine started drilling a further project for the St. Petersburg metro in early 2011, its longest access shaft.

At a depth of 102m below the surface, Admiralteyskaya is the deepest station of the deepest subway system in the world. The access shaft will have a drilling length of 160m.

This explains why the station has been spending so long in hibernation. Until now, no technologically and financially viable solutions could be found to make the connection. The Obvodny Kanal job was the first time that engineers were able to open up a viable possibility for such a mission.

There is also a third job in the planning phase, another sloping shaft in St. Petersburg similar to the previous two.



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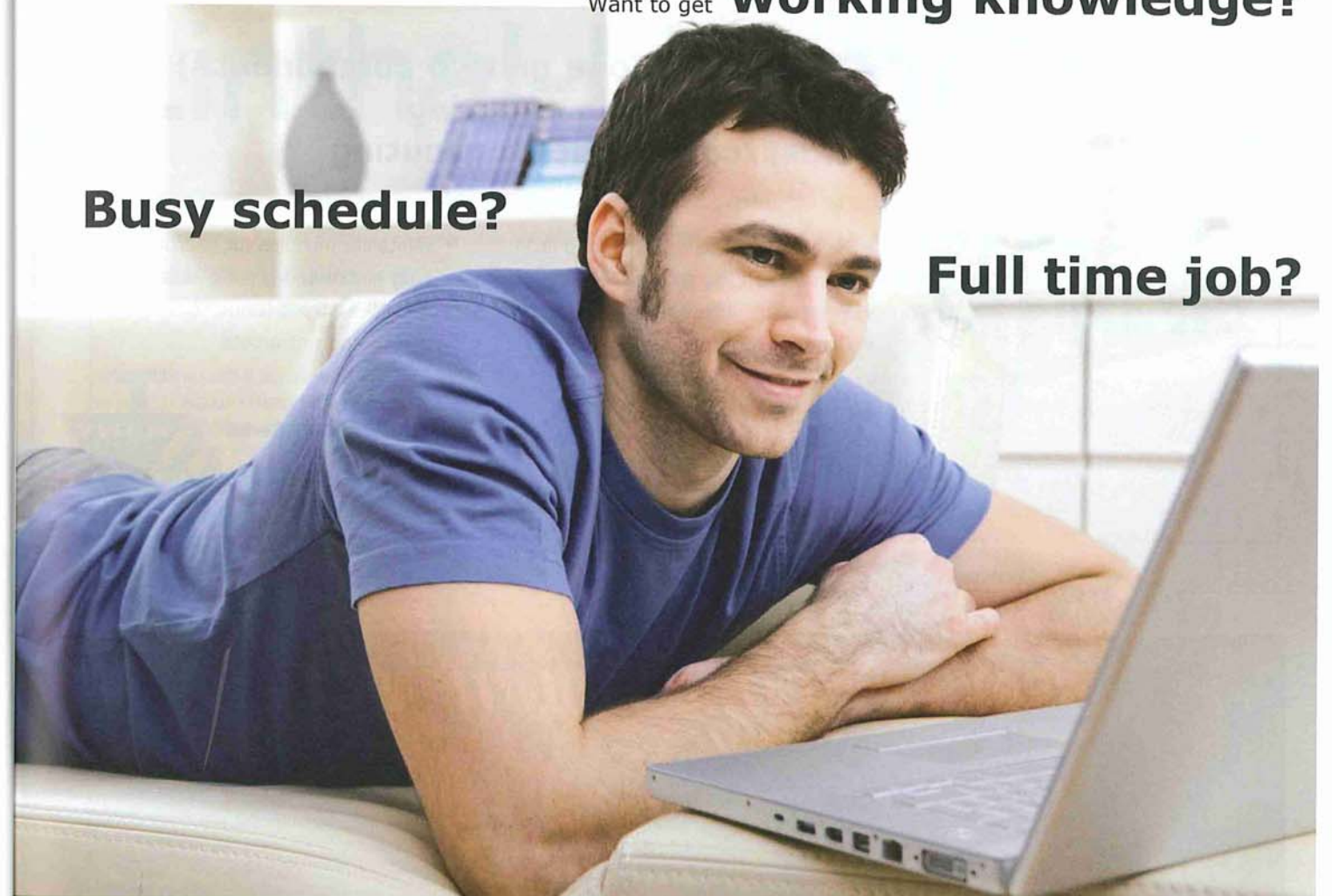
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# Powering up at Linthal-Limmern

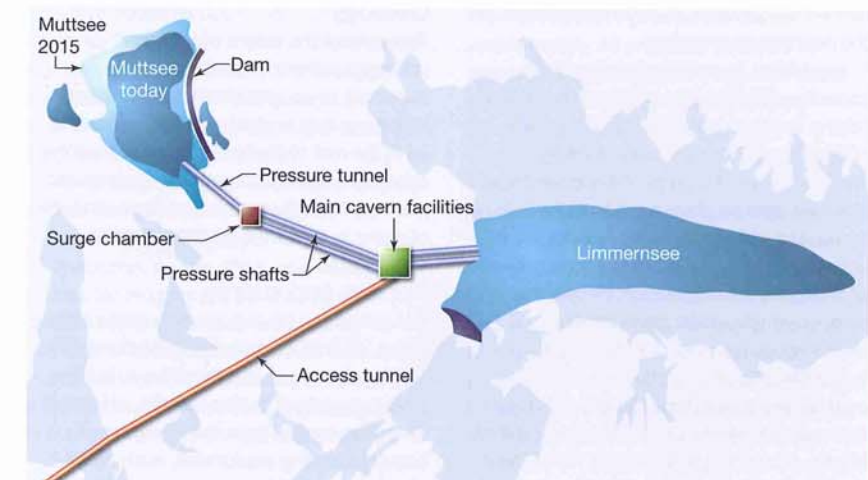
The topography of alpine and similar mountainous areas presents both many challenges and opportunities for tunnelling engineers. Whereas the current focus has naturally been on rail base-tunnels, the business of constructing and expanding hydropower facilities continues apace. Maurice Jones summarises recent developments at the Linthal-Limmern hydropower complex

The USD 2.2bn Linthal 2015 project includes steep TBM drives, drill-and-blast caverns and access drives within a mountain, cable-car access for major supplies, and even the frequent use of helicopters, all within a picturesque area, of course covered in snow in winter, but also with daily falls of up to 200mm in summer. Such conditions present major challenges for design engineers and contractors.

The purpose of Linthal 2015 is to increase the pumped storage capacity of the 450MW Linth-Limmern hydropower complex by 1000MW. Originally constructed between 1957 and 1968 in the Switzerland Canton of Glarus, Linth-Limmern is operated by Kraftwerke Linth-Limmern (KLL), a partnership of Swiss utility group Axpo (85 per cent) and the canton of Glarus (15 per cent). The new plant will be a major facility to increase out KLL's peak-load capacity, at the same time generating more income as the pumping is carried out at lower cost periods. This will supplement Switzerland's usual baseload generating facilities from nuclear and run-of-river hydro plants.

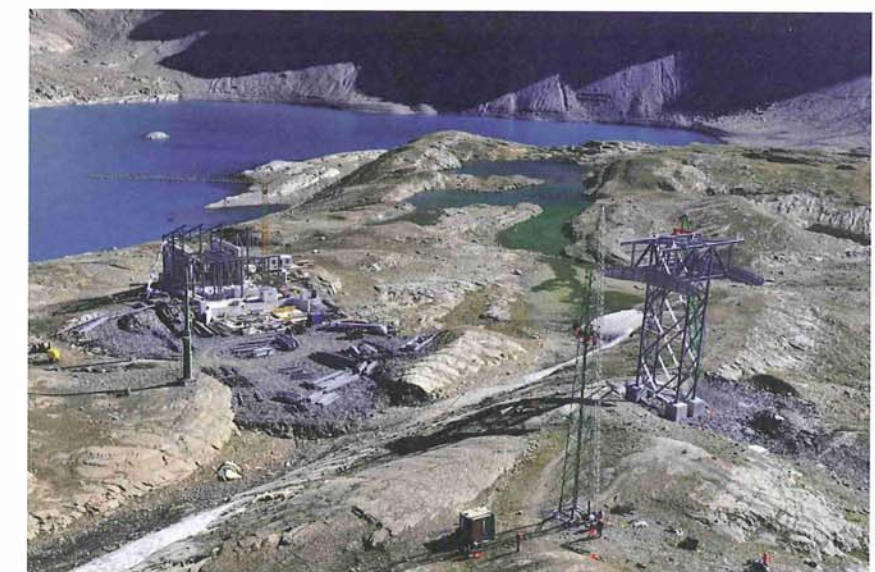
The existing plant comprises four power plant stages between Muttsee and Linthal itself – a difference in elevation of 1800m. The main reservoir capacity is Limmernsee, a dammed reservoir that will also form the low point of the new facility. This holds up to 92M m3 of water.

The new development necessitates the construction of an underground powerhouse, transformer cavern and a balancing chamber, all around 600m inside the mountain, as well as associated access tunnels, two TBM-driven headrace tunnels and two tailrace tunnels. These are situated mainly between two mountain lakes used as reservoirs. The lower Limmernsee is at



Above: Diagrammatic plan of the relationships between the upper Muttsee, lower Limmernsee reservoir and access tunnel under separate contract. (The excavations for the existing power plants are omitted for clarity)

Below: Construction site at Muttsee for the new dam and water intake



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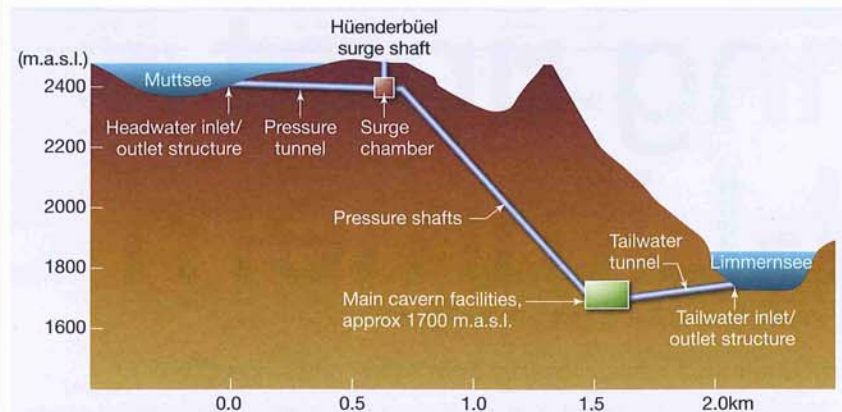
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an elevation of 1700m, from which water is pumped to the Mittsee, about 630m higher. The return of the water under gravity head of 560-709m, through two headrace tunnels will be used to drive the turbines in the new power chamber.

In addition, in order to increase the capacity of Mittsee from 9Mm<sup>3</sup> to 25 Mm<sup>3</sup>, raising the potential head by 28m a new 1000m-long, 35m-high dam is being constructed on the edge of the corrie, whilst there will also be other modifications to both intake and outfall structures at both lakes.

Axpo, which serves around three million of Switzerland's population, has let the work contracts under open tender assessed on bid price and technical capabilities to a consortium of Marti companies, called Arge KW Limmern, for the main power station works. The value of Marti's contract (Lot A) is USD 727M. Arge Zugangstollen (Limmern-AZL) consortium is driving a steep access tunnel to house a funicular railway for permanent access to the new plant. The participants are

**Right:** One of the many rock faces being wired up for blasting seen from an Atlas Copco E2C drill-rig (Photo: AZS)

**Below:** View of the Thierfehnd base supply station from up the Garavanta cableway (Photo: AZS)



Rothpletz, Lienhard & Cie, Wayss & Freytag Ingenieurbau, Barsel, G Lazzarini, Andrea Pitsch and Ragotti+Weber Bau.

### Geology

Throughout the extent of the new underground workings the ground is expected to consist of medium-to-hard limestone that is stable and dry. However, as in the rest of Switzerland, the limestone adopt a karstic structure with caverns and passageways that can allow large amounts of water to flow through the structure.

### Access and supply

Not only does the topography mean access to the 20-odd worksites at elevations up to 2500m above sea level is difficult, but the Linthal area itself is also remote, at least in European terms. Thus the transport of heavy tunnelling equipment, such as 36-t drill rigs and TBM components, and a concrete batching plant, has been difficult.

From the base station, every one of the heavy items of tunnelling and construction

**Left:** Section along to new excavations of Linthal 2015 from Muttsee down to the new power station and water transfer to Limmernsee

equipment has to be carried to its required location by two cableways of up to 40-t capacity using special suspension arrangements or standard containers hanging from the Doppelmayr Garavanta cableways, as well as a passenger cabin on each. These were installed at an early stage in the development of the Linthal 2015 project, from 2007, and, compared to road transport in very difficult conditions, are essential and remarkable in that the 40-t capacity is a world record. The lower one, from Tierfehnd to Chalchtrittli, will be removed once the project is complete. This rises the loads through 1051m over an inclined length of 1922m. The upper cableway runs from Ochsenstafeli to the upper reservoir and dam site at Muttsee. In this case the vertical lift is 596m over an inclined length of 1771m.

The Marti construction consortium also operates the logistics chain, which includes a number of specialised Terberg CC-RT222, 4-wheel-drive Ro-Ro container carriers, and RT (port tractors). Like other equipment they arrived at the Tierfehnd base station for the project. Most, particularly smaller equipment arrives by rail in standard 20-ft (6.1m) containers, so the first duty for the container carriers is to transport the containers from the railhead to the base of the first cableway.

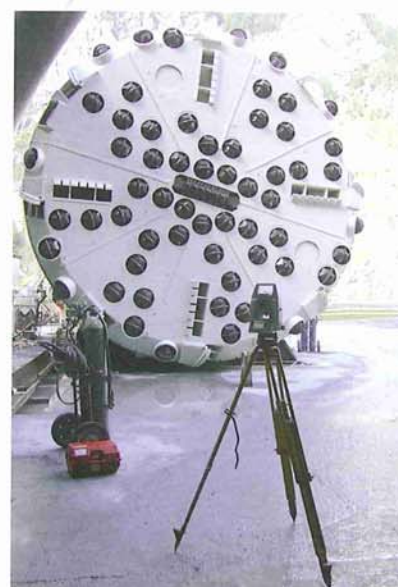
Further up inside and around the mountain the Terberg trucks carry out a number of duties between the cableways and ten different worksites, including



driving through access tunnels. Thus they take the supply containers to where required, open-pan carrying of aggregates from excavation for concrete production, and even containerised Schwing-Stetter concrete mixers that are used to supply sprayed concrete units. The cableway and Terberg containers transport will have to carry an estimated 100,000t of cement and 40,000t of construction steel to where they are required.

Most of the access tunnels, as well as the caverns, are being driven by drill-and-blast using five Atlas Copco drill-rigs. Three of the most recent Boomer E2C design (two drill booms plus basket) using 2238 rock drills, and Marti also has a two-boom 281-1B rig. The fifth rig, an L2C, is rented from Atlas Copco. Within Marti's contract the drill-and-blast tunnels total about 5km in length. Together with the caverns the expected excavation rate is 500-700m<sup>3</sup> daily. Sections range from only 5 to 1000m<sup>2</sup> for the main power station cavern.

Under a separate contract to the Arge Zugangstollen (AZS-Limmern) consortium an 8.03m-diameter Aker Wirth hard-rock TBM is being used to drive a 4km-long access drive inclined upwards at an incline of 24 per cent to rise from 800m ASL at Tierfehnd up to 1800 ASL. This will be used to house a funicular railway for permanent transport to the new installation for maintenance and general operational access, such as to the control centre. The tunnel is being driven up to the main power chamber from, effectively, the 'base station' at Tierfehnd, which is also the location of another KLL hydropower plant. The open double-gripper TBM with double



bracing features a 160m-long back-up system, with anti-slip device, manufactured by Rowa Tunnelling Logistics and weighing 1500t in total. Aker Wirth and Rowa entered into partnership to supply the required equipment assembly.

Aker Wirth says that tunnelling the Limmern will be the largest ever shaft to be completed by a TBM, the previous largest being of 6m diameter. "Aker Wirth's TBMs have been successfully used in inclined shaft projects since the mid-1960s," says CEO Christoph Kleuters.

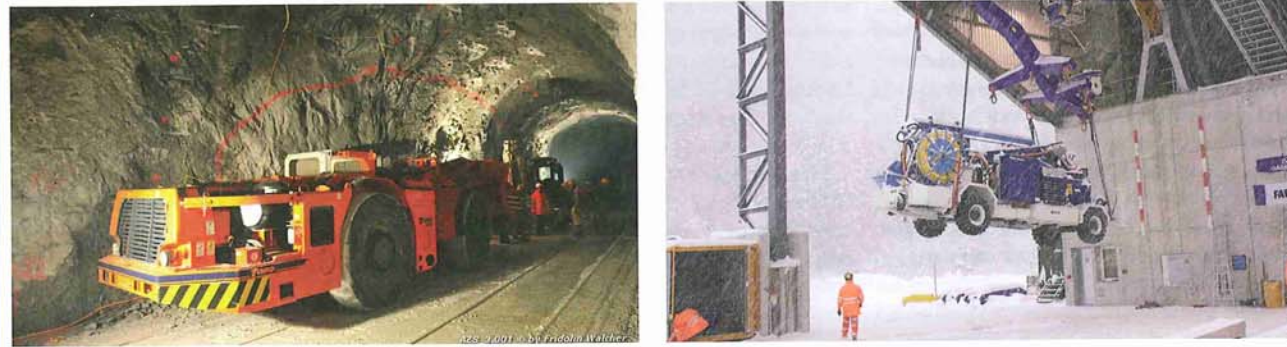
Arge AZS-Linthal construction manager Christian Ris adds, "It has never been possible before to use such a big TBM to excavate such a steep ascending tunnel."

The Aker Wirth TBM and Rowa back-up is required to negotiate a vertical curve of 300m radius to align it with the planned 24 per cent incline. This is aided by the installation of a PPS (Poltinger Precision Systems) TBM guidance system that was fitted and calibrated by PPS on site last September.

Rowa also designed and manufactured a hoist car used to carry supplies to the TBM, and a belt conveyor to remove spoil to the portal. As the TBM progresses, side niches for refuges are excavated by conventional means, as will be a lay-by for the future railway operation half-way along the drive. In a third phase the bore will be lined with cast in situ concrete using the hoist car to supply the concrete mix.

**Below, left:** Arge ZSL's 8.03-m diameter Aker Wirth hard-rock TBM at the village of Thierfehnd in the Linth valley with total station used to sent up the PPS TBM guidance system (Photo: PPS); **Below, right:** Motorised theodolite prisms mounted on the Aker Wirth TBM as part of the PPS guidance system for inclined drive (Photo: PPS)





**Above, left:** One of many wheeled loaders used by Marti on the project, a Sandvik Toro mining-type load-haul-dump vehicle in a cavern excavation (Photo: Fridolin Walcher for AZS); **Above, right:** One Marti's four Meyco Potenza Robojet sprayed concrete applicators beginning its journey in typical alpine conditions by a Garavanta cableway to its work-place

drives. Each is a 5.3m in diameter, and inclined at 40 degrees (87 per cent), thus presenting a major challenge in itself. Although steeply inclined TBM drives have been tackled before, this is the first time that larger-diameter Herrenknecht TBMs have been involved. On such a steep incline there is no room for error, thus placing extra demands for attention on the personnel operating it, and requiring some design adaptations on the TBM itself.

Negotiation of the start of the drives is particularly tricky in that the alignment includes a vertical curve of only 150m radius right at the start of the drive to follow a launch incline of 25 degrees to advance to the main drive's 40-degree incline in the length of only 50m. The length of the TBM and back-up system is 150m.

VMT's role in these drives includes the supply of a special SLS-HR (hard-rock) navigation system. This has not been used on an incline as steep as 40 degrees before. Reference surveying practices have to be adapted to the steep working angles, with the survey team carrying out control measurements that can be referenced by the laser guidance system including co-ordinates in the incline.

The first headrace drive is making good progress it is reported, having advanced 200m since launch in mid-December last year. Completion of the bore is expected around this Easter at a scheduled 22m advance per day, after which the TBM will be dismantled a transferred to the second drive, allowing the first headrace to be lined with steel.

DSD Noell of Germany has won a contract to design, manufacture and install the two penstocks to be installed on the headraces.

#### Tailraces

Like the access tunnels at power station level, the tailrace drives are being

excavated by drill-and-blast. There are two, each 500m long, running from the turbine discharge manifold to Limmensee, acting as a 2-way water passage for pumping and gravity discharge. As the design pressure is low compared to the headraces, now special steel lining is required.

#### Support and concrete

Much of the concrete required in the project is produced using aggregates sourced from the excavations, and an underground batching plant.

