

NOVEMBER 2010

tunnels & tunnelling INTERNATIONAL



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T&TI takes a look at Chile's tunnelling boom and Panama's hydro power demands

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How rapid developments in computing and laser technologies are boosting productivity

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comment

Record breakthrough

Last month I wrote that October was set to be a month of cuts but, while the axe has fallen on several projects, October will certainly go down as a month of triumphs.

London's Crossrail had GBP 1bn lopped off its budget. New York and New Jersey's Access to the Regions Core project was killed for the second time. But two other news stories grabbed the world's attention.

The first was the rescue of the 33 Chilean miners trapped some 700m underground in a collapsed copper mine. Their plight first caught the eye of the world's media when, after 17 days of being trapped, the miners were discovered by a probe hole alive and relatively well.

Three rescues attempts were launched, together costing the Chilean government between USD 10M and USD 20M and it quickly became a race between the tunnellers, the oil drillers and the deep well excavators.

The raise borer launched as the tunnellers' effort was known to be the slowest method due the two stage bore process – a pilot hole followed by a reamer. But as a well-established technology in Chile it was a safety net for the faster but less tested alternatives.

The deep well hammer drill won the race but the tunnelling industry had more to give. Those with sharp enough eyes to see through tears of joy may have noticed that all references to commercial enterprises, even helmet stickers, disappeared from their TV screens before the arrival on site of President Sebastian Pinera and his entourage, leaving only the Chilean flag recognisable. This was after government orders to that effect.

One of the logos to be removed was that of Austrian contractor and equipment supplier Ostu-Stettin Hoch- und Tiefbau of Leoben. Mining project director Gerhard Brugger explained that the company owned the famous yellow hoisting frame and winch used in lifting the Fenix 2 escape capsule through the narrow bore, and its employees set it up on site and operated it throughout the rescue.

It is nothing short of a miracle that these miners were found and rescued. Luis Urzua, the shift supervisor who was credited with helping the men survive the first 17 days before rescue teams made contact, was the last man to be rescued. After 70 days underground, Urzua now holds the world record for the longest time trapped in a mine.

A second world record was broken last month. On 15 October the Channel Tunnel lost its title as the longest transport tunnel in Europe and Sei-Kan tunnel in Japan lost its title as the longest transport tunnel in the world. The Gotthard Base Tunnel west bore now cuts 57.017km under the Alps with a maximum overburden of 2.5km.

Gotthard is a massive feat of engineering and shows the world the extreme conditions that tunnellers are able to overcome with current technologies and understanding. It is a very proud month for the tunnelling industry as a whole and everyone who played a part on making Gotthard a success deserves that recognition. The supplement accompanying this issue of T&TI goes into details on the base tunnel with interviews from the engineers on site. It is well worth a read!

Jon Young

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T&TI pays a visit to Mexico City's Metro Line 12 work site (page 21)