Initial support is generally by sprayed concrete using Meyco BASF equipment and concrete mixes featuring BASF Construction Chemicals additives. Two Meyco Potenza mobile spraying units have been used in the main cavern for securing initial support, allowing subsequent decisions on the extent of secondary/permanent support required, if any.

In the headrace drives, the TBM leaves exposed rock that receives immediate sprayed concrete support using a Meyco DM dry-mix spraying machine, and a Meyco Rama 6 spraying arm mounted directly on the Herrenknecht TBM.

In one of the access drives, excavated by drill-and-blast, using another Meyco Potenza unit is being used for primary support. This machine will apply about 60 000m<sup>3</sup> of sprayed concrete including BASF Meyco SA 166 accelerator and also Rheobuild T3 plasticiser to improve handling of the mix.

The underground batching plant also includes a casting facility for production of segments to be used for lining the inclined drive being driven under separate contract by an Aker Wirth TBM for the permanent funicular railway for power station access. Meyco's Glenium ACE 30 hyperplasticiser and MicroAir 302 air-entraining agent are both used in mix preparation in the batching plant for the

casting concrete.

Concrete for spraying is carried to the spraying equipment using the Terberg vehicles mentioned previously carrying containerised Schwing-Stetter concrete mixers to keep the mix agitated.

The fourth Potenza Robojet is being used by Marti around Mast 3 adjacent to the Mutsee for slope stabilisation etc in connection with increasing the capacity of the upper reservoir.

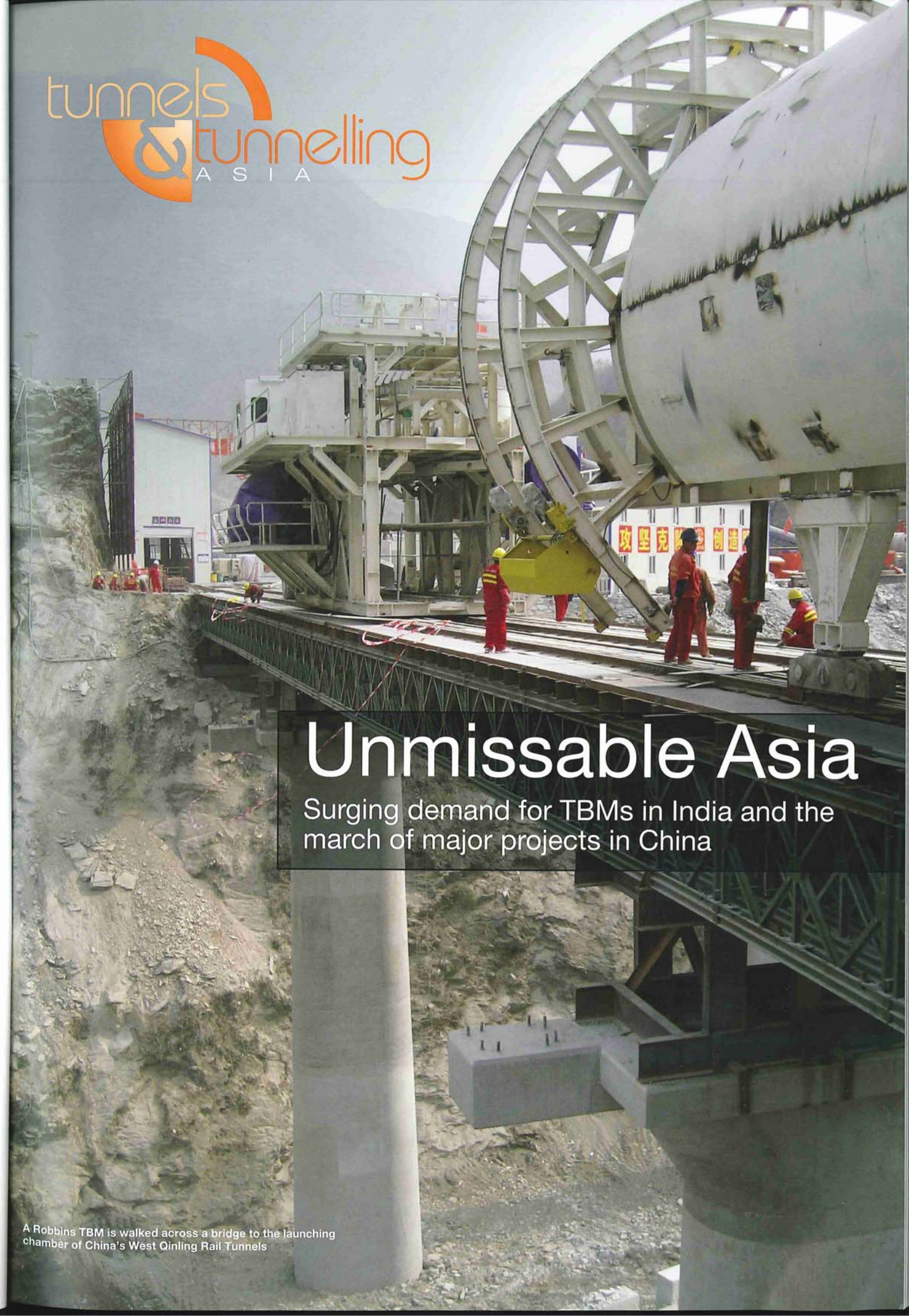
At the lower end of the project Rothpletz Leinhard, part of the Arge ZSL consortium, is using a Meyco Spraymobile together with a Meyco Suprema concrete spraying unit for work around Tierfehd in the valley floor. This is the lower access point for the project and the start-point for the funicular railway drive. Additional wet-process concrete spraying equipment from Meyco is being used on the Aker-Wirth TBM excavating this drive, again for immediate support of the rock exposed by the TBM as with the Herrenknecht headrace bores.

#### Schedule

As it's name suggest, project Linthal 2015 is due for completion in 2015-2016 in two phases. Marti's work began in October 2009. At the end of last year over 1.5km of drill-and-blast tunnels had been completed and both TBMs were in action. The Herrenknecht headrace drives are scheduled for breakthrough by the end of this year, after which lining and support will be completed and penstocks installed for commissioning in 2015 and 2016. ▀

#### Reference

Marclay, R, Hohberg, J-M, John, M, Marcher, J & Fellner, D. 'The new Linth-Limmern hydro-power plant - design of caverns under 500m overburden



# Unmissable Asia

Surging demand for TBMs in India and the march of major projects in China

A Robbins TBM is walked across a bridge to the launching chamber of China's West Qinling Rail Tunnels



## THREE MACHINES, TWO TUNNELS, ONE AIM: FLOOD PROTECTION IN HONG KONG.

A comprehensive flood protection program is being realized in Hong Kong in order to better control the heavy annual rains and typhoons. The program includes building huge sewage tunnels to collect the heavy annual rains and typhoons. The program includes building huge sewage tunnels to collect the masses of rainwater and feed them safely into the sea.

The "Dragages Nishimatsu Joint Venture" relies on Herrenknecht's Double Shield technology for the construction of the "Hong Kong West Drainage Tunnel". The S-486 and S-487 sister machines with diameters of 8.28 and 7.21 meters respectively, have been driving the tunnels since April and June 2009, respectively. On January 17, 2011, breakthrough of the eleven kilometer long tunnel was achieved right on schedule. From 2012 onwards, the West Drainage Tunnel will protect the financial and business center of this huge city against flooding.

The "Lai Chi Kok Transfer Scheme" is planned for completion in 2011. Since March 2010, the "Leighton John Holland Joint Venture" has been excavating the 3.5 kilometer long tunnel with the Herrenknecht S-536 Mixshield. The 5.67 meter diameter TBM has already completed excavating work for the 2.5 kilometer branch tunnel on January 18, 2011.

In future, these tunnels will also be able to provide protection against the storm surges that occur about every 50 years. They will soon contribute significantly to Hong Kong's flood protection system.

### HONG KONG | CHINA

#### PROJECT DATA CONTRACTOR

**S-486, S-487**  
2x Double Shield TBMs  
Diameter: 8,280mm, 7,210mm  
Cutterhead power: 3,150kW, 2,800kW  
Tunnel lengths: 6,640m, 4,360m  
Geology: granite, volcanic rock

Dragages Nishimatsu JV:  
Dragages  
Hong Kong Ltd.,  
Nishimatsu  
Construction Co. Ltd.

#### S-536

Mixshield  
Diameter: 5,670mm  
Cutterhead power: 1,575kW  
Tunnel length: 3,484m  
Geology: fresh granite, granite with varying degrees of weathering

Leighton John Holland JV:  
Leighton Contractors  
Pty. Ltd., John Holland  
Engineering PTY. Ltd.



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## Incredible India: On the cusp of a major TBM upsurge

India arguably has the most potential of any TBM market outside of China, particularly for water diversion, hydroelectric, and metro tunnelling projects. However, the realisation of this TBM potential still requires solutions to some difficult problems.

### Savings through subways

The Indian economy (GDP) is growing at a fast clip of approximately 8-10 per cent per year, which translates to a doubling of the economy every 6-7 years. Despite this growth, one of the major hurdles in the country's development is the lack of infrastructure. Another problem is the fact that India imports more than 80 per cent of its hydrocarbon fuel. This costly practice means that oil imports account for the major expenditure to the national exchequer, or treasury. Good public transportation networks are needed to help keep India's fuel costs down (with the added benefit of decreasing the carbon footprint). Efficient public transportation is essential for India's economy, and therefore metro tunnels in major cities are a definite growth area that will see an uptick in the next several years.

### Mitigating seasonal monsoons

Another hurdle to overcome and to strengthen financial security is weather-based. Approximately 80 per cent of the Indian populace is agrarian, based in thousands of villages spread across the country. Food security and farming is of utmost importance to maintaining the well being of the majority of Indian people. Unfortunately the wellbeing of farmers is linked to the vagaries of the monsoon—a seasonal deluge that has worsened in recent years. Many farmers see this as a dangerous game of 'Russian Roulette'. The consistent supply of water for farming is of absolute necessity and is critical for garnering votes in a democracy. The government has no option but to accelerate irrigation schemes and in effect control the water gift the monsoon provides.

Directing fresh water where it is needed, such as in the arid states of Andhra Pradesh and Madhya Pradesh, is also a challenge. Much of India's fresh water flows over relatively steep gradients into the Arabian Sea and the Bay of Bengal. Dams have been built, but during the monsoons the floodwaters must be disposed of through the gates as reservoirs become full. A logical solution is to



Above: Probe Drilling at Veligonda: Probe drilling operations on a 10m Double Shield TBM for the Veligonda Water Transfer Tunnel in arid Andhra Pradesh state

carry these floodwaters through controlled head gates and tunnels into balancing reservoirs for storage and use in the summer months. Presently, the water has to be fed back to higher elevations for irrigation at huge energy costs through pumped storage networks. Water transfer projects that mitigate these costs, such as the AMR and

Veligonda tunnels that will harness floodwaters from the Srisaillam Reservoir and Krishna River, are another essential step in stabilising Indian infrastructure.

### Training a growing workforce

India has over one billion people and is growing very fast in all demographics. The



Above: AMR Onsite Assembly: India's water transfer projects, such as the AMR tunnels, have the potential to harness the country's floodwaters from seasonal monsoons for irrigation and drinking water



**Above: Sleemanabad Onsite Assembly: India has much tunneling potential, particularly for urban rail tunnels, hydroelectric tunnels, and water transfer tunnels like the Sleemanabad Tunnel Project**

stage is set for a huge surge of either employment or unemployment depending on the country's rate of economic growth. Given the opportunities that the country's growth has so far presented, it is obvious that there will be more young people with tunneling experience from India and China in the coming years than any from the developed world.

It is foreseeable that in the same way that the Channel Tunnel spawned a generation of great tunnel engineers, the massive infrastructure and river linking projects in India will herald the next generation of experts in tunneling. Robbins currently has close to 100km of tunnels in active operation across the country. The experience gained is evident, as we are now sending people trained in India overseas to projects in the East Asian region and beyond. Within 10 to 15 years, I believe most of the high tech labour for mechanised tunneling will be from India and China.

#### Remaining challenges

India's challenges are not unsolvable—they simply require foresight and extra planning by those companies wishing to pursue projects in the Indian market. For example, most of the infrastructure projects in India are government-owned. The mechanism of allotting jobs by public tender has its flaws when it comes to tunnelling, because there are always unknowns in respect to geology. The risk sharing and contractual flexibility seen in many international tunnelling projects have yet to reach Indian shores. This presents a unique dilemma where all those involved know what the problem is, but the 'red tape' prevents people from fixing the problem.

Another issue standing in the way of successful tunnelling projects is financial. When

projects are approved they are based on a financial report that deals with investment and return on investment – which is time-based. Banks charge interest per annum and not per kilometer of tunnel bored. In many cases the choice of the type of TBM to use is based on the notion that 'simultaneous tunnel boring and lining' saves time and cost. This often leads to a choice in tunnel boring machine type that is less than ideal or practical.

Lastly, an obstacle affecting the success of many projects is the lack of experienced workers available for training local personnel.

While training has to date been very successful, it can be difficult to get the most experienced people, who are often from Europe

or the U.S., to work on a project in a developing country. The tunnel industry is seeing an upsurge worldwide, and many of the best tunneling people can get jobs closer to home. Unfortunately, the result is that some of the largest and most difficult projects, which need good people, don't always get them.

It is for these reasons, among others, that TBM projects in India have met with mixed success. With such potential and need for infrastructure, however, India is poised to become the next frontier of tunnelling. More and better infrastructure can only help to aid the country in its planned economic growth.

**Shyam Chengalath,**  
director of Robbins India



**Above: New Delhi Breakthrough: Rapidly expanding population and lack of infrastructure make urban rail tunnels, such as the New Delhi Metro project, of paramount importance**

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**Another Breakthrough:**  
Lai Chi Kok Transfer Scheme, Hong Kong



# Hard and soft for NFM

NFM Technologies/NHI's shields on Yintao water tunnel and Tianjin-Tanggu rail link are facing quite different challenges. Report by Patrick Reynolds

**A**mong the many projects underway in China and being bored by shields from NFM Technologies/NHI, the tubes being excavated for the Yintao water tunnel, in Gansu province, and the rail tunnels near Tianjin, south east of Beijing, face contrasting geological challenges with their quite different lengths and environments.

NFM/NHI has supplied two hard rock shields to Yantao for two consecutive long drives that form only part of the colossal water conveyance scheme, and two slurry machines for separate tunnel works to create an urban link tunnel in Tianjin, and at the east end of the high-speed extension from Tianjin to the district of Tanggu, to the south east and next to the coast.

Geology on the Yantao drives comprises extensive single tube bores through granites and schists and other rocks of varying intact structure and stability, ranging from good to weak, across the rural landscape. The much wider but shorter urban bores at central Tianjin and Tanggu district have to contend with classic alluvial conditions of soft ground and high water tables.

The tunnelling works at the Yantao drives have been underway for much longer than on the city centre rail bores where the Tanggu shield has yet to commence excavation, and will do so as the Tianjin TBM nears completion of its run.

Taken together, the projects help show some of the range, scale and nature of many of the tunnelling schemes underway across the country.

## Yintao water tunnel

The Yintao project is a major water transfer scheme under construction in north west China to improve industrial, urban and agricultural development, especially for growing maize and cotton on irrigated land. It is one of a number of large, state-sponsored projects to strategically share and redeploy water resources from the south to northern areas.

Yintao has two parts to the overall scheme – the Jiudian Gorge Water Control Project and the Water Supply Project, respectively. The latter is being constructed

in two phases and will divert water from the Tao River, a tributary of the Yellow River. Tunnelling for the first phase is underway, and includes 18 tunnels with a total length of almost 97km.

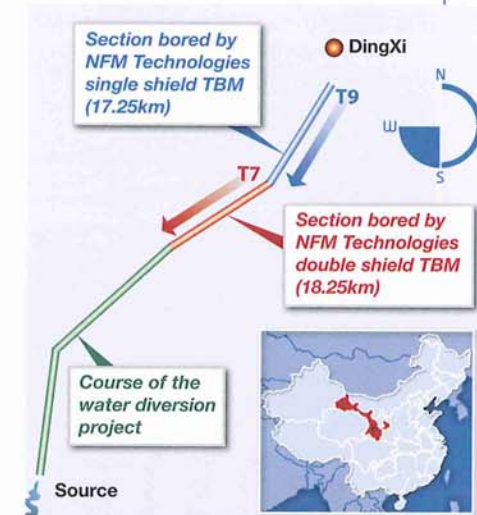
Excavation of the sections of the water transfer tunnel will be mostly by TBM with only a minority by drill and blast. Other major civil engineering structures and works on the scheme include three main canals with combined length of 150km and 12 pipelines totalling more than 113km.

Construction work on the overall Yintao scheme began in 2006 but, for the first phase, excavation of the two drives (T7, T9) at the northern end of the main tunnel alignment commenced in 2009. For the tunnelling works two NFM/NHI hard rock TBMs are being employed, and the contractors are: China Railway Tunnel Group (CRTG), on T7; and, the Chinese-Italian JV contractor CMC Ravena with Sinohydro Engineering Bureau 4, on T9.

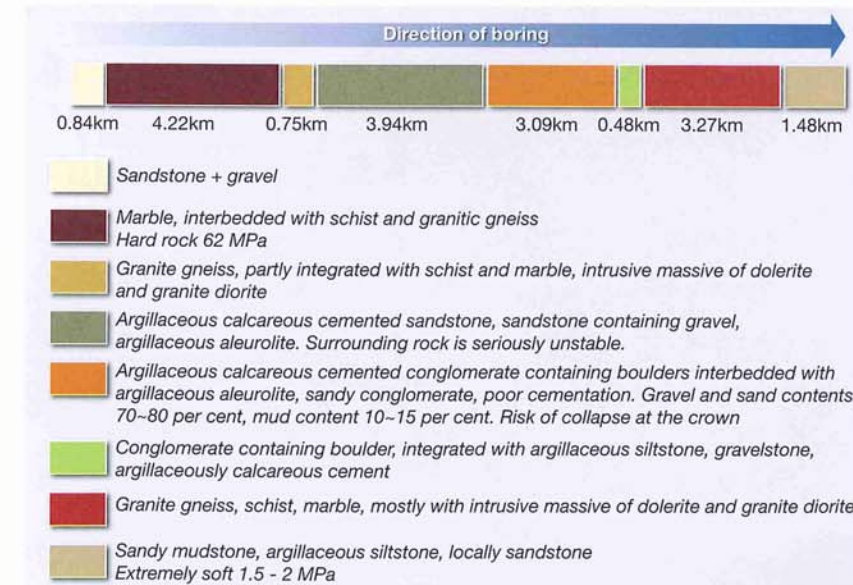
The TBMs are driving comparable lengths of approximately 17-18km and

while they are both 5.75m diameter, and the standard internal diameter of the concrete lining is 4.96m, they are not a pair. One is a short single shield, the other a short double shield – the former arrangement having been elected to help counter potential difficulties with a stretch of squeezing ground along the alignment, which passes through clay and argillite.

Geology on the route of the double shield is mostly rock, comprising silty sandstone



**Right:** Location map of Yintao water tunnel showing T7 and T9 sections; **Below:** Geology along the T9 section on Yintao water tunnel, being bored by double shield NFM/NHI machine

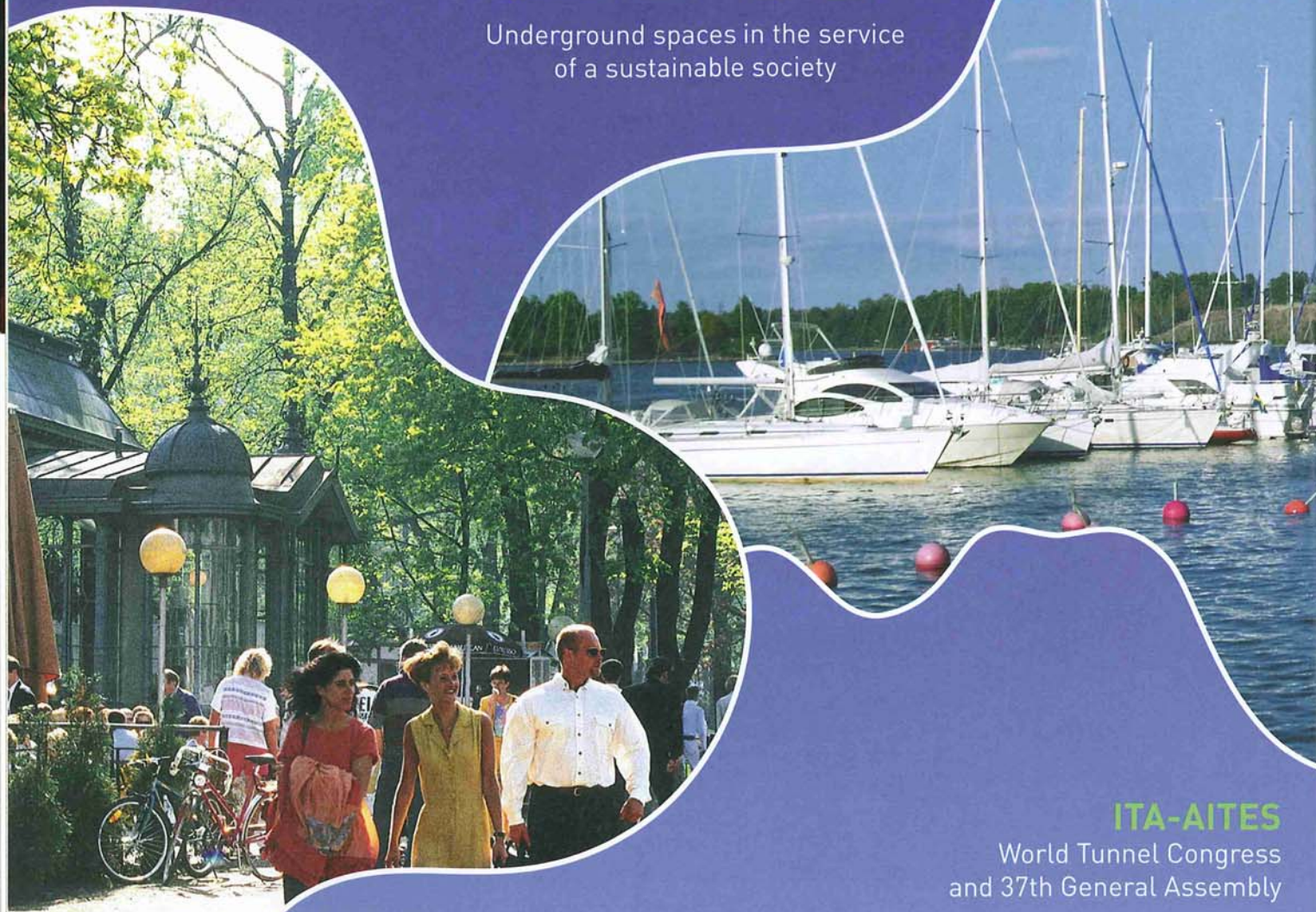


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Scandinavian way

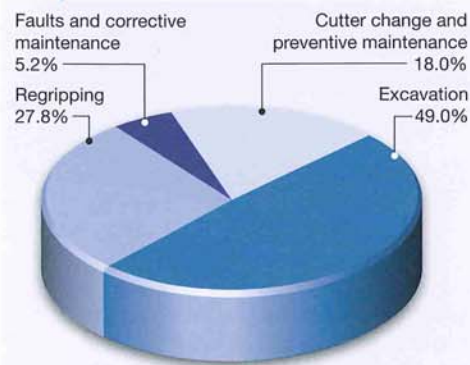
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Left: TBM utilisation on tunnel T9, Yintao project

launched on T9 in February 2010.

On the T9 drive, the double shield has a total thrust of 21,420kN and its nominal and breakout torques are 5,000kNm and 6,350kNm, respectively.

Like the single shield on T7, the rotation speed of the cutterhead is up to 7.9rpm with seven electric motors and the maximum speed of advance is 120mm/min. Their cutterheads are equipped with disc and reamer cutters, and have vertical offsetting of 50mm.

The backup train on T9 has 15 gantries whereas there are two more on T7.

By late April 2010 each machine had bored more than 2.5km, and their best weekly advances had then achieved 252m (T9) and 317m (T7), respectively.

The performance rates on the T9 machine have continued to improve and in September 2010 the best weekly advance reached 434.6m.

By then, the progress rates for the best day and month were 86.7m and 1463.7m, respectively, and achieved in conglomerate with boulders, gravel and sand and some

with granite, gneiss and marble inclusions, with no risk of squeezing conditions. Both TBMs are driving at altitudes of approximately 2200m a.s.l., and cover to the alignments is up to 350m.

#### Tunnelling - Yintao

The two hard rock TBMs were launched just over a year ago, both boring southwards. The machine on the T7 section set off in December 2009 and the double shield was

Below: Hard rock TBM from NFM/NHI for T9 drive of Yintao water tunnel



mud content, more than 10km, or almost 60 per cent, into the 18.25km long drive. The double shield is erecting lining of 1.6m long rings of 280mm thick hexagonal segments, each weighing 5.2 tonne and four to a ring.

Utilisation rates saw 49 per cent of the time in excavation, 27.8 per cent in regripping and 18 per cent dealing with faults and corrective maintenance. Slightly more than 5 per cent of the time was taken by cutter changes and planned maintenance. The TBM is working with an electrode system to scan the ground up to 30m ahead of the face for problem areas as well as suitable sections to help plan maintenance works, says NFM/NHI.

Since then, those best day, week and monthly advance rates remain in place and the TBM had bored a total of 11,542m by mid-February 2011, a year into the drive.

However, the TBM on T7 – having bored 2633m by June last year – has been at a standstill for the last eight months. Details surrounding the stoppage, and plans for the remainder of the drive, were not immediately available.

To date, almost 14.2km of tunnel has been excavated on T7 and T9.



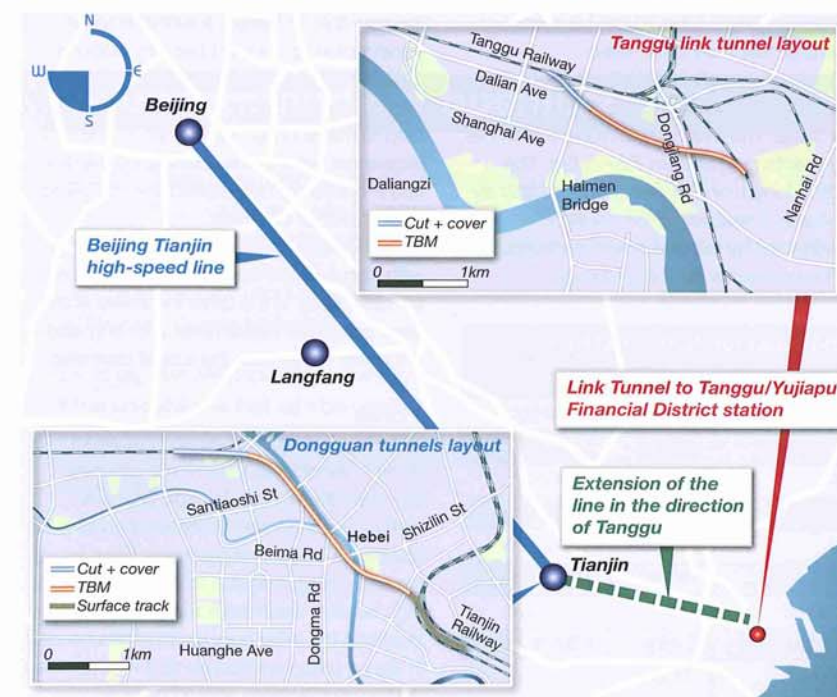
Above: Longitudinal profile of TBM and backup train about to bore T9 section of Yintao; Right: Rail link tunnels in and near Tianjin

#### Tianjin rail link – tunnels

Global financial centres carry ever more weight today and the latest being developed, by China, is in Yujiapu in the Tanggu area of the key city of Tianjin.

Naturally it is attracting significant investment in transport links, one of the key elements of which is extending the high-speed rail line out of Beijing to Tianjin through to the Tanggu and Yujiapu areas.

The main line is designed to have 'Bullet Train' services run faster than 300km/h and came into service two and a half years ago. Once completed, the extended line will allow journeys between the Beijing and Yujiapu in less than an hour. The current, 120km long journey from the capital to Tianjin takes half an hour, and the extension will add a further 60km link between Tianjin and Yujiapu where the trains would travel at





Above: NFM/NHI 11.97m diameter slurry TBM for Tianjin's interconnection tunnel

more moderate speeds.

At the eastern end of the high-speed extension, in Tanggu, to take the link into Yujiapu financial district the line goes into a twin-track, single tube 10.6m i.d. tunnel that runs near the Haihe River.

Geology comprises sand, clay and silt, and the groundwater level is high in the river zone. The overburden along the tunnel alignments ranges from 7.5-15.6m. The 2.25km long tunnel is being built mostly by TBM with a relatively short section constructed by cut and cover methods.

The contractor is China Railway

**Slurry TBM data for Tianjin rail tunnels**

Slurry TBM data for Tianjin rail tunnels

Project for slurry TBMs	Tianjin	Tanggu
Excavating Diameter	11.97m	11.97m
Total Length	57m	63m
Total Weight	1262t	1262t
Total Thrust	140.7MN	140.7MN
Drive Power	1800kW	2030kW
Shield Articulation	None	Passive
Segment Handling	1.8m	1.5m or 1.8m
Lining Diameter	10.6m	10.6m

Construction Corp's (CRCC) Bureau 16.

Separately, towards the western end of the new link, in Tianjin, a tunnel is to be constructed to connect two key stations in the city – Tianjin West and Tianjin. The interconnection tunnel – Dongguan – will help to make Tianjin West station one of the largest rail hubs in the country, connecting into the existing high-speed line to Beijing and a number of others.

The Dongguan tunnel is to be 5km long with about 42 per cent of the length bored by TBM. Early in the drive the shield is to pass below the Haihe River with only about 9m cover – less than the tunnel diameter.

**TBM's**

NFM/NHI have designed and delivered two Benton' Air shields to bore the separate tunnels – the link into Yujiapu financial district and the interconnection between the stations in Tianjin, respectively. The company says that due to the soft ground, high head of water from the groundwater level and the large bore excavations needed in dense urban environments it was decided that slurry machines should be used.

The TBM on the Dongguan tunnel was launched in September 2010 and is due to complete its drive by August this year. NFM/NHI reports that good progress is being made with availability rates high – above 95 per cent since launch.

Excavation of the Tanggu/Yujiapu bore, at the end of the high-speed extension, is scheduled to start in June this year. The TBM will be launched by CRCC slightly west of Tianjin station, on the east bank of the Haihe River, and then pass below to the west bank and run almost parallel to the channel before turning west and rising to finish the drive.

The TBM will have main thrust of 140,700kN, and cutterhead power and speed of 2030kW and up to 2.5rpm. The nominal torque from the cutterhead drive is 17,500kN.m

Concrete lining for the Tanggu/Yujiapu bore is to be formed of 1.5m long rings built from 500mm thick segments.

From the TBM bored section towards, but stopping short of, Tianjin West station the final section of the Dongguan tunnel will be built by cut and cover.

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TEC is involved in challenging international projects such as Busan Geojje 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.

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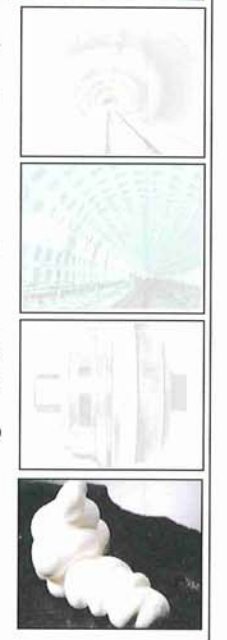


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# Building the Hong Kong Zhuhai Macao Bridge link

Construction work is underway on one of the most ambitious bridge-tunnel links ever attempted. The project is pushing the limits of immersed tube tunnelling and testing the skills of the designers and contractors on the project. This paper is by J.C.W.M. Hans de Wit, of Tunnel Engineering Consultants (TEC), which is supporting the HZMB Administrative Authority on the design, construction, and operation and maintenance of the tunnel and the artificial islands

The Hong Kong – Zhuhai – Macao Bridge (HZMB) link is one of the largest fixed links ever realised. The link comprises various bridges, causeways, artificial islands and tunnels and has a total length of more than 50km. The Main Bridge project covers the main offshore section of the HZMB link of some 30km, crossing the Pearl River Estuary from the border with Hong Kong to the Zhuhai/Macao Boundary Control Facility Island. The link will accommodate a dual carriageway with three traffic lanes in each direction.

To allow the passage of sea going vessels, major cable stayed bridges will be included in the design of the link. The crossing of the main shipping channels at the eastern side of the Pearl River Estuary will be realised using a 6.75km long tunnel, of which approximately 6km will be immersed. The transition from the bridges to the tunnel will be realised with artificial islands with a length of 625m each.

## Geotechnical conditions

The immersed tunnel can be considered as one of the most challenging parts of this project and special in a number of ways. The structural design of the immersed tunnel is determined by various boundary conditions. The seabed level in this area varies between -8m and -15m. Holocene deposits of a thickness from 10-25m are found below the seabed. These soils consist of muck, mucky clay and mucky clay mixed with sand and can be classified as very soft, highly compressible and normally consolidated.

Under the Holocene deposits Late

Right, top: Plan view of the HZMB Link;  
Right: Indicative geotechnical profile

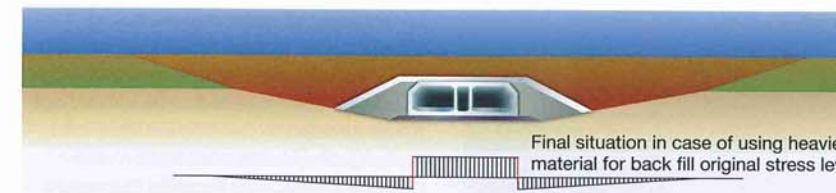
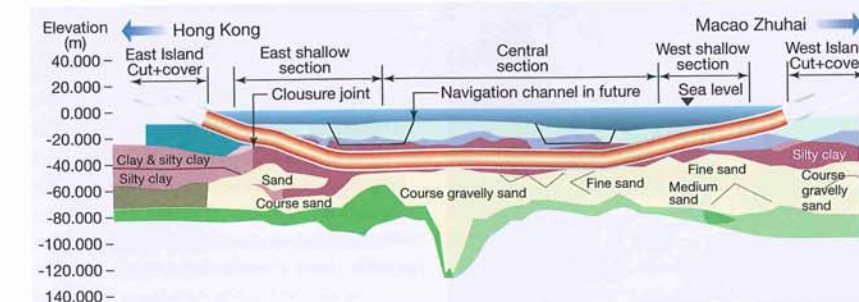
Pleistocenes are found, with a thickness that varies between 37m and 102m locally. The Pleistocene deposits appear to be over consolidated and mainly consist of clay with thin layers of loose to medium dense silty sand, silty clay and sand and gravel. The sand and gravel generally underlay the cohesive soils. Underneath the Pleistocene deposits rock/granite is encountered.

## Structural design

The design of the immersed tube elements that will make up the tunnel when placed in

line on the sea bed has to overcome a number of different challenges. For the HZMB tunnel a number of accidental loads had to be considered, such as:

- Explosion / implosion in one traffic tube
- A sunken ship load representing a general cargo ship
- A fallen anchor load, based upon a 300,000 tonne oil tanker - anchor weight 22 ton, impact velocity 9m/s
- Extreme high water and wave; high tide level with return period of 1000 years
- Seismic events the project area has light to moderate seismic activity



Above: Indicative stress levels at cross section

As the project site is located offshore, the transport and immersion phase of the tunnel elements has to accommodate offshore conditions. The tunnel elements will be built in a construction dock located some 10km from the project site and during the transport and immersion stages adverse wave conditions may be encountered.

For the structural design of the tunnel cross section a number of aspects had to be considered:

- Large spans of 14.55m due to road design with a three-lane dual carriageway
- The tunnel is placed at a deep level of 29m below the lowest design sea level, to allow the future passage of 300,000 tonne oil tankers in two navigation channels with a total width of 2.810m
- As the navigation channels will only be dredged in the future, the immersion trench is allowed to fill with sedimentation up to the existing sea bed level, which means a ground cover that could exceed 20m
- The ground conditions are relatively poor. Time dependent effects of the cohesive soils that are encountered have a significant impact on the tunnel support characteristics. To overcome/reduce these geotechnical complications, ground improvement has to be carried out over a large part of the tunnel alignment
- The fact that the tunnel element must be able to float during transport and immersion stages implies that there are limitations to the structural dimensions as they determine most of the weight of the floating tunnel

For the cross section design the conventional reinforced concrete option was compared with an option with post tensioning in transverse direction (in roof and base slab). Finally it was concluded that the conventional reinforced option was still preferred when considering costs, risks and the execution of the works.

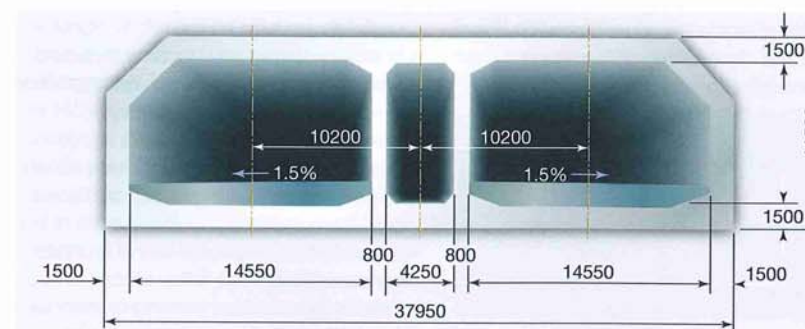
For the longitudinal design of concrete immersed tunnels in general two options can be distinguished: the segmental tunnel and the monolithic tunnel. With a monolithic tunnel the individual tunnel elements are continuous and capable of absorbing normal and shear forces and bending moments. With a segmental tunnel a tunnel element consists of several segments of 20-25m.

In the operation phase the joints between the segments allow for deformations in longitudinal direction and rotations in both the horizontal and vertical plane. Shear keys are provided in the joints to avoid discontinuous displacements over the joints in both horizontal and vertical direction. In order to make the segment joints watertight provisions are required e.g. rubber water stops.

For HZMB tunnel both options were thoroughly studied. A straightforward selection for the longitudinal design was not obvious, since both options have advantages and disadvantages under the given particular project conditions. The following aspects were considered:

- Geotechnical conditions including variation
- Surcharge loads, magnitude and variation
- Accidental loads such as seismic events and sunken ships
- Internal forces: bending moment, shear

Below: Cross Section of tunnel element



- forces etc
- Construction costs

Based upon the various studies, it was concluded that the segmental tunnel was more economical and capable of accommodating the adverse geotechnical and surcharge conditions and impact of the accidental load cases.

The higher costs for the monolithic option were the result of the heavy longitudinal reinforcement, the waterproofing membranes and the shorter feasible maximum length for a tunnel element, which implies a larger number of transport and immersion operations.

For the segmental tunnel the joints are identified as critical items. Shear keys in the outer walls are required to accommodate the impact of variation in tunnel support and surcharge and seismic loads. In the roof and base slab shear keys are applied to absorb the horizontal seismic shear forces. For water tightness purposes a double seal was selected to provide additional safety.

The immersion joint between the different tunnel elements is provided with a traditional Gina and Omega layout for water tightness and with a shear key arrangement similar to the segment joints.

## Foundation design

The structure/soil interaction is one of the governing factors in immersed tunnel design. This includes the foundation bed that is installed between the tunnel structure and the dredged trench and the geotechnical characteristics of the underlying soils.

The foundation bed is required because dredging accuracies generally do not meet the structural limitations related to uneven tunnel support and differential settlements. For the HZMB immersed tunnel the gravel bed was selected as the most appropriate foundation bed and capable of absorbing moderate to heavy seismic events. A gravel bed can be installed in berms and with a high accuracy from a floating barge in advance of the tunnel element immersion.

As indicated, earlier ground treatment is required over a considerable part of the tunnel alignment. The objective of the ground treatment is to improve the foundation conditions for the tunnel. In this way the settlements and differential settlements can be limited and therefore the internal design forces in the tunnel. In addition, ground treatment is applied to promote a smooth transition from one tunnel part (i.e. piled cut and cover tunnel at



Above: Transport and immersion Busan Geoje (Photo Mergor)

the islands) to the other (i.e. immersed tunnel). Two design approaches were adopted for the preliminary design phase of this project:

1) Improvement of the ground properties in terms of strength and stiffness and to increase the uniform behaviour of the ground.

- Replacement of soft soils by mean of sandy gravels or gravel
- Settlement reduction piles in soft cohesive layers with no end bearing!
- Sand compaction piles

2) Foundation piles on bearing ground layers in case the ground is too weak or too unpredictable, such as close to the artificial islands where large reclamations are carried out.

In the next phase of design, the detailed design, an extensive soil investigation is planned that is supposed to provide a better insight of the soil profile and properties. This will make it possible to better assess the risks involved and introduce design optimizations, where relevant.