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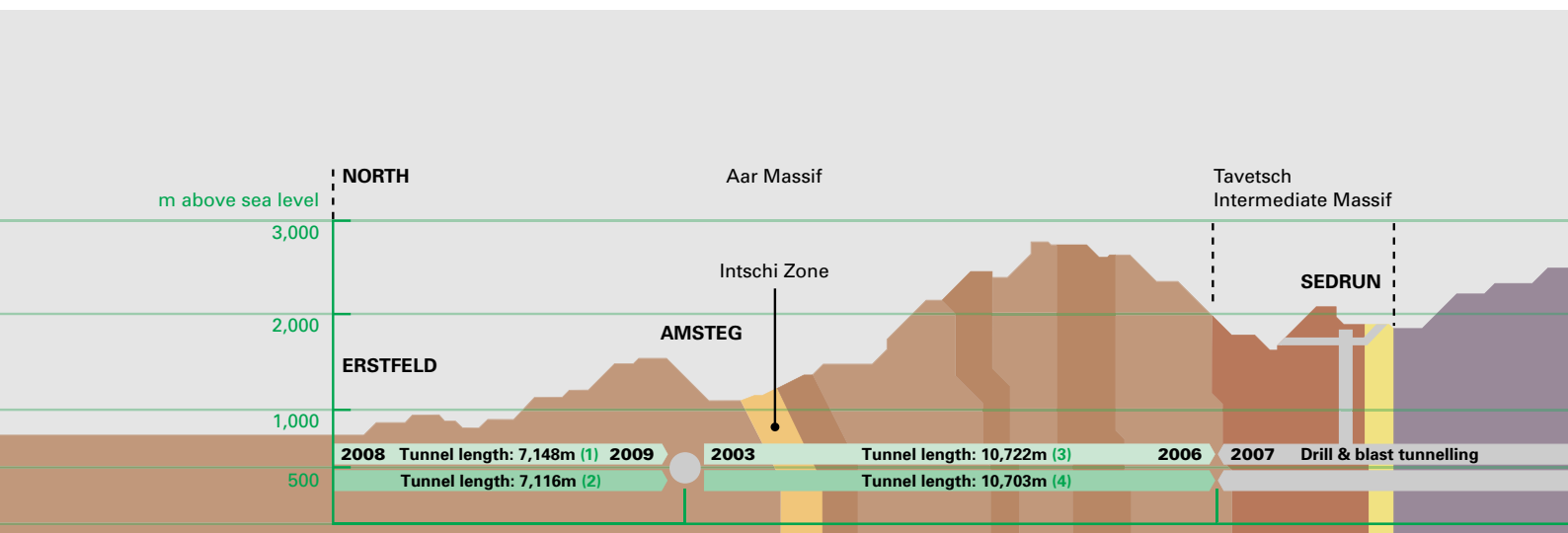
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WORLD RECORD

CONGRATULATIONS ON THE FINAL BREAKTHROUGH

The breakthrough at the Gotthard Base Tunnel on October 15, 2010 marks the most significant milestone on the way to completing the longest railway tunnel in the world. Europe salutes Switzerland's achievement in creating this 2 times 57 kilometer long epoch-making project to connect northern and southern Europe by rail through the Alps. Our thanks go to the client AlpTransit and our customers for allowing us to be part of this spectacular feat and historic undertaking with our tunnelling technology.



ERSTFELD/AMSTEG

AMSTEG/SEDRUN

AGN Consortium: STRABAG AG Tunnelbau Schweiz (CH) / STRABAG AG (A),
Project Manager of the AGN – Gotthard Base Tunnel North Consortium: Beat Blindenbacher



(1) Gabi I, Herrenknecht Gripper TBM S-421, Ø 9.58m
(2) Gabi II, Herrenknecht Gripper TBM S-422, Ø 9.58m

(3) Gabi I, Herrenknecht Gripper TBM S-229, Ø 9.58m
(4) Gabi II, Herrenknecht Gripper TBM S-230, Ø 9.58m

- ▶ **April and May 2008:** Start of regular tunnelling.
- ▶ **July 19, 2009:** 56m of new tunnel are created in just 24 hours. This is deemed to be a world record for a hard rock TBM of such dimensions.
- ▶ **June 16, 2009 and September 16, 2009:** The machines reach their targets after just 18 months – 6 months ahead of schedule. Deviation from the ideal axis measures only 4mm in the horizontal and 8mm in the vertical.
- ▶ **Top tunnelling performances:** 56m/day, 185m/week, 711m/month.

- ▶ **October 2003 and January 2004:** Start of regular tunnelling.
- ▶ **2004:** The TBMs pass the Intschi fault zone more quickly than planned.
- ▶ **June 2005:** A mixture of water and fine material entered the cutterhead in the western tube. The TBM must be freed and cannot restart tunnelling until November.
- ▶ **June and October 2006:** The construction site teams successfully complete tunnelling at the end of the lots, 9 and/or 6 months ahead of the schedule.
- ▶ **Top tunnelling performances:** 40m/day, 210m/week, 688m/month.