**Transport and immersion**

The immersed length consists of 33 tunnel elements, of which most have a



Above: Settlement reduction

length of 180m. With the cross sectional dimensions of 11.5m by 37.95m the elements will become the largest concrete tunnel elements in the world. The offshore transport and immersions stages are essential for the tunnel element design and challenging from a risk point of view. This, among others, includes the selection of the tunnel element production location and the design wave and wind climate conditions.

The location of the production facility of tunnel elements is very important since the transport distance and the possible wave and wind conditions are governing the design in terms of feasibility, risk and construction costs. From the potential locations that have been studied, Guishan Island, approximately 10km from the project location, appeared to be the most favourable.

For the transport and immersion design of the immersed tunnel elements the design forces during the various stages (bending and torsional moments, shear and normal forces) have to be determined and the stability of the floating body has to be considered.

As there is a large dependency on the shape and dimensions of the tunnel elements, the local wave and wind

conditions, the water depths during transport and at the immersion location and as dynamic influences are involved, detailed studies needed to be carried out. It was decided to develop an advanced numerical model in combination with physical model test. By using the results of the physical model tests the numerical models can be validated and used for various parametric studies (e.g. variation in wave conditions) and alternative execution stages.

Developing an optimal transport and immersion design means that a balance needs to be obtained between structural capacity (quality), acceptable risks and costs. A tunnel element that is required to accommodate practically all wave and weather conditions may be structurally not feasible or extremely costly. Therefore a design philosophy will be applied in which a decision model based upon a wave forecast system is used, where numerous wave data are collected.

With these data and the weather forecast a go or no go decision can be made for every transport and immersion operation, thus limiting risks and enabling design optimisations. This approach was successfully applied at Busan Geoje in South Korea.

**Artificial Islands and transition to tunnel**

In the HZMB Link the transition between the bridges and the immersed tunnel will be realised by means of an artificial island. The islands are approximately 625m long and 160m wide. The technical service building for the tunnel will be located on the islands.

As for the tunnel, the geotechnical conditions for the construction of the artificial island are not very favourable. As large land reclamations and extensive back fill operations are involved, the geotechnical design is quite delicate in order to meet the settlement requirements that were defined. Therefore the following concept has been developed:

- Excavate soft top layers of mud
- Install sand compaction piles to improve underlying cohesive layers
- In fill with coarse sand to be compacted
- Form sea defence walls consisting of rock layers and revetments of doloses
- Install circular sheet piled walls as retaining structures for the cut and cover tunnels (locally serving as part of the sea defence in the final phase)
- Construct cut and cover tunnel founded on bored piles
- Finishing works

The interface area between the artificial islands and tunnel is very complex from a geotechnical point of view. Large land reclamations in combination with ground improvements (artificial islands) are carried out close to large excavations with ground improvements (trench excavation of the tunnel) but scheduled in different periods of the project program but with a considerable mutual and subject to time dependent behaviour. Complicated time dependent 3D geotechnical processes will take place in the sub ground. The prediction of these processes is difficult even with state of the art 3D geotechnical FE models. And however the immersed tunnel is capable to deal with differential settlements, it was decided to apply robust design solutions in which a smooth transition from the island cut and cover tunnel section to the immersed tunnel section is implemented. This involves:

- A cut and cover tunnel founded on bored piles in / on the deep rock.
- The first elements of the immersed sections will be founded on steel piles penetrating the bearing sand layers (above the rock)
- Adjacent immersed tunnel section will be direct founded, however, the soft soils will be treated with settlement reducing measures such as settlement reduction piles or sand replacement
- The middle part of the immersed tunnel will be direct founded on the sub ground

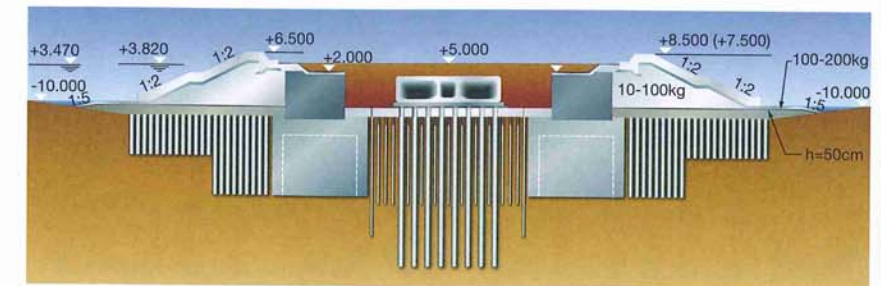
For the detailed design phase it has been advised to develop a state of the art 3D FE model in which the transition area is considered, taking into account the various construction stages. This model is supposed to be verified and validated by means of an extensive monitoring program during construction. This will enable the Designer to make more reliable predictions with the progress of the works and to adjust or optimize the design where relevant and possible.

**Various items**

**Tunnel safety / tunnel ventilation**

The length of the sub-sea tunnel, which stands at over 6km, poses specific challenges while considering tunnel safety. The HZMB needs an integrated safety concept for the whole of the project, and specifically so for the immersed tunnel.

Ventilation principle in operational phase and in case of a fire to the structural element, such as the tunnel, but also to all other elements within the system, such as measures to prevent accidents as much as possible (alignment, design speed,



Above: Typical cross section of artificial island and cut and cover tunnel

sightlines), monitoring and detection measures in case of an accident (fire detection, cameras etc), measures to control accidents (ventilation, sprinkler system, emergency posts, traffic management etc.), escape ways and strategies (safe haven, self rescue principle) and the tunnel operations, that for example include the emergency response procedures.

Tunnel ventilation is an essential item of the tunnel installations design when it comes to health and safety in the operational phase and regarding incident control. A ventilation concept has been selected with longitudinal ventilation in the operational phase (jet fans supported by natural ventilation induced by the piston effect and enhanced by the traffic).

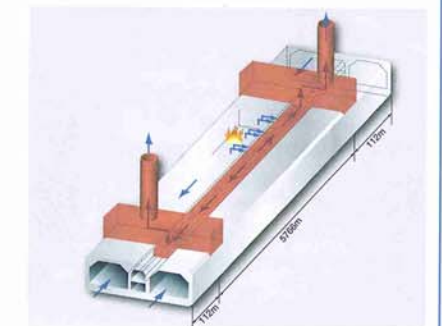
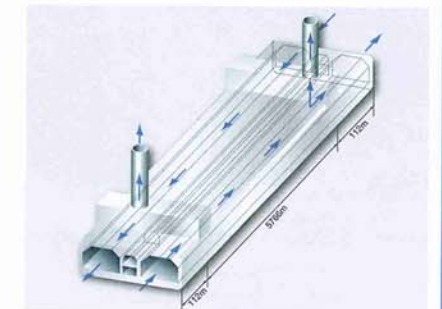
In case of a fire a parallel smoke extraction system will be activated using a semi transverse ventilation system including a separate smoke extraction cell located above the escape cell combined with an additional system like a foam mist fire extinguishing system or a sprinkler system.

**Durability**

The design service life of main work of this project is 120 years, which is the first ever specified for such extended period for infrastructure in mainland China. In addition the HZMB project is located in a marine and very corrosive environment. Therefore specially dedicated durability design criterion that include crack control criterion and concrete production technology have been made for this project. Use has been made of field experience and of Codes from Europe and America.

As part of the HZMB Main Bridge project, special durability related studies have been carried out that used the European DURACRETE and FIB 'Model code' as their bases.

Even though the design has produced a configuration that will meet the 120 year life time, it is obvious that the actual life time expectancy will also be created during the construction stage.



Above: Ventilation in principle operation phase (top) and in case of fire (bottom)

Inadequate concrete compaction, reinforcement designs that hamper the flow of concrete, offspecification concrete mixes, all contribute to sub-design life time expectancy.

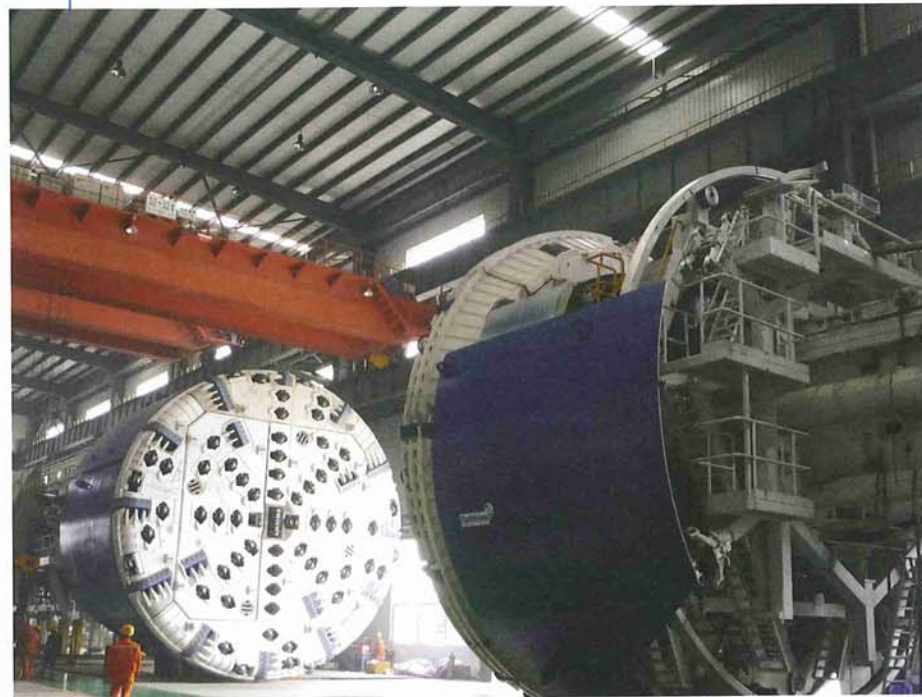
A good tunnel inspection and maintenance strategy is undeniable an essential part of the durability strategy of this project. Therefore the inspection and maintenance strategy of this project should embody the full service lifetime concept to guide the design. During the preliminary design phase, the designs have been verified against accessibility, inspectability, maintainability and replaceability.

For permanent works, i.e. those that are not replaceable, the design should meet 120-year design life while for others a shorter design life period could be used where the element should be replaced; i.e. depending on the optimal life cycle cost solution. ▀





# Coping with Chinese hard rock



In China's Gansu Province and its mega-city Chongqing, ground support systems for main beam TBMs have been adapted to boost advance rates in extremely poor ground, John McKenna reports

**T**he grand scale of China and everything that it does has become an axiom for our times. If its economic growth falls below double digits, the rest of the world panics about another recession.

Much of this growth is underpinned by substantial investment in domestic infrastructure, especially since its 2008 stimulus package provided USD 586bn for new projects.

Rail and metro lines feature prominently among the projects currently under construction in the People's Republic, and US-based TBM manufacturer Robbins has its machines deployed at multiple sites across the country.

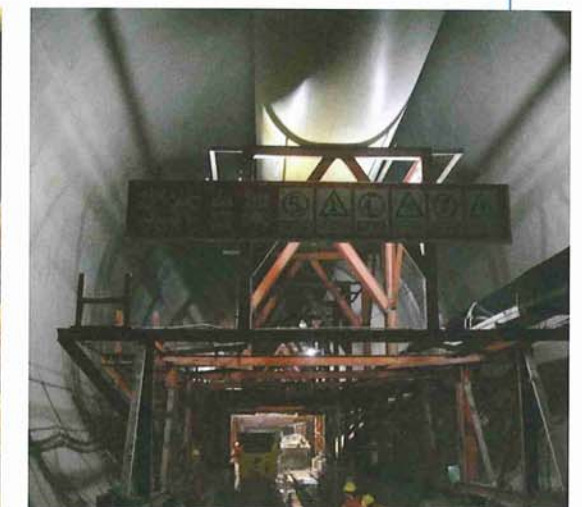
While most of the machines are making their way through soft ground conditions, Robbins does have four main beam TBMs boring through hard rock.

These four TBMs are deployed on two projects with scales befitting China's role as a modern behemoth:

- The excavation of twin 12km long tunnels for the first phase of Chongqing's metro Line 6, one of three lines under construction in this mega city of 35 million people.

**Left, top:** Two 10.2m diameter Robbins Main Beam TBMs with newly designed ground support systems were designed for China's West Qinling Rail Tunnels;

**Left, bottom:** The Robbins machines were launched on parallel 16.6km tunnels at China's high cover West Qinling project in Spring 2010



**Above, left:** Both Robbins machines were walked into 2,000m launch chambers, with the back-up and muck haulage systems starting from bridges across a deep valley; **Above, middle:** Ground support in the high cover tunnels consists of ring beams, wire mesh, and rock bolts, with the McNally support system optional in unstable ground; **Above, right:** Final lining with concrete is taking place behind both Robbins TBMs at West Qinling

- The boring of twin 16.6km tunnels in West Qinling, Gansu Province, as part of an USD 11.5bn railway that will link the province's capital Lanzhou with Chongqing.

The Chongqing Metro Line 6 tunnels were the first new lines to be excavated for the city's metro system, which is planned to include a network of nine rail routes and approximately 30km of tunnels excavated by both TBM and drill and blast.

The routes will be both above and below ground to accommodate the hilly terrain of the city.

Excavating the Line 6 tunnels are two 6.4m diameter Robbins Main Beam TBMs, launched in winter 2009-2010. The two machines are boring under sections of very low cover ranging from 10 to 60m in

sandstone from 12 to 50 MPa UCS.

As of December 2010 the machines were 6,664m into their twin drives and were stopped at the site of the fifth station (there will be 11 underground stations in total). Work on the station is still underway, and the machines are expected to start up again in March.

The machines have been achieving advance rates of up to 47m per day, and one machine has achieved a best month of 1,148m.

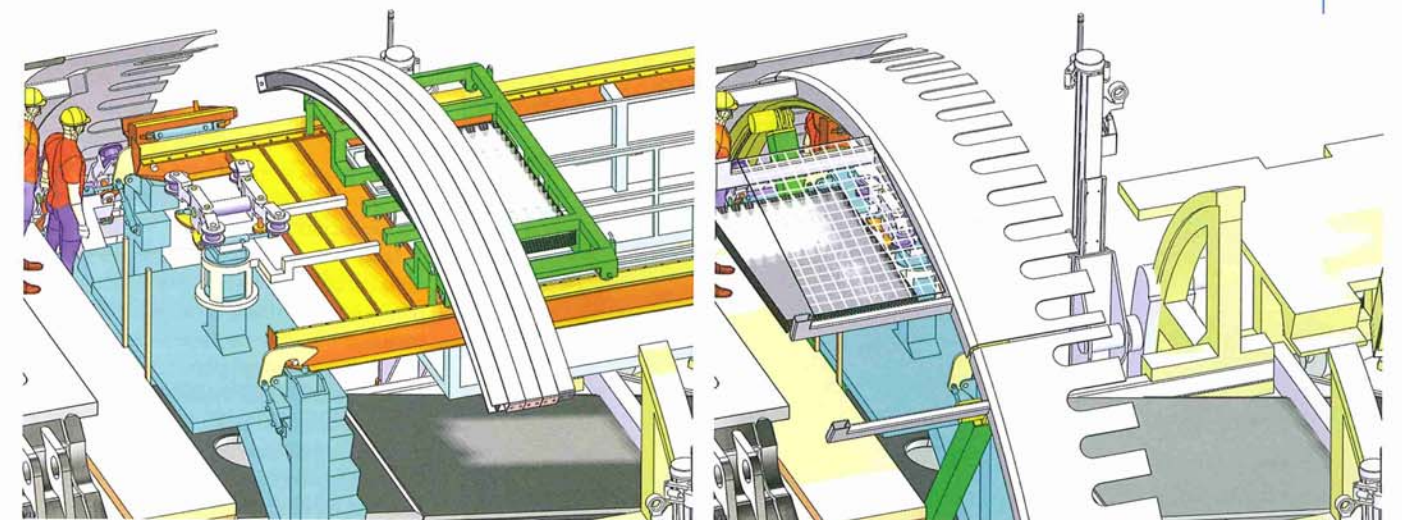
On the West Qinling scheme, being built by contractor China Railways 18th Bureau, the new railway will shorten transport times

from 17.5 hours to 6.5 hours and enable an annual freight capacity of 100Mt. Trains will run on the double track lines at 160 km per hour, with a 50-train daily maximum. The entire railway is expected to open to traffic in 2014.

Two 10.2m diameter Robbins Main Beam TBMs are excavating 16.6km long tunnels from parallel launch chambers just 40m apart, with their back-up and muck haulage systems starting from bridges across a deep valley.

The jobsites are located on the lower reaches of Qinling Mountain, about 1,000m above sea level.

**Below, left:** Ground support on the Robbins Main Beam TBMs at West Qinling foregoes roof shield fingers for mesh installation windows in the roof shield and streamlined materials handling on an automated cart; **Below, right:** Workers can install mesh panels into the tunnel crown from below the safety of the roof shield





Each machine has advanced just over 2km, with an advance rate of up to 423m per month.

**Difficult ground**

Both projects for the most part use ground support methods traditionally associated with main beam TBMs: on Chongqing ring beams are being placed every 1.5m in soft sandstone and mudstone rock, along with a layer of shotcrete 100mm thick.

Though the sandstone is abrasive, and can wear the tips of the disc cutters to a



point, the 19-in disc cutters on the machine have experienced relatively little wear. Each machine is going through about four cutters per month.

However, on both schemes, and West Qinling in particular, the contractor was concerned that it would encounter some extremely difficult ground conditions.

Ground in the West Qinling tunnels consists of 30 to 80 MPa UCS sandstone and phyllite rock beneath more than 1,400m of cover. Broken, fractured rock is expected in a 915m wide section of tunnel, with three large faults specifically identified. The faults, ranging in width from 190m to 310m in width, consist of fragmented limestone and sandstone with gravels and breccias. Some ground water and karstic features are also expected during the tunnel drives.

**Left:** The McNally System, which involves steel or wood slats being installed to hold back unstable ground, can be used on the Robbins TBMs at both West Qinling and Chongqing Metro; **Below:** Two 6.4m diameter Robbins Main Beam TBMs are currently excavating China's Chongqing Metro Line 6, following their March 2010 launch



The solution was that on both projects the TBMs were supplied without finger shields.

Instead, there is a roof shield canopy containing mesh windows, for installation by workers under the safety of the shield structure.

Mesh windows, installed in the roof shield, allow workers to slide panels of steel mesh in the annular space between the shield and the tunnel crown from the safety of the shield structure. The panels are then pinned or secured with rock bolts. Traditional ground support includes no specific provisions for mesh installation and little cover from falling rock.

High cover tunnels such as West Qinling are host to a range of problems from squeezing ground to falling rock. In cases of severely unstable ground, tunnelling is hindered by structures such as the finger shield. The structures allow the rock to fall several millimetres before they are stopped, creating substantial problems with bolting back the falling rock.

In addition to the mesh and rock bolts, ring beams have been installed every 180 to 900mm, depending on the severity of ground conditions.

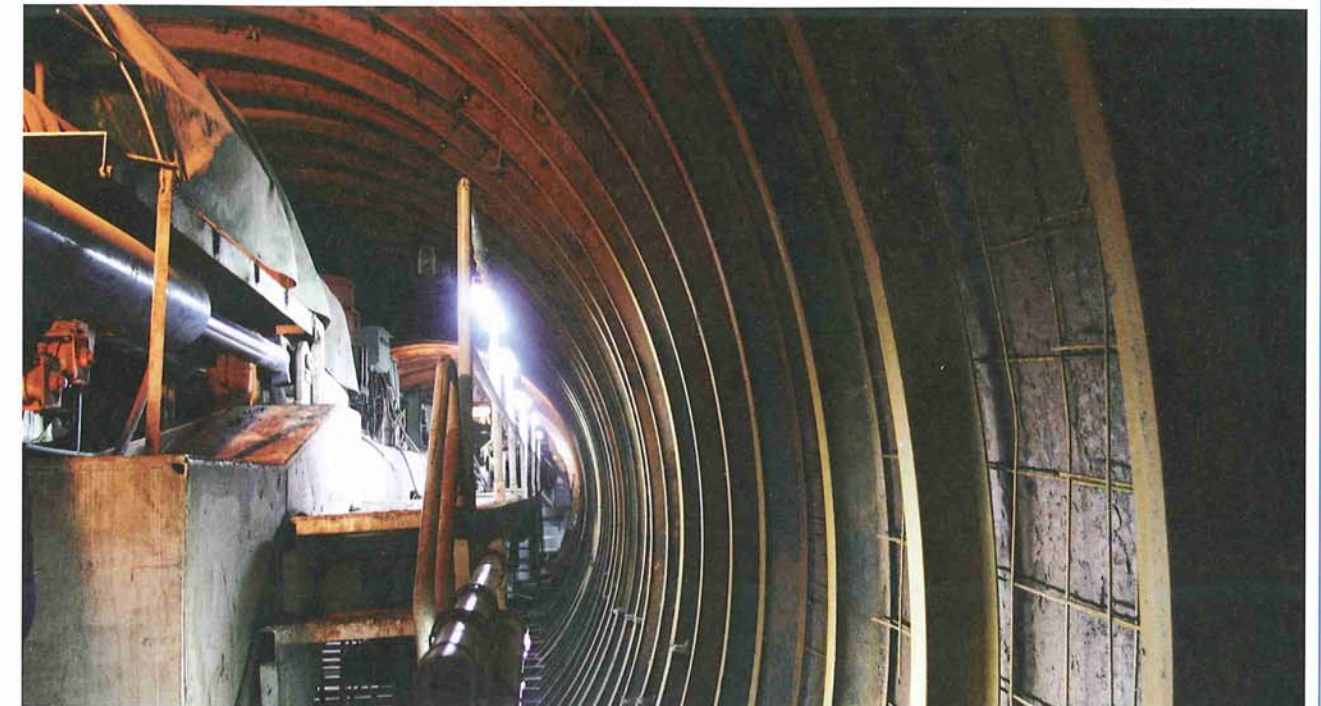
Ring beams are installed using an erector consisting of the assembly ring and expander. The rotating assembly ring is fixed axially and used to loosely assemble five ring beam components. Once the components are loosely assembled and pinned to the assembly ring, the expander, which moves fore and aft, expands the components to a preset pressure against the tunnel wall.

A sixth Dutchman piece is installed in the resulting space, and the ring beam with tightened connections is bolted to the tunnel wall. The assembly and expander can also be easily converted for installation of steel straps, rather than full rings.

In addition to the rock bolts, mesh and ring beams, the contractor opted to also install a 300mm thick continuous concrete lining for the length of each tunnel.

Both tunnels have commenced lining works, which consist of nailing a waterproofing membrane to the tunnel walls, followed by a 120m long concrete pour.

Ground support components are loaded onto the back-up using a crane, and placed onto a carriage riding on an electric transport car. The carriage is designed to hold a stack of mesh panels, ring beams, rock bolts and other materials. The remotely operated trolley carriage transports the materials to a rack located in front of the ring beam guide rollers where they can be easily placed.



**McNally System**

Should extremely poor ground be encountered, the mesh windows can be relatively easily modified to use the McNally Support System, patented by C&M McNally Engineering of Toronto, Ontario, Canada for exclusive use with Robbins TBMs. The McNally System utilises steel or wood slats to provide continuous support along the roof area of the tunnel, protecting workers from falling rock. Crews would bolt McNally pockets inside the mesh pocket structures, allowing a space to slide short slats of steel or wood into the area where roof drills can operate.

"By capturing the loose rocks that other systems allow to fall, we created a circular arch that was otherwise unavailable," says Mike McNally, the man behind the system.

"The difference is that you can't tighten a rock support system against rock using finger shield because the fingers are in the way."

Being able to tighten rock bolts while loose rocks are still held up by the shield or metal slats traps those rocks that may have otherwise fallen. It leads McNally to make a bold claim.

"[The system] pretty much makes shotcrete unnecessary," he says.

"Our slat drillage is an alternative membrane to shotcrete."

Despite this claim, shotcrete is still being employed on both West Qinling and Chongqing Metro Line 6, for reasons which Robbins Far East Operations vice president Biyue Li says are purely financial.

**Above:** Current ground support in the Chongqing Metro tunnels includes ring beams, rock bolts, and wire mesh, but the two Robbins TBMs can utilise a modified version of the McNally roof support system if unstable ground is encountered

"The McNally system has been technically well accepted, but on Chongqing it has yet to be used," he says.

"When operating, the system requires a lot of rebar to be put into the pockets, which can become expensive. The Chinese contractors do not want to use it unless they have to."

At West Qinling, where unstable ground is far more likely, the system has been used, but sparingly so as the machines are only 2km in to their 12km drive and the cover is still relatively low: 250 to 300m.

McNally came up with the system when working on a combined sewer overflow tunnel in Toronto in 2000, and it has been used on numerous projects in Canada since. The first time it was used outside Canada was in 2007 on the Olmos Trans-Andean tunnel in Peru.

"I am certainly a proponent of the McNally system," says Dean Brox of tunnelling consultant Hatch Mott MacDonald, who worked on the Olmos tunnel project.

"The system can be easily modified to comprise different capacity support components, making it ideal for varying rock conditions. In shallow tunnels with horizontal geology, for example, the system can comprise relatively low capacity support components that are easy to install. For deep tunnels where high stress conditions exist with possible

rock bursting, the system can be enhanced with high capacity, larger components that can still be practically installed with TBM excavation."

On West Qinling in particular, the system is likely to see more action later this year as the main beam TBMs progress in to the higher cover section with broken, fractured rock and large faults. It is here where the cost of rebar is likely to prove favourable to halting the drives to deal with rock bursts.

Li says he is confident the system will be used on further hard rock projects in the region – Robbins is currently in negotiation with China railways for it to be fitted to a main-beam TBM they have ordered for a project in Vietnam.

However, for it to be widely accepted, there needs to be a change of attitude in designers, not contractors, as the key challenge the system represent is to design principles, rather than cost.

"The system doesn't really cost much more to put on the TBM – it only becomes really expensive if you are using a lot of rebar," says Li.

"If the system is to be used more in China then designers have to be happy with the concept of allowing loose rocks to stay in the ground. Traditionally in China they have not allowed loose rocks in the ground, and contractors are required by the designers to take the loose rocks out." ■

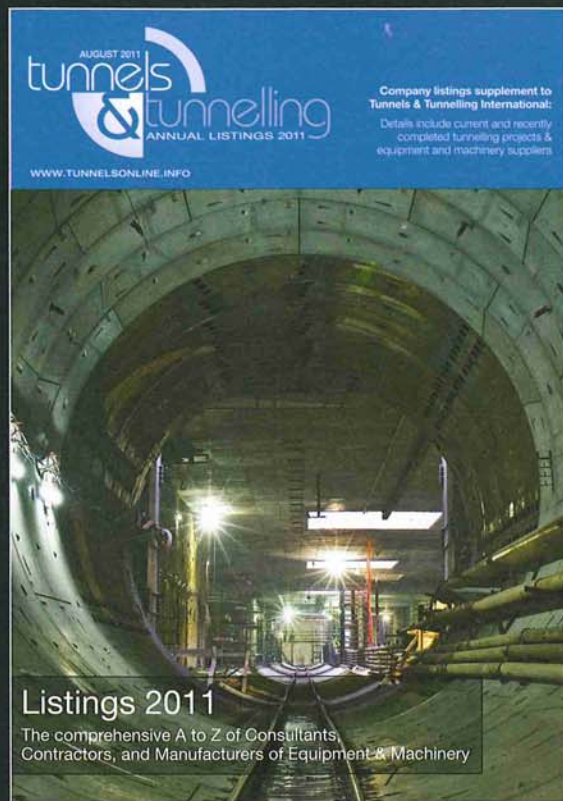


# T&TI's annual company listing and rankings have gone digital

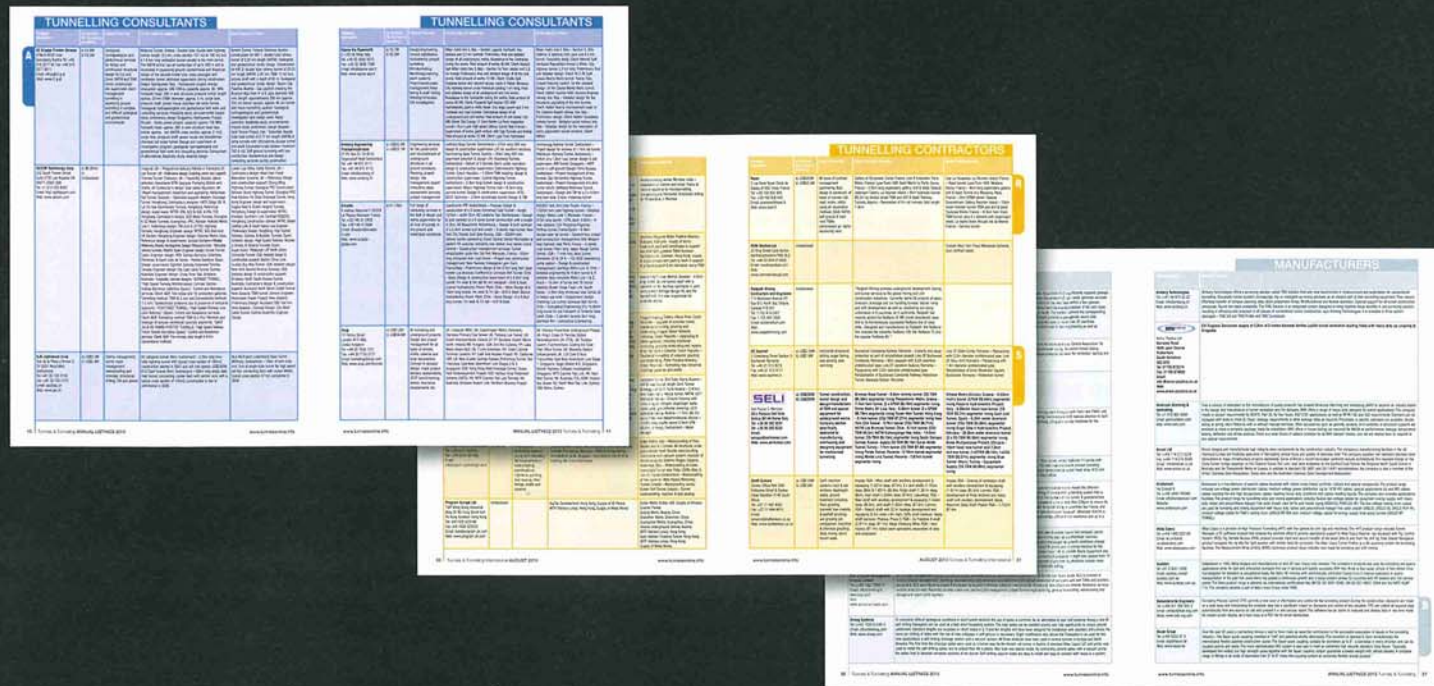
All entries now need to be completed via the online entry form

**Deadline for completion is 1 May 2011**

The listings will be published with the August issue of T&TI



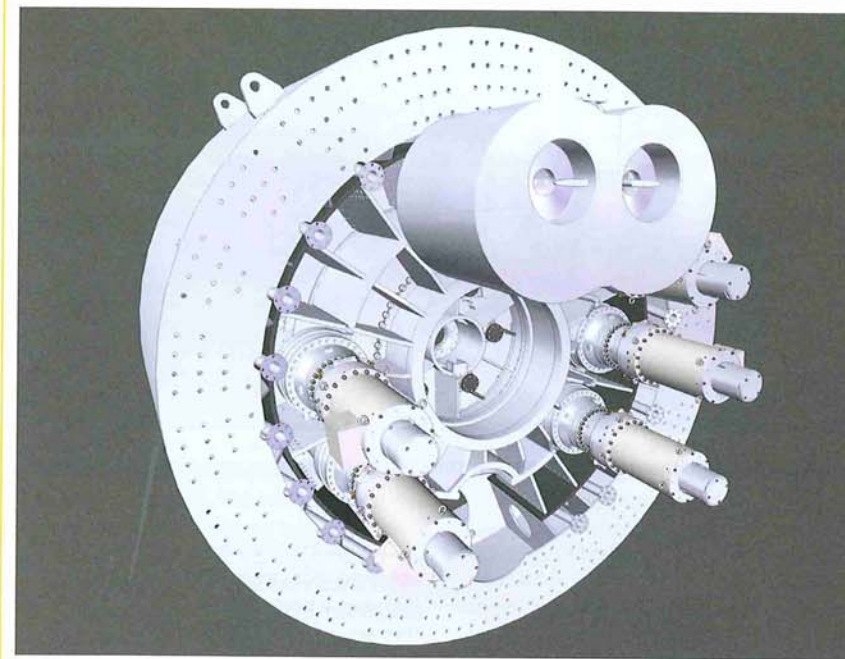
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# Earth pressure education

Soft ground tunnelling experiences are guiding new TBM designs. Robbins technical writer Desiree Willis explains



**Above:** The next generation of Robbins EPBs, seen here as a cross-sectional view of a machine from the back, include modular VFD motors and man-locks oriented at the top of the machine

China's vast variety of EPB tunnelling projects, in a wide spectrum of geologies, has been instrumental in developing the next generation of soft ground TBMs. The lessons learned in difficult ground on recent projects have guided the design of new EPBMs, from modular drives to high-powered screw conveyors.

Field experiences range from tunnelling in layered ground at Guangzhou Metro to achieving record advances in permeable alluvium at Chengdu Metro. "There were multiple challenges that we got through successfully," said Jason Xiao, Robbins field service manager, of tunnelling on the Guangzhou Metro, Guang-Fo Line in 2009. "There were sensitive building structures and research sites, permeable ground, and

sticky clay that all had to be dealt with." The drives at Guangzhou would begin a string of engineering improvements from project to project, with often record-breaking results.

### Soil complexity in urban surroundings: Guangzhou Metro

Two 6.3m diameter EPBMs began boring Lot 12 of China's Guangzhou Metro, Guang-Fo line in January and February 2009, through the country's characteristically complex soils. Ground consisted of layers of highly weathered to slightly weathered granite, coarse sand, and silt at earth pressures up to four bar.

The machines were designed for mixed face, variable ground using spoke-type cutterheads with a 37 per cent opening

ratio. Both carbide bits and 17in hard rock single disc cutters were used to combat both the clay-like and rocky conditions.

Each EPBM cutterhead was driven by ten variable frequency drive (VFD) electric motors, for a total cutterhead power of 900kW. Cutterhead rotation was kept low (around 1.5 rpm at maximum), in order to reduce ground disturbance and surface settlement in non-self supporting geology. At the same time, the machines were designed with high torque to increase the rate of instantaneous penetration in soft ground.

### Sticky ground

The machines were launched from cut and cover station sites in a densely urban area of Guangzhou. "From the start, the viscosity of a red, clayey soil layer was higher than expected, making the mud cake easy to form, but also often blocking the central area of the cutterhead," said Xiao. In order to pass through the sticky layer, foam was added to reduce viscosity, while reserve water injection holes inside the man-lock were used to flush any clogged soil from the central cutterhead area. The situation was aided by a system of four independent foam injection points on the cutterhead, which prevented clogging of multiple ports on one side of the cutterhead, an occurrence that can lead to uneven wear.

### Urban complexity

During tunnelling, the urban area and low tunnel cover (10 to 15m) required strict monitoring of surface settlement. An artificial lake, with a lake bed composed of oyster shell and sandy soil, sat directly overhead the tunnel alignment, creating a high risk for water inflows. Crews utilised the polymer injection system to inject polymer into the layer and absorb water, improving soil conditions for a smooth discharge of muck.



**Above:** The Robbins EPBs at Guangzhou Metro broke through ahead of schedule, despite facing challenges including low tunnel cover and layered soft ground with rock.

The 4m deep Huadi River and its surroundings were another area for concern—the Pearl River Fisheries Research Institute sits nearby the river, with numerous research ponds directly above the tunnel route. Because of the sensitive nature of the research, there was no way to probe the pond to determine the geology and its resulting risks. Polymers were again injected in the area below the ponds to keep settlement to a minimum. As the TBMs passed, the ponds were visually monitored for signs of disturbance. Other than a few small bubbles visible at the surface, no ground settlement was detected.

As the machines passed below the Scientific & Development Building, part of the research institute, more careful



measures were needed. The building, built in the 1980's, was determined to have a very low tolerance to vibration and ground disturbance. "We needed to strictly control the earth pressure to about two bar below this section, in order to allow the machine to move forward at an even rate of speed. Cutterhead speed was controlled to one rotation/min in order to achieve this, and get through the section safely," said Xiao.

Other methods were used in concert with the TBM tunnelling measures. "We stabilised a number of the building sites using pile foundation underpinning. We also controlled settlement using surface stabilisation and mucking volume control to decrease the chance of voids," said Ju Yicheng, vice chief project engineer for the contractor, China Communication Construction Corp., 2nd Navigation Engineering Bureau (CCCC).

**Left:** The Robbins EPBs at Guangzhou Metro faced a particular challenge under the Pearl River Fisheries Institute, requiring polymer injection and steady control of advance rates

Despite the challenges, the machines achieved more than 16 project records including a best month of 377m—higher than any of the 16 TBMs that worked on the Guangzhou Metro, Guang-Fo Line Project. Both EPBs completed tunnelling more than a month early, in September and October 2009.

#### Stemming settlement: Xi'an Metro

In June and July 2010, commencement of Xian's Metro Line 1 began with two 6.3m diameter TBMs. A combination of sand, pebble, and clay geology and ancient architecture including a 12th century bell tower and city wall translated to extensive measures for preventing settlement. Due to the sensitive area in one of China's most ancient cities, regulations stipulated a maximum of  $\pm 15$ mm surface extrusion or settlement for any tunnels.

Spoke-type cutterheads and 800mm diameter shaft-type screw conveyors were used to aid in efficient advance while maintaining a water-tight seal and balanced pressure.

The high-powered machines were

also designed with 3600 tonnes of thrust force to guarantee a fast advance in the ground conditions. The high thrust force additionally required a robust reaction frame.

"The shield machines launched in sandy soils with cobbles more than 200mm in diameter—a type of ground with high risk of settlement," said Xiao. Crews carefully monitored the excavation rate and overall muck removal volume, by adjusting the thrust force, advance rate, and screw conveyor speed, while keeping the cutterhead speed low, at one rotation per minute. Bentonite was also used to improve soil conditions at the tunnel face.

Sections of collapsible, water bearing soils are also present along the tunnel alignment.

Crews are tackling these sections with similar measures, including strict earth pressure control in the mixing chamber, paired with injection of bentonite and water for soil conditioning. Tunnelling at Xi'an Metro is ongoing, with Line 1 scheduled to open at the end of 2011.

#### Managing permeability: Chengdu Metro Line 2

China's Chengdu Metro Line 2 travels 31.6km below the city, and will open to rail traffic by the end of 2011. Its most recent tunnelling breakthrough, at Lot 18, underscored the usefulness of EPB tunnelling in permeable ground. The 6.3m diameter Robbins EPB was designed to excavate a complex matrix of alluvial geology, found nowhere else in China. Geotechnical surveys of the tunnel area indicated highly permeable ground, with lenses and layers of glacial boulders up to 250mm in diameter, along with sand and stiff clay.

#### Effective machine design

To excavate in the conditions, a mixed ground cutterhead was provided, mounted with carbide bits and seven 17in diameter disc cutters around the gauge. The large cutterhead opening ratio allowed for a smooth flow of muck into the mixing chamber. The cutterhead was powered by ten 90kW variable frequency drives.

The machine was designed with active articulation for curves with radii as small as 500m. The active configuration was utilised, because it engages articulation cylinders between the front and rear shields to steer the machine independently of the thrust cylinders. The process allows the thrust cylinders to react evenly against all sides of the segment ring during a TBM stroke in a curve. The setup eliminates segment deformation, or racking—a common cause of project delays when



**Above:** The 6.3m diameter EPB at China's Chengdu Metro Line 2 achieved a project record of 180m in one week while excavating through the area's permeable alluvium

passive articulation is used through curves.

A foam injection system was used to stabilise any running ground, with each cubic meter of foam mixture able to stabilize about 40 rings of advance. "The TBM allowed very good control of foam and other additives into the ground at the face," said Li Quanshe, project manager for contractor China Railway Construction Corporation (CRCC), Bureau 23. Four independent foam injection points on the cutterhead were used, in a similar configuration to those on the Guangzhou Metro.

#### Riverbed challenge

The TBM excavated mainly through stiff red clays under about two bar earth pressure, but had previously experienced a short mixed face section consisting of rock and earth while tunnelling 3.5m below Donggan River. "Only three cutter changes were required, while passing through this section—two in the left tunnel and one in the right tunnel," said Xiao. One cutter change required 1.5 bar of air pressure, while the other two were done in free air because the ground was very stable.

**Below:** The Robbins EPB at Chengdu Metro excavated an area of harder ground and glacial boulders below a river, requiring only three cutter changes. The machine broke through in December 2010



The machine completed tunnelling in December 2010, having achieved project records of 180m in one week, and 459.5m during its best month—higher rates than 11 other machines working on Line 2.

**The next generation of EPB design: Chengdu Metro West Extension**

A new generation of EPBs is currently being built, from the lessons learned at the above projects and others, including India's New Delhi Metro, the Upper Northwest Interceptor Sewer in California, USA, and Mexico City Metro Line 12. These next generation EPBs are optimised for fast excavation, particularly in China's harder ground, while minimising machine wear. The first two EPBs to utilise the designs will be a pair of 6.3m diameter machines for the West Extension of Chengdu Metro Line 2. "The machines are designed to give higher power and higher torque, which is ideal as long as the ground is stable. These features also make the machines adaptable for a variety of tunnel lengths and geologies," said Shinichi Konda, Robbins chief EPB engineer.

One way to achieve the higher power, for a variety of diameters, is with a modular cutterhead drive system. The cutterhead drive is standardised, while the number of motors can vary. "For example, up to eight motors can be installed on a 6m diameter, metro size TBM," said Konda. Within days, the number of motors can be changed on a machine by removing or adding pinion housings, making the machines flexible and easily customisable. The design also has the added benefit of allowing the man-lock to be moved from the center of the cutterhead to the top, increasing worker

**Below:** Ground conditioning equipment including bentonite soil injection was used to stabilise sandy soils with cobbles below the ancient city of Xi'an



safety when the cutterhead mixing chamber is partially filled with muck.

To match muck removal to the faster advance rates, high powered screw conveyors are being designed specifically for the harder, less fluidised ground seen in many Chinese EPB projects and in other countries. The designs are capable of up to 230kNm of torque, and offer greater flexibility as well as added abrasion protection.

The main seals are also being redesigned to cope with the extra heat generated during fast tunneling. Many commonly used main seals in the industry consist of a hard urethane rubber with low heat resistance, so that water must be added during fast tunneling to cool the rubber surface. New

**Above:** Two Robbins EPBs at Xi'an's Metro Line 1 are excavating below ancient structures including a 12th century bell tower and city wall

EPBs will utilise an NBR rubber for the main seals, which is softer and offers more heat resistance. The seals are also being reinforced with hard facing for added abrasion resistance.

Engineers are currently overseeing the assembly of the newly designed EPBs at the China South Locomotive & Rolling Stock Corporation (CSR) manufacturing facility in Chengdu. The machines will be launched to bore parallel 3.2 km long drives for China Engineering Railway Company (CERC) in late spring 2011.

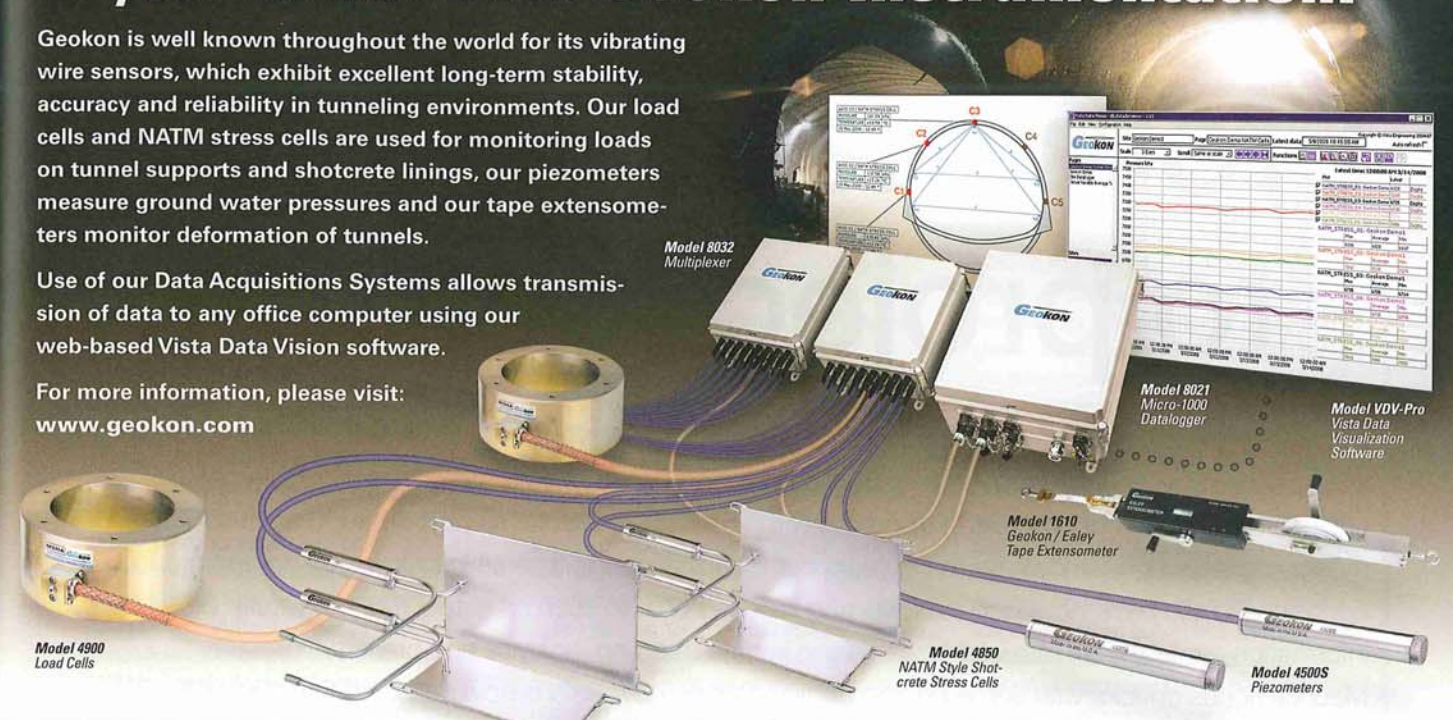


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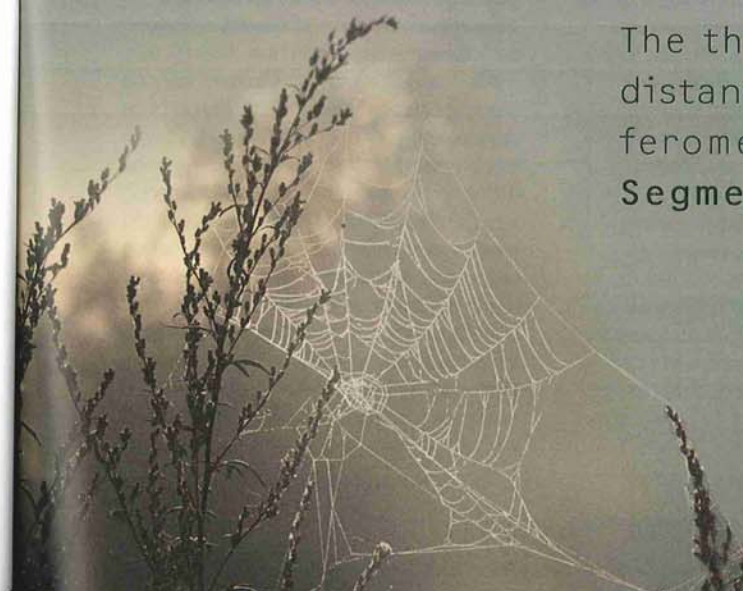
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1 μm

The thickness of a spiders web and the distance resolution of the Laser Interferometer used in VMT's Mould and Segment Measurement system.



# From the ground up - to project control

What happens when underground construction practice doesn't follow design theory? How can engineers find out what is actually happening with accuracy to reduce risk? The principles of structural monitoring have been known for many years but technical developments in instruments to test ground conditions in situ have increased reliability and reduced cost to such an extent that the wealth of information available has required new thinking in data handling, analysis and presentation. Maurice Jones checks with some leading participants on how data is now collected handled and used, plus how improvements might come about

**M**atching underground design carried out by numerical methods to ground and structure performance data, thus checking to see whether the design is performing in practice to design requirement, should ensure a successful outcome. There are many stages in this process, including construction processes that could have greater inherent risk than achieving the final structure. Monitoring ground reactions, any neighbouring structures that may be affected, and the performance of any temporary structures should reduce overall risk.

## Sensor design

The vibrating wire design of sensor for monitoring various values has served the industry well over many years (see page 69) but, although it will continue to do so in many cases, alternatives are now available.

One of the major advances has been the development of small electrolevels. These comprise of a level vial of conducting fluid fitted with three or more electrodes. A tilting action alters the amount of conducting fluid between electrodes, thus giving the basis of measurements due to changes in electrical resistance. Their advantages include simplicity, robustness, reliability, stability and their ability to be installed in many situations due to small size. Correct installation, calibration and interpretation of data should also result in high accuracy.

A typical electrolevel tiltmeter (EL) is available from Interfels, now part of itmsoil. This particular model is used mainly for the monitoring of the inclination of structures, particularly high ones such as towers and bridges, as may be affected by ground movements due to underground construction. It includes one of two electrolytic tiltsensors to cover ranges up to three or ten degrees. There are no mechanical or moving parts, making it very robust and reliable. Current readings are compared to the initial reading.

Other designs making an appearance include fibre-optic distributed sensors, especially for high accuracy strain measurement and other spatial values (see References below).

## Cost trends

The reduced costs, in real terms, of geotechnical sensors has enabled more to be installed, given better coverage of a structure or strata of interest, further increasing the reliability of an overall installation as more redundancy can be tolerated. There is also the new availability of wireless transmission of signals in many situations (although more limited underground), allowing more efficient monitoring processes. Geotechnical monitoring cost reduction relative to overall project costs is particularly fortunate for urban tunnelling as it allows a greater proportion of the overall budget to be devoted to risk reduction.

## Tunnel deformation

One application of electrolevels in tunnelling, introduced about 17 years ago, is in the detection of deformation of tunnel linings that may be affected by adjacent excavations. It was introduced to the construction of the Jubilee Line Extension in London, starting with the London Bridge site, and consists of the use of electrolevels mounted on interconnected beams. Developers of the system (Bassett *et al*, 1999) say that it is accurate enough to detect the small cylindrical displacements due to tidal effects, while being robust enough against the effects of temperature, vibration and dust.

Computerised logging has made it easier to utilise electrolevels for active warning systems as well as passive recording of data. This includes the monitoring of the effects of processes such as compensation grouting whereby the process can be adjusted according to its effects, whether desirable or excessive.

An alternative approach to the deformation of segmental linings has been developed by VMT as the Ring Convergence Management System (RCMS). It employs a series of inclinometers for data collection on relative movements of tunnel lining segments. The sensors are mounted round the lining ring intrados for continuous monitoring. The data can be integrated into the VMT Controlled Boring Process via the computer of the TBM guidance system.

## Data handling

The collection and treatment of data is another area in which major advances have led to increased reliability, as well as expanding the possibilities for better understanding of project performance through computerised analysis. Automatic data collection has been available for many years but its recovery, publication and the identification of problem areas could be laborious. With computer analysis, the first advantage was the automatic identification of problem areas (or failed individual sensors) according to pre-set warning levels or alarms. These warnings can then then transmitted as an SMS message to the mobile phones of responsible engineers, emailed to a central control office, or otherwise log the emergency situation according to agreed project procedures for action.

Software packages can now analyse data to provide visual presentations that often make it easier to identify problem areas and, using colour coding, to indicate the extent of major changes. It is claimed, in many cases, that the use of these and related techniques, have enabled major projects to be built more safely and efficiently, at lower cost.

Geotechnical instrumentation installations come with a wide range of site situations, sizes and purposes, and this helps determine the type of data logging required. 'Boxed' data loggers can be installed on or near the site and the instrumentation, with facilities for downloading their information. Traditionally the data transfer method has been hardwired or by plug-in connections, but now wireless transfer is available if the location makes it possible. Whilst underground transfer by this method, as in other locations with radio interference, can be problematical, the datalogger could be hardwired from the instruments to a more suitable location.

Interfels of Germany (itmsoil group) has used data loggers produced by Campbell Scientific of the US as well as designing its own. The basic Interfels models are housed on steel or reinforced (grp) IP65 enclosures and come with additional modules including power supply (12V or mains) and communications kits. Solar cells or wind generators as well as the mains can provide power. There is a switched mode AC 'bus' system available for where locators are located away from mains power. Communications can include GSM or GPRS modems to send warning or alarm text messages. The loggers are flexible in use for configuration of large numbers of similar or different sensor types, and each

datalogger is tested with a program specifically for the sensor types being used on the project and configured to customer requirements.

Geokon's datalogger interrogation system, for which new software is now available, is designed for Model 8002 (LC-2) Series dataloggers including 2-, 4- and 16-channel versions. Called LogView, the new software simplifies the task of configuration, communication, monitoring, data collection and data reduction. To do this the computer display uses an explorer 'tree' in the left-hand pane and 'views' on the right-hand side. The system includes screens for configuration, connection, measurement and data collection, plus a real-time, text-based monitor, a graphical monitor and terminal emulator.

Dr Hai-Tien Yu, chief technology officer of itmsoil, pointed out to T&T that the much-quoted process of 'real-time data handling' is not really new. "We've been doing it for 20 years," he says, "although technology has advanced quite a bit in that time. In the 1990s the data logger and the IBM PC were combined to form a powerful tool in a Trafalgar House R&D venture. As part of the Cairo Wastewater Project, chemical grouting against water inflow was controlled with the aid of real-time monitoring so that grout pressure and volume could be maintained at the right values to avoid blockages while completing the work. Volumes injected and together values were recorded and could be reported for three grouting machines each with four lines of values."

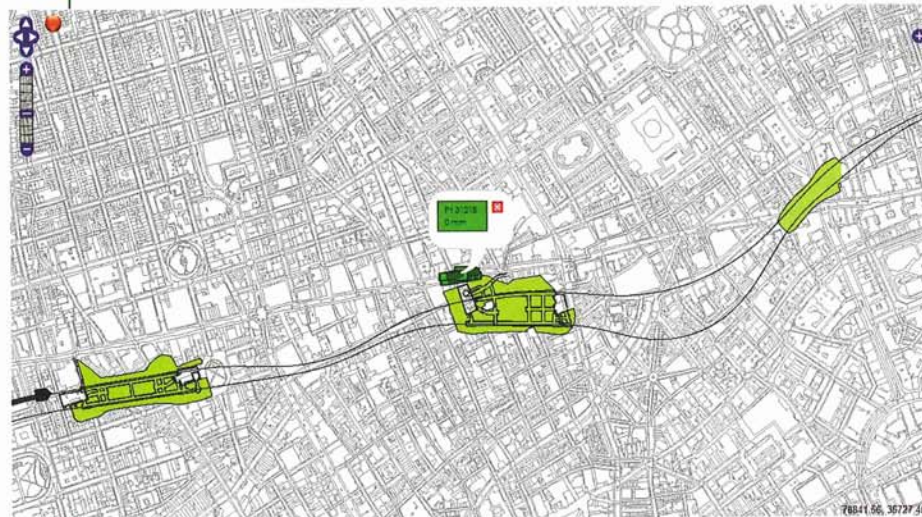
## Risk management

VMT's Nod Clarke-Hackston states that the real challenge for using geotechnical instrumentation data is to convert notable values to action within the tunnelling operation, particularly between any surface movements and underground excavation, annular grouting, etc. As previous collapses have shown, it is a matter of 'cause and effect' unless necessary and timely actions are taken according to the data collected. "You need an experienced person to be available to assess the data and to do something, whether it's to stop excavation, increase support or other action to prevent deterioration. This is so whatever the time. Significant geotechnical data received on 16:00 on a Friday cannot be resolved by a meeting on Monday! You need 24-hour a day coverage on behalf of a continuity team with the authority to respond."

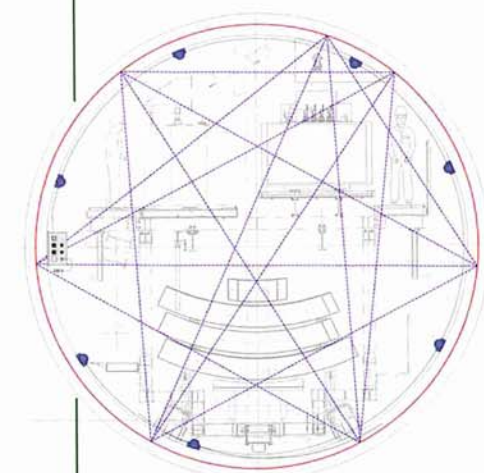
Having introduced its own tunnel management system, the CBP (Controlled Boring Process) information system [T&T Dec 2009 pp. 26-28], VMT has entered into a joint venture with Strabag group contractor Zublin to form ITC Engineering. The CBP is a system for documentation, storage and monitoring of all operational parameters, including geotechnical data, with the function of evaluation and analysis for mechanised tunnelling. This enables data to be supplied to experts in as near 'real-time' as possible to enable decisions to be made for safe process control. ITC Engineering is further developing the concept using the process data management system IRIS (Integrated



Above: Display image of sensor points in itmsoil's Argus software with integrated GIS



Above: Another GIS view from Argus at a smaller scale to show the tunnels' routes



Above: Typical installation of VMT's Ring Convergence Measurement System (RCMS) using inclinometers to check on pre-cast segment lining movement

Risk and Information System). The development is described in a new paper by Schneid and Franzius to be published in English in the future issue of *T&T*.

As part of the European Union-funded Tunconstruct programme, Geodata of Austria, together with Geocisa of Spain and GIScience, also of Austria, has developed the Underground Construction Information Systems (UCIS) incorporating Godata's Kronos tunnel information system relating surface monitoring and TBM performance.

### Project performance

The successful outcome of underground construction projects is increasingly related to geotechnical performance both for their own sake and for minimal disturbance of surrounding structures.

This is particularly so in the case of urban tunnel projects, such as in the boom in metro construction.

International geotechnical and construction monitoring specialist contractor SolData, part of the Soletanche Bachy group, has been engaged on many underground construction projects including metro running tunnels and stations. SolData is also a distributor for Gage Technique instruments and sensors. For the Budapest Metro, Line 4, project SolData has been carrying out real-time monitoring of buildings and ground deformation, as well as noise and vibration. The equipment employed included 30 Cyclops/Centaur robotic total station systems, 50 extensometers, 20 inclinometers and 120 electrolevels. The results from this automatic equipment were complemented by traditional levelling together with surveyors Hungoed.

The data is transmitted wirelessly to a central database from which it can be visualised in real time using SolData's monitoring software, Geoscope Web. The results can be accessed remotely via the Internet for evaluation and interpretation. An automatic alarm system is included within which, in the event of predefined threshold limits being exceeded, an automatic SMS message or email is sent to the appropriate managers and engineers.

### Crossrail

Another important urban rail project Crossrail across London. In view of the problems occurring in some sections of the last major urban rail project in the centre of London, the Jubilee Line Extension, there is increased interest in the monitoring of construction along this route is heightened.

The itmsoil group has been awarded the Crossrail C701 instrumentation and monitoring contract. This includes the supply and installation of automated monitoring instrumentation and monitoring of a range of existing tunnels, buildings and infrastructure including that of London Underground, the Docklands Light Railway, and Network Rail. C701 is claimed to be the largest single contract for geotechnical instrumentation and monitoring ever undertaken in the UK. itmsoil has previously worked on the Victoria Station Upgrade, the Channel Tunnel Rail Link and Jubilee Line Extension in London.

itmsoil will be providing, maintaining and managing a central database to collect data from all site instruments and other locations along the contract route. Termed the Underground Construction Information Management Systems (UCIMS), it is designed to collate, manage and present information on construction progress together with data from the monitoring instrumentation. This will be accessible by all contractors and supervisory teams.

Hai-Tien Yu has had project geotechnical monitoring experience in the US since 1998 including in the reconstruction of the subway in the New York World Trade Center after the 9/11 collapse, the Second Avenue Subway, and the Eastside Access tunnelling also in New York.

At the World Trade Center the original subway (metro) tunnel for the No. 1 Line was replaced with a reinforced concrete box structure in 2002. Further property development on adjacent sites rather than on Ground Zero itself (to be left as a memorial) called for excavations under the subway box to create other structures. The box was supported by 450 minipiles drilled into the bedrock, and a beam placed over them to distribute the load of the box, with load-transfer beams and rods.

All this work required precise monitoring of the box structure and surrounds to ensure no disturbance of the working railway and the stability of the whole structure.

The World Trade Center work demonstrates the advantages of modern geotechnical instrumentation. Originally adjacent instrumentation options were limited to horizontal inclinometers on roofs with manual reading. There were also 70-80 electrolevels at both ends of the 'box' where it was difficult to take manual readings reports Yu. "Over a length of 300-400ft (90-120m) it took a whole day to take readings, and the results were not very good."

Later an additional 270 electrolevel beam instruments were installed on both sides of

the tunnels with remote data collection. "These were in place from since 2008, and I think they're still running now. Manual readings were totally scrapped."

On Crossrail Dr Yu says it is too early to comment on the actual installation of geotechnical instrumentation under itmsoil's contract, but the basic system will include itmsoil's Underground Construction Information Management System (UCIMS) that was developed by a team led by Dr Yu. He commented to *T&T* however that available computer power has increased more and more which, together with the development of remote-reading sensors, allows, in technical terms, more to be installed giving a better 'picture' of the project. C701 will be managed from itmsoil's new Major Project Office in Holborn, opened in September last year to house over 20 staff.

Each major technical development has been associated with a major project. For example the JLE project was followed by development of the Bassett Convergence System using prototype installations in active metro running tunnels around London Bridge for the JLE Project. Later, with the construction of the Portcullis House parliamentary office block over the new Westminster Station, the structural load had to be transferred to the tunnel level including the interim use of hydraulic jacks.

This process necessitated the use of hundreds of sensors and the project was the first to use 'Windows'-based data presentation to more easily handle the large amount of resultant data.

### Web-based data

With the use of computerisation being widespread it requires only the use of common compatible software to allow all relevant parties in the project to share data and its analysis. It has become more efficient to use web-based data management, especially for widespread access to and presentation of geotechnical data, allowing remote monitoring of projects. "The biggest change was in 2004," says Yu, "when systems could change from 'Windows' to a web-based systems for better sharing of data."

One such system is Argus, an itmsoil product developed by Interfels that was acquired by itmsoil in 2007. This is totally web-based software developed for the open-source LAMP (i.e. Linux, Apache, MySQL and PHP) computer system. There is no need for special software on users' own computers or licence payable; only standard browsers. Argus can be operated

across the whole Internet or just in a local network. It has been used on Crossrail already and several New York projects.

Yu says that Argus is under 'constant development to satisfy new user requirements including Geographical Information Systems (GIS) functionalities, construction progress information management and is compliant to the AGS (Association of Geotechnical and Geoenvironmental Specialists) data format. In addition standard functions Argus specialities include:

- A purchase or rent option (the latter based on itmsoil servers).
- Multiple-language support.
- User-definable formulae with references to any sensor on the project.
- Ability to present in two engineering units in one plot (dual Y-axis).
- Alarm if no data has been received in a set time.
- 'Virtual sensors' to allow calculation of values such as averages and data corrections.
- Automatic issue and distribution of reports as pdfs.

- Back-ups to users' own PC.
- Additional project information input.

The latest version includes GIS functions, facilities for TBM data input, multimedia records including videos and photographs, and permission group management.

### What do you expect?

*T&T* would be interested to hear from users of geotechnical data systems in tunnelling, particularly those with experience of their integration into tunnel project management systems. What works for you? Is there a danger of too much information and computer work that keeps you away from your core tasks, or are such systems a great aid to efficient and environmentally friendly underground construction? And what about costs? Some large software systems have been costly failures. Does this concern you, or is the investment worth it? ■

Please send your views to:  
Jon.Young@tunnelsandtunnelling.com or  
Maurice.Jones@tunnelsandtunnelling.com

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# Responsibility for monitoring and instrumentation

With 50 years of geotechnical instrumentation experience on many projects, the author, John Dunnycliff MS, SM, PE, Dist MASCE, is well positioned to comment on who should be responsible for monitoring and instrumentation during the construction of tunnels. Here he details his views.

**W**e all know that tunnel construction is not an exact science and that, therefore, monitoring often plays a crucial role in ensuring that the tunnel and surrounding properties are safe and meet the design intent. Monitoring often includes the use of geotechnical instrumentation. If significant decisions are to be based on the monitoring data, data quality must be maximised.

- If instrumentation is used, the tasks include:
1. Buying instruments
  2. Installing instruments
  3. Collecting data
  4. Interpreting data

How can we ensure that these tasks are assigned to the people who are most likely to maximise quality?

The golden rule is: 'The people who have the greatest interest in the monitoring and instrumentation data should be given direct line responsibility for obtaining the data.' Or, put another way, who has the motivation to do these nit-picking tasks with enough care?

**Who are the candidates?**

The candidates for this responsibility are the staff of the project owner, the designer, the construction manager, the principal construction contractor, possibly a temporary works contractor, possibly a design-build contractor, and often a specialist geotechnical subcontractor. The selection depends on the specifics of each project, on who has 'the greatest interest'.

If principal construction contractors, design-build contractors, temporary works contractors or specialist geotechnical subcontractors have initiated the monitoring programme, clearly they have the greatest interest, and all's well. But if the designer of the project has initiated the programme, personnel in these organisations may not have enough motivation to ensure quality. Let's look at the options for this situation.

**Options for tasks 1, 2 and 3**

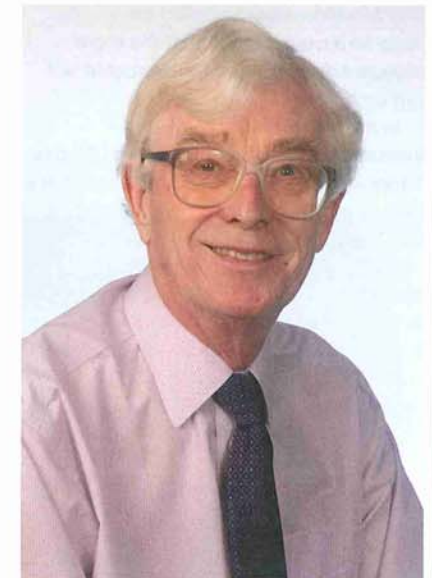
When the designer of the tunnel has initiated the monitoring programme, the options for assignment of tasks 1, 2 and 3 are as follows.

Let's call these three tasks of buying and installing instruments and collecting data 'field instrumentation services'. Use of the conventional low-tender procedure, whereby these tasks are included as items in the bill of quantities, has often led to poor quality data. Is there an alternative? Yes, there is.

There are four specific reasons for assigning responsibility for field instrumentation services to personnel selected by the project owner or designer and under direct contract with the owner.

**First reason – quality of data**

Principal contractors may not have enough motivation to ensure quality. A few years ago a UK colleague and I put together ideas about how to maximise quality when the designer of the project has initiated the



Above: John Dunnycliff

monitoring programme. We made a strong plea for using a qualifications-based selection procedure for field instrumentation services.

If you have any interest, you can download these ideas from [www.geotechnicalnews.com/instrumentation\\_news.php](http://www.geotechnicalnews.com/instrumentation_news.php) (scroll down to the only entry for 2001).

Our preferred option is that the people responsible for field instrumentation services should be selected by the project owner or designer, and under direct contract with the project owner. Our publication includes many comments from the technical literature in support of a qualifications-based selection

procedure, which can be useful when trying to convince decision makers to accept this method.

**Second reason - cost**

Colleagues in New York discuss the issue from the viewpoint of an instrumentation subcontractor to the principal construction contractor—see [www.geotechnicalnews.com/instrumentation\\_news.php](http://www.geotechnicalnews.com/instrumentation_news.php) and scroll to Geotechnical Instrumentation News Sept. 2009. They warn:

"The award of instrumentation work based on the 'bottom line' includes little consideration for quality, if any at all [...] After the contract is awarded to a construction contractor, potential instrumentation subcontractors are invited to re-bid, so that the construction contractor can compare line item breakdowns. Instrumentation bidders revisit their costs and strip contingencies. The firm ultimately awarded the work is likely to have assumed that the more stringent specification requirements will not be enforced."

In my own experience as an instrumentation subcontractor in US, this 'stripping' can be up to 20 per cent. Let's look at whether owners get a fair deal if this happens.

As an example, if the amount assigned for field instrumentation services in the construction contractor's tender is GBP 800,000 (USD 1.294M) the project owner pays that amount, but only receives work that costs GBP 640,000 (USD 1.035M). There's a strong message for owners there.

**Acknowledgements**

John Dunicliff holds masters degrees from both Oxford and Harvard universities. In his project geotechnical instrumentation work he emphasises obtaining high quality data to help answer specific geotechnical questions.

He has taken the lead role in teaching more than 100 continuing professional development courses in geotechnical instrumentation worldwide. He is author of 'Geotechnical Instrumentation for Monitoring Field Performance' (1988 and 1993), and co-editor with Don Deere of 'Judgment in Geotechnical Engineering: The Professional Legacy of Ralph B Peck' (1984 and 1991). He is also co-editor, with Nancy Young, of 'Ralph B Peck, Educator and Engineer - The Essence of the Man' (2006).

In 2011 he was selected by *International Water Power and Dam Construction* as "One of the 20 people who have made the largest difference to the dam engineering sector over the past ten years."

**Course: Geotechnical Instrumentation for Field Measurements**

John Dunicliff is Course Director of the University of Florida Division of Continuing Education course on 'Geotechnical Instrumentation for Field Measurements' on 3-5 April 2011 at Doubletree Hotel, Cocoa Beach. The course is for practitioners and is taught by practitioners with field experience.

In addition to Dunicliff lecturers include Martin Beth Geotec Eng, INSA Lyon, technical manager for the Soldata Group, Aaron Grosser MSCE, PE, geotechnical engineer of Barr Engineering Co, Minneapolis; Daniele Inaudi PhD, fibre optic sensing expert and chief technical officer of Smartec and RocTest; W Allen Marr PE, PhD, DGE, NAE, founder and president of Geocomp Corp, US; Justin Nettle, PE, chair of the US Society on Dams Subcommittee on Best Practice for Dam Safety; Tony Simmonds BSc, international projects manager at Geokon, Lebanon, New Hampshire; and Robert Taylor BASc, PEng, president of RST Instruments, Coquitlam, BC, Canada.

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Dunicliff also features in the 'Geotechnical Instrumentation and Monitoring' conference and workshop in London on 16-17 March.

**Table 1: Recommendations for assignment of tasks 1, 2 and 3 when the tunnel designer has initiated the monitoring programme**

Type of monitored data	Recommendations for assignment of tasks 1, 2 and 3
Pre-construction baseline data	Specialist firm under contract with the project owner
Data during construction, outside principal contractor's work area	Specialist firm under contract with the project owner
Data during construction, within principal contractor's work area	Either: • Specialist firm as nominated subcontractor, or • Principal contractor, with partnering, and rigorous and enforced specifications.

**Third reason – adequacy of baseline data**

If construction work is likely to impact on neighbouring structures, and monitoring with instrumentation is required to mitigate the impact, there's another important reason for favouring a contract directly with the project owner. If field instrumentation services are included in the principal construction contract, monitoring can't start until the award of that contract. In that case there's rarely sufficient time to establish adequate records of pre-construction behaviour (baseline data).

Structures move and groundwater regimes often change from season to season, and monitoring data cannot be interpreted correctly if adequate baseline data are not obtained.

**Fourth reason – cost on multi-principal contracts**

For multi-principal contract projects, there would be one monitoring subcontractor for each principal contract, hence greater cost when compared with a single assignment.

**Recommendations for tasks 1, 2 and 3**

When the designer of the tunnel has

initiated the monitoring programme, my recommendations for assignment of tasks 1, 2 and 3 are given in Table 1.

**Options for task 4 - interpreting data**

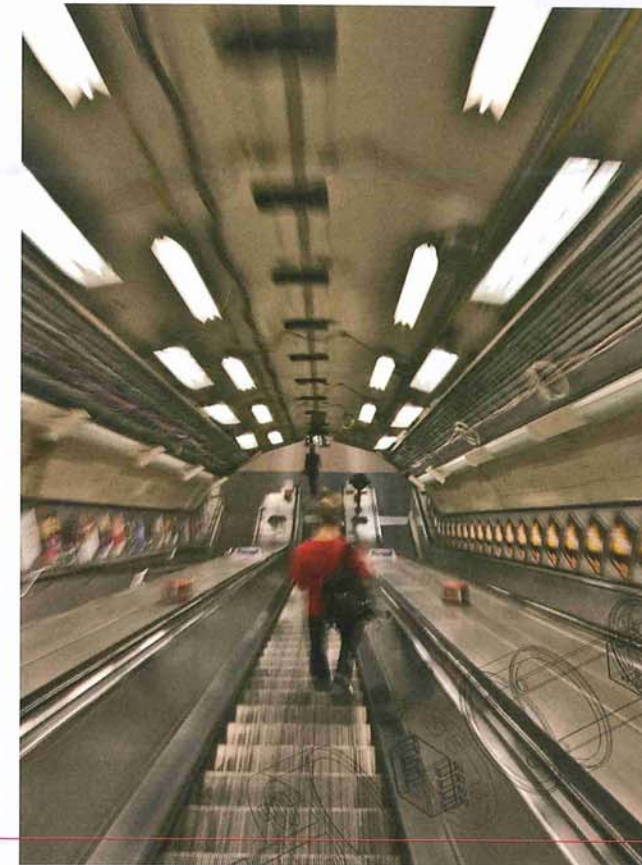
Clearly the people who initiated the monitoring programme (in this case the tunnel designer) should have a role in interpreting the data.

However, the principal contractor MUST pursue a parallel effort, and construction documents must specify that the principal contractor has the primary responsibility for interpretations and that it must stay on top of the data flow at all times.

**Conclusions**

I know very well that it isn't easy to convince owners (and project managers in design firms, who supposedly have the owner's interests at heart) that it's in their interest to adopt the above recommendations, but it is!

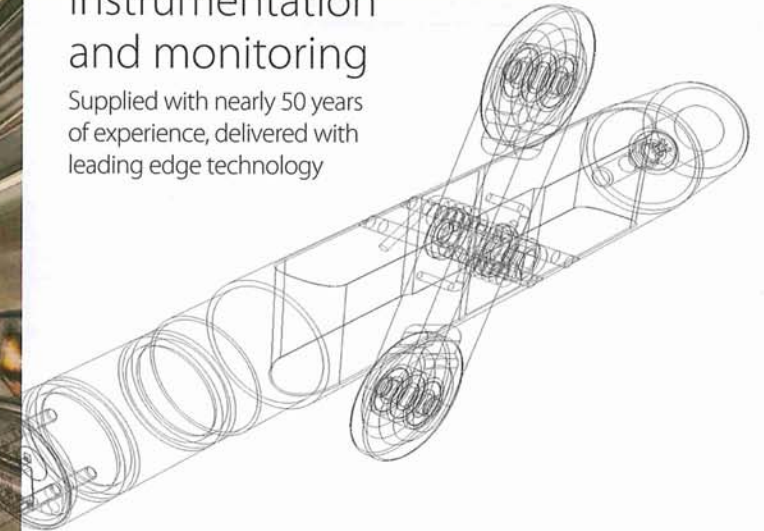
Join the campaign to ensure that the people who have the greatest interest in the geotechnical monitoring and instrumentation data should be given direct line responsibility for obtaining the data. ■



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# How does it work? – Vibrating wire instruments

This is the first of a new series of articles in *T&T* dealing with subjects, usually technical, in a more fundamental manner to assist newcomers to the tunnelling industry and perhaps to brief more senior specialists that have not had to deal with the particular subject before. The idea came about as a result of discussions with the British Tunnelling Society Young Members, but input from young tunnel practitioners worldwide would be very welcome. In this article, Barrie Sellers, president of Geokon of New Hampshire, US, describes how vibrating wire geotechnical instruments work, and their advantages

Vibrating wire sensors have been around for well over a century. Their initial concept can be traced back to 1888, yet commercial development did not begin until around 1930, pioneered by companies Maihak in Germany and by Telemac in France. Most of these vibrating wire sensors were designed for use in dams.

In the 1960s further developments in the UK by the Building Research Establishment, now BRE, and in Norway by the Norwegian Geotechnical Institute (NGI), were made available to the public through Gage Technique in England, and through Geonor in Norway.

Designs during this period tended to be highly complicated, but had the added advantage of providing some excellent results, in combining long-term stability and survivability with a high level of accuracy.

The 1970s saw the rise of Geokon of Lebanon, New Hampshire, US, who redesigned the basic vibrating wire sensors along more elegant lines and used the latest electronic techniques in their readout equipment.

Geokon's low-cost designs became so popular that they were, and still are today, copied by numerous companies worldwide and thus Geokon is recognised as the world leader in vibrating wire sensors.

How has the vibrating wire sensor remained the preferred type for use in

harsh geotechnical environments for all these years?

The answer lies in the basic simplicity of what is really a mechanical transducer comprising of a length of tensioned steel wire, which vibrates at a frequency depending on the strain in the wire. The plucking of the wire is carried out electronically through a simple electrical coil (see diagram below), which, after the pluck, becomes a sensor outputting an alternating electrical current with the same frequency as that of the vibrating wire.

This basic relationship between vibrational frequency and strain is then used in a variety of sensor construction configurations (see [www.geokon.com](http://www.geokon.com)) to measure strains, stresses, pressures, temperature, tilts, displacements and loads, in tunnels, mines, dams, bridges, foundations, piles, landfills, unstable

slopes and many other geotechnical, civil and structural applications.

The relationships between the vibrating wire characteristics and movement is given by:

$$f = \frac{1}{2L} \sqrt{\frac{T}{m}} \text{ or } f = K_1 \sqrt{\epsilon} \text{ where } K_1 = \frac{1}{2L} \sqrt{\frac{AE}{m}}$$

$$\Delta \epsilon = K_2 (f^2 - f_0^2)$$

Where:

f = frequency of vibration

L = wire length

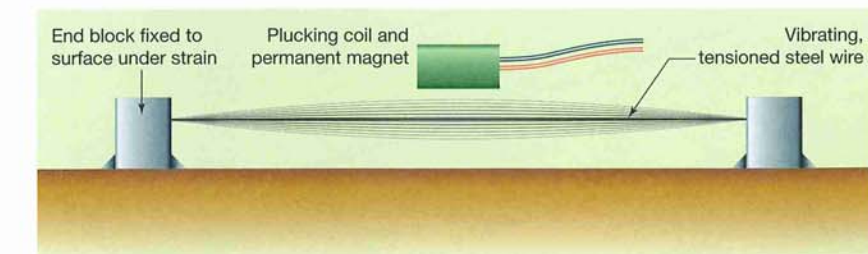
T = tension

m = wire mass per unit length.

What are the advantages of vibrating wire sensors?:

**1st:** They are very resistant to water intrusion, the instance of which would usually spell instant death to more sophisticated electronic devices.

**Above:** Schematic representation of the operating principles of a vibrating wire transducer for a geotechnical instrument

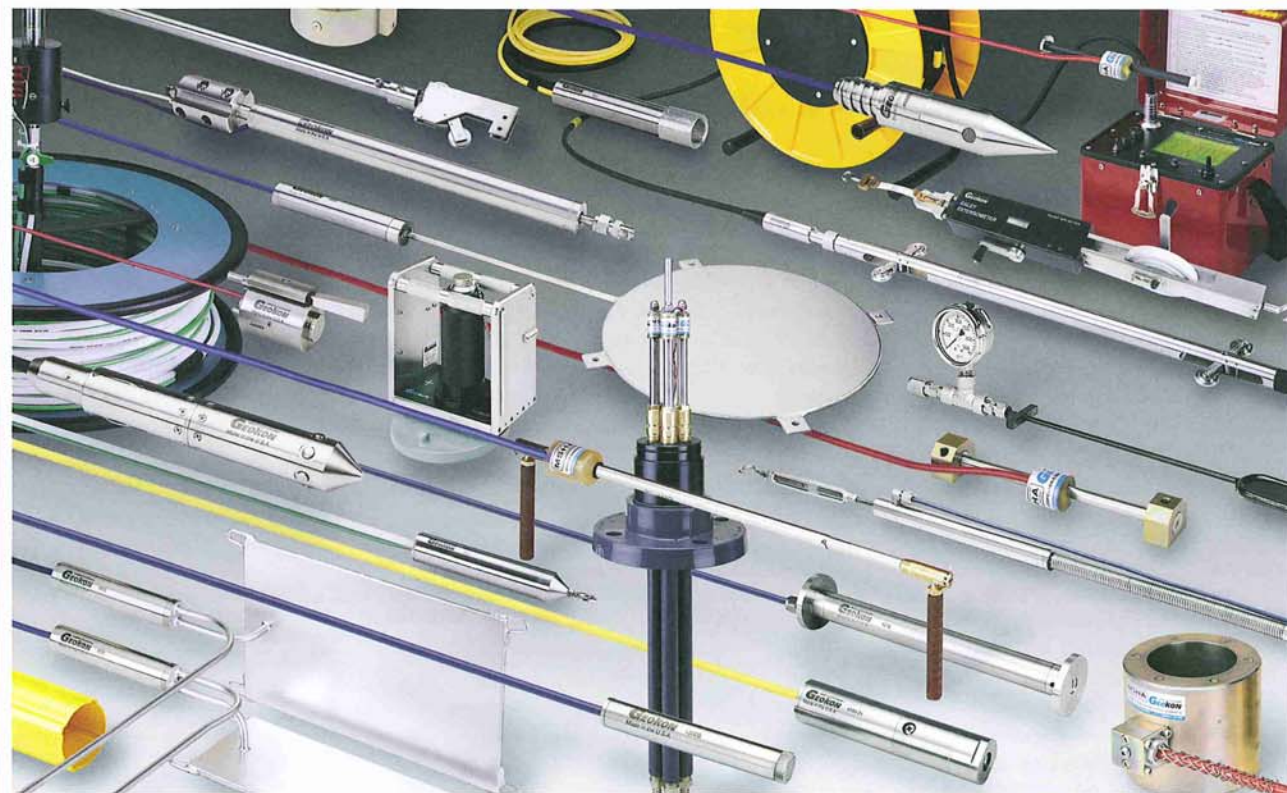


The frequency output of a vibrating wire sensor is not affected by changes in contact resistance, leakage to earth, or in changes of signal cable resistance. Cable lengths of up to several kilometres can be used successfully to reach remote sensor locations.

**2nd:** The long term stability of vibrating wire sensors is legendary. The all-steel construction of the basic sensor leaves nothing to deteriorate with time. Vibrating wire strain gages and piezometers typically show zero drifts of less than 0.1 per cent of full scale per year (FS/year) and sensor life can be counted in decades. There have actually been reports of sensors installed over 60 years ago in European dams that are still functioning.

**3rd:** Vibrating wire sensors, unlike 4-20-mA sensors, have no delicate electronics to 'fry', so they have a very high resistance to lightning damage. The vibrating wire plucking coil can be given still further protection through the incorporation of a gas discharge tube fitted inside the sensor that short-circuits to earth if the voltage across the coil ever exceeds 40V.

**Below:** An array of Geokon vibrating wire geotechnical instruments and accessories



**Want more?**

If you have any comments on this new series of articles, especially about subjects that would benefit from simplifying or explanation, please feel free to contact any member of the T&T editorial team.

Remember the intention is to help young tunnel engineers and to help fill in any gaps in the knowledge of others, particularly related to our scheduled technical review features, but also to tackle other areas.

Suggestions for subjects of a technical nature should, in the first instance, be sent to the technical editor, Maurice Jones, on maurice.jones@tunnelsandtunnelling.com, and on other subjects to the editor on email jon.young@tunnelsandtunnelling.com. We cannot, at this stage, answer specific or detailed questions, especially in the short-term, but would welcome any comments.

**4th:** Vibrating wire sensors can be easily multiplexed and connected to automatic data acquisition systems (ADAS). Several companies, such as Campbell Scientific and Datalogger, have developed dataloggers to handle Geokon-type vibrating wire sensors (which can also be adapted to all SCADA [Supervisory Control and Data Acquisition] systems). Improved electrical noise suppression techniques using Fast Fourier Transform (FFT) techniques, (e.g. Campbell Scientific's Model AV200) allow the vibrating wire signals to be measured accurately in electrically noisy environments.

Specialty vibrating wire sensors have also been developed to measure temperatures of up to 230 degrees C. They

are particularly useful, where other types of sensors have failed, in monitoring small changes of pressure and temperature at great depths in steam-assisted, gravity-drainage (SAGD) oil recovery wells.

Vibrating wire sensors are also able to survive in very high radiation environments and have been used to monitor nuclear waste disposal processes.

The one area in which vibrating wire sensors are at a disadvantage happens to be for measurement of dynamic (rapid changing) parameters – the length of time required for the pluck and read sequence is just too long.

However, for accurate and reliable quasi-static measurements in harsh environments, there is no equal to the vibrating wire sensor. ■

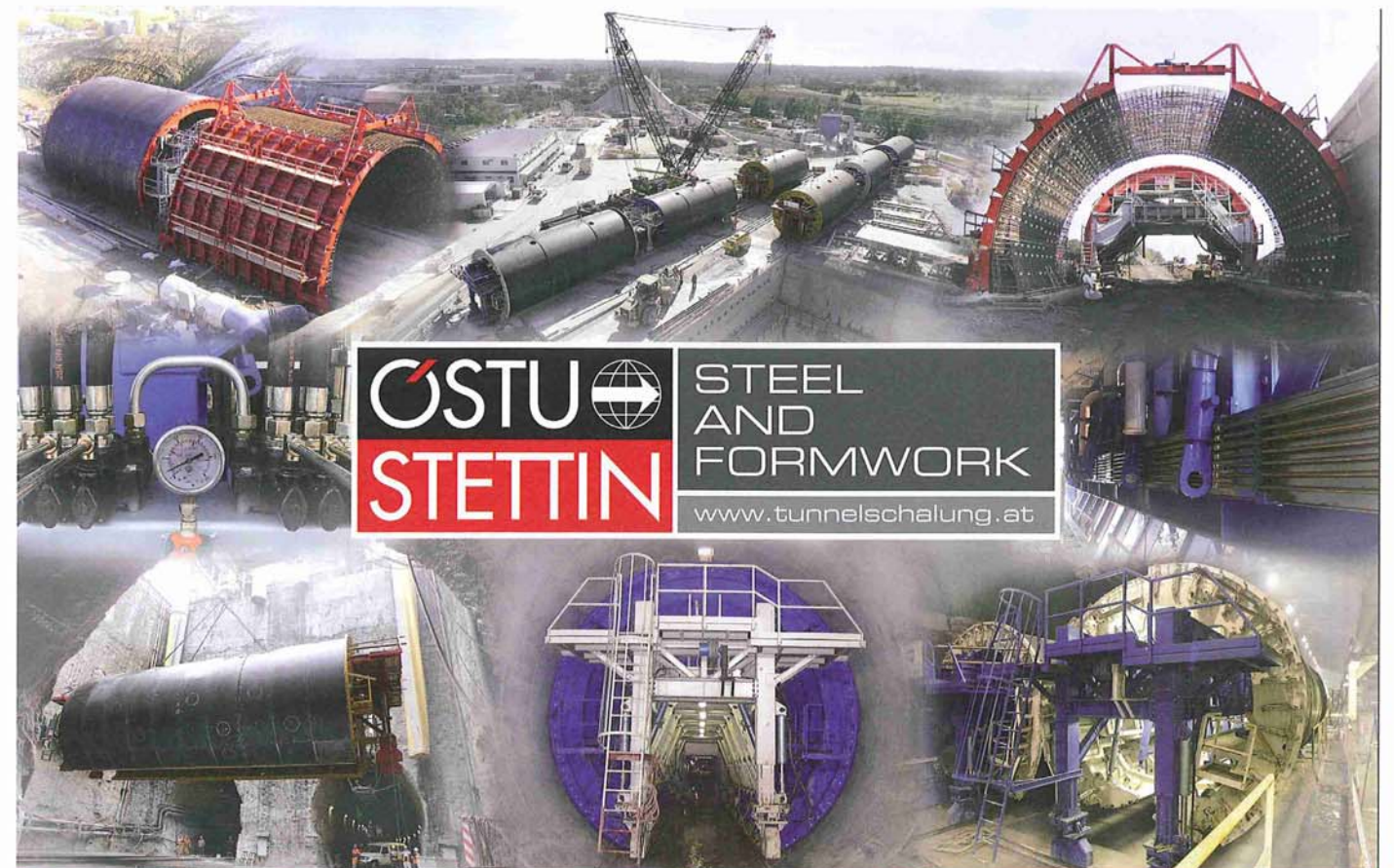
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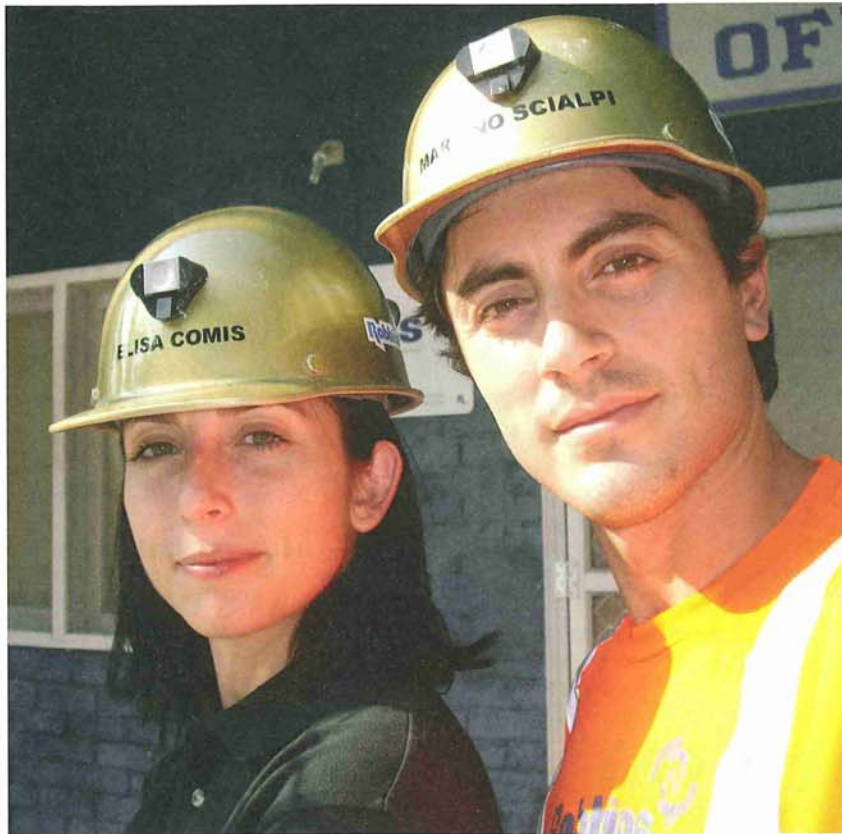
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# Not a job for everybody



**Left:** Elisa Comis and Martino Scialpi share fond memories of unofficial but helpful signs at worksites around the world, including 'This TBM has no brain – please use your own' and 'Your mother doesn't work here, please wash your own dishes'

portal, repaired and modified on site, re-assembled at 3.8km, then finally resume the excavation of a by-pass tunnel. The memory of the desperate struggle to get this job successfully done is something that will forever join all the people who worked there.

"Both of us, our skills and characters have been forged in Ethiopia, by experienced 'old style' supervisors in a very difficult work environment. The tiredness and frustration sometimes felt there has made us stronger, and made the satisfaction of our first breakthrough greater. In the same experience, we understood even the most advanced TBM cannot do anything without a carefully selected team. This is the reason why nowadays we daily spend so much energy looking after the personnel."

However strong the working friendships are, the Italians are a long way from home. "We are learning to appreciate the minor things when we are back even for a few days. The most difficult aspect is the distance from families and friends, and the special moments of their lives we are missing."

On working far from home together, they say, "We use our university and professional training to be complementary: geotechnical and managerial aspects from one side; mechanical and procurement matters from the other. The constant communication and dialogue makes each of us present in two places in the same time. The constructive discussion of two different points of view helps us in making important decisions. Outside of work, we have our lucky life together, our plans for the future but also our families and friends far away from here. The reciprocal encouragement to persist also in sad moments drives us forward."

"I'm proud to be an active part of these enchanting constructions," says Martino. "I'm proud to share this interest with a close circle of people, because this is not a job for everybody."

Elisa finishes by adding, "In this close circle of people, women are even rarer. I'm proud to be a field service technician." ■

Martino and Elisa are now employed by Robbins in a remote area of India working on the AMR project, the longest ever TBM-bored tunnel without intermediate access. Martino's day-to-day job involves overseeing the boring process and corrective measures as well as TBM and geology interaction management, with some time spent on client and partner relationships. Elisa's role revolves around TBM maintenance, including breakdown analysis, spare parts procurement and technical reports to upper management.

Elisa adds, "All are things that require an early wakeup, some daily time spent in the tunnel, and a good internet connection."

Although they point out that their career has not been a long one, they already know the bracing side to a life spent tunnelling. "In Ethiopia we lived an unrepeatable experience of work and life. It was the site at which we faced and overcame a major geological event, probably the worst ever encountered by a TBM. The machine, stuck in squeezing ground under a pressure of 40bar, had to be rescued 4.2km from the

Martino Scialpi has a story familiar to many in the industry: childhood memories of whizzing through tunnels in his father's car, staring up in wonder as they pass through one after another. Elisa Comis has a tale possibly familiar to many more – having studied mechanical engineering with a specialisation in materials science and technology in Rome; she worked for two years after graduation in the Interdepartmental Laboratory of Electronic Microscopy. "By pure chance I left microns behind for huge machines," she says.

After a short training period in Italy with Condotte, Seli employed Martino as site manager, working on the Gilgel Gibe II tunnel in Ethiopia in 2007. Elisa was also employed by Seli - in 2007 she supervised the design and the first assembly/test of a double shield TBM at the factory for the MAVI Tunnel Project in Turkey.

The two met in 2008 when Elisa joined the project in Ethiopia. They moved to Hong Kong to work on the Tsuen Wan drainage tunnel in 2009.

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8 - 10 MARCH 2011

**The 14th Australasian Tunnelling Conference**

Organisers are aiming for a meaningful conference to mark the start of the Second Decade of the 21st Century, setting a standard for the 2014 ITS Conference in Sydney. An extensive array of topics are to be covered.  
Contact: Belinda Martin, the AusIMM. Tel: +61 3 9658 6125  
Email: [bmartin@ausimm.com.au](mailto:bmartin@ausimm.com.au)

13 - 16 MARCH, 2011

**2nd Annual Tunnels & Underground Construction Summit, Abu Dhabi**

Building on the success of the 1st Annual Tunnels & Underground Construction Middle East summit, which was held in May, in Abu Dhabi, IQPC is delighted to announce the dates for its 2nd annual event. Featuring:  
\* A transport projects focus day  
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\* More participation from Saudi Arabia, Qatar and Egypt  
Tel: +971 4 364 2975  
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20 MARCH 2011

**ACG Shotcrete Quality Assurance and Quality Control Workshop, Canberra, Australia**

This workshop is aimed at the site personnel/supervisors/operators charged with implementation of a design which they may not have developed. All site personnel, supervisors, operators, geotechnical engineers and relevant suppliers and consultants should attend!  
Contact:  
Josephine Ruddle, marketing manager  
Australian Centre for Geomechanics  
Ph: +61 8 6488 1864, [www.acg.uwa.edu.au](http://www.acg.uwa.edu.au)

7 - 9 APRIL 2011

**Underground Space - 1st Scientific Symposium on Tunnels and Underground Structures in South-East Europe**

The intention of this symposium is to proliferate the knowledge of tunnelling and use of underground space which is already the state-of-the art in other parts of the world. The topics focus on all aspects of durability of structures from conceptual stage to design, construction, operation and maintenance phases. Contact: Symposium Secretariat manager, Ms. Tanja Rabar  
Tel: 00385-51-322-854  
Email: [tanja.rabar@hubitg.com](mailto:tanja.rabar@hubitg.com)

21 - 26 MAY, 2011

**WTC 2011 Helsinki - Underground spaces in the service of a sustainable society**

The Finnish Tunnelling Association awaits you in Helsinki. A boom in tunnelling is currently underway in Finland. In this exciting environment WTC 2011 has been organised. General subtopics to include: planning the usage of subterranean spaces, municipal services, operational technologies, traffic and logistics, geologic disposal of nuclear waste, renewable energy, project management.  
Website: [www.wtc11.org](http://www.wtc11.org)  
Booking / accomodation enquiries:  
Tel: +358-9-5607500 Email: [wtc11@congreg.fi](mailto:wtc11@congreg.fi)

19 - 22 JUNE 2011

**RETIC 2011 - Rapid Excavation and Tunneling Conference and Exhibit, San Francisco, California**

RETIC is an international forum for the exchange and dissemination of developments and advances in underground construction. For more information contact event organiser: RETIC Exhibits, 8307 Shaffer Pkwy, Littleton, CO 80127, 303-948-4213, [gury@smentet.org](mailto:gury@smentet.org)

22 - 23 JUNE 2011

**Tunnel Design and Construction Asia, Sentosa, Singapore**

Featuring best practices in geotechnical investigation, EPC contracting, project funding and risk management for Asia's tunnel infrastructure. The keynote speaker will be Heinz Ehrbar, chief construction engineer of AlpTransit Gotthard. Tel: +65 6722 9388  
Email: [enquiry@iqpc.com.sg](mailto:enquiry@iqpc.com.sg)

29 - 30 JUNE 2011

**Underground Construction Conference and Exhibition, London**

The eyes of the global tunnelling industry are swivelling towards the UK with some of the world's largest underground construction projects getting underway. Event includes: technical and design developments in underground construction, tunnel operation and maintenance, sustainable development and minimising the impact of underground works, a world wide tunnelling perspective, UK projects - today and the future, ground investigation, treatment and monitoring.  
Tel: +44 (0) 207 973 6695  
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12 - 16 SEPTEMBER 2011

**6th International Symposium on Sprayed Concrete, Tromso, Norway**

Main themes will be design, construction and durability of wet-mix sprayed concrete in underground structures. The Norwegian Concrete Association is currently revising the Publication No. 7, Sprayed Concrete for Rock Support. This will be debated during the symposium. Contact: Siri Engen Email: [siri.engen@tekna.no](mailto:siri.engen@tekna.no) Website: [www.sprayedconcrete.no](http://www.sprayedconcrete.no)

14 - 15 SEPTEMBER 2011

**IUT 2011, Sargans, Switzerland**

Those involved in tunnelling will get together to exchange views and inform themselves about the latest trends and technologies. The traditional IUT Evening on the first day of the fair, being held in a VSH cavern, will be a highlight: here exhibitors and visitors will be able to exchange views against a relaxed background and experience an unforgettable evening. Contact: Deltacom Projektmanagement +49 (0)40 35 72 32 - 0  
[info@deltacom-hamburg.de](mailto:info@deltacom-hamburg.de)

**BRITISH TUNNELLING SOCIETY**

17 MARCH 2011: **Green Park Step Free Access**

The works included a south-eastern extension to the existing ticket hall incorporating a ramp from the adjacent Green Park directly into the station, and the installation of two lift shafts. This presentation will discuss the development of the design and construction of the elliptical lift shaft and stub tunnel using SCL methods & escalator jacking system and the instrumentation and monitoring equipment employed.

21 APRIL 2011: **Harding Prize Competition**

The Competition is open to all aged 33 or under at the end of 2010. Entrants must submit an original paper relating to any aspect of tunnelling which they consider of interest to those in the tunnelling industry. The closing date for submission of papers is 28th February 2010.

19 MAY 2011: **BTS AGM + Limerick Immersed Tunnel**

The Limerick Tunnel will provide a new road crossing under the River Shannon The tunnel comprises five 100m long immersed tunnel elements, a cut and cover tunnel and approach ramps on each bank.

29 JUNE 2011: **High Speed Railway Tunnels in Spain**

With the opening of the new Levante line, the Spanish High Speed Railway network has become the longest in the world. HSR lines with their demanding alignments require the design and construction of an unusually high number of tunnels, some of which are amongst the longest and more important in the world. This presentation provides information of three good examples of the tunnels recently built in Spain: Guadarrama tunnel, Pajares tunnel and finally Atocha-Chamartan tunnel. This is an evening BTS Presentation being held at the "BTS Underground Conference 2011" on 29th to 30th June 2011. It is a 2 day conference being held in the Earls Court Exhibition Centre.

15 SEPTEMBER 2011:

**Crossrail**

Status update. Latest developments on this major London project.

20 OCTOBER 2011:

**BTS / BGA Joint Event. Towards a Specification for the Ground - The use of Geotechnical Baseline Reports in the UK**

Ground References Conditions. Working title details to follow.

**A DATE TO REMEMBER...**

If you know of a tunnelling related conference, event, seminar or exhibition that is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site: Editor, 'Tunnels & Tunnelling International', Boundary House, 91-93 Charterhouse Street, London, EC1M 6HR, United Kingdom.  
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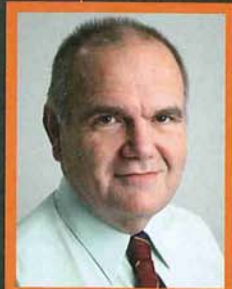
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## Underground Construction

Conference and Exhibition  
Incorporating the International Tunnelling Exhibition

Earls Court, London, UK  
29th and 30th June 2011



The eyes of the global tunnelling industry are swivelling towards the UK in anticipation of some of the world's largest underground construction projects getting underway. Already some £20bn of tunnelling work can be foreseen with Crossrail, the massive Thames Sewer Tunnel, underground rail line extensions, Dublin's DART project, and tunnels at the new nuclear power stations being started shortly.

In recognition of the interest that these projects will create, we are pleased to announce the Underground Construction Conference and Exhibition at Earls' Court, London on 29th and 30th June 2011.

The two-day Conference is being co-ordinated by British Tunnelling Society, Institute of Materials, Minerals & Mining, the Pipejacking Association and the International Tunnelling Association with support from many other professional bodies.

For further information, or for details on the Call for Papers please contact:  
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For additional information on reserving a stand at the associated International Tunnelling Exhibition please contact:  
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