AT THE GOTTHARD.

AT THE NEW GOTTHARD BASE TUNNEL.

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Chairman of the Board of Management



Dipl.-Ing. (FH) Gebhard Lehmann
Vice Chairman of the Board of Management

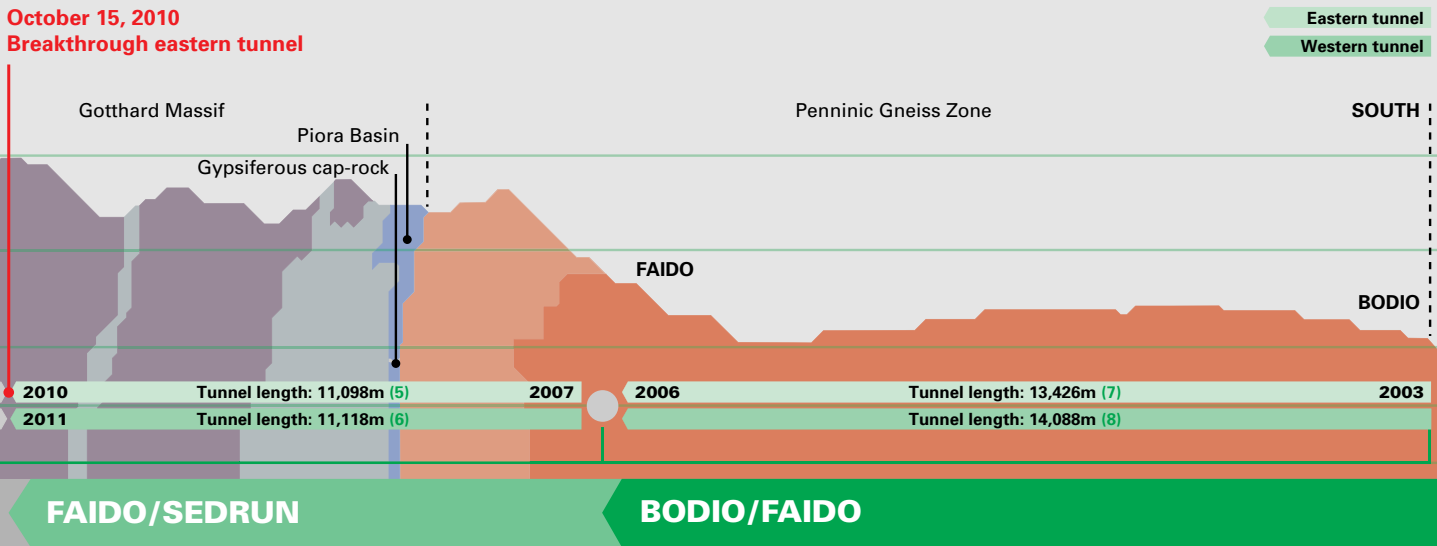


Betriebswirt (VWA) Kurt Stiefel
Member of the Board of Management

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October 15, 2010
Breakthrough eastern tunnel



TAT Consortium: Implenia Industrial Construction, Alpine Bau GmbH, CSC Impresa Costruzioni SA, Hochtief AG, Impregilo SpA,
overall Project Manager of the TAT Consortium (Tunnel AlpTransit – Ticino): Olivier Böckli



(5) Sissi, Herrenknecht Gripper TBM S-210, Ø 9.43m
(6) Heidi, Herrenknecht Gripper TBM S-211, Ø 9.43m

- ▶ **July and October 2007:** The TBMs begin tunnelling the second construction phase in the south with new, larger cutterheads (Ø 9.43m).
- ▶ **October 2008 and February 2009:** The 150 meter long Piora Basin is crossed successfully.
- ▶ **March 2010:** A rock fall in the western tube and the subsequent stabilization measures interrupt tunnelling here until July.
- ▶ **October 15, 2010: Breakthrough in the eastern tube. World record.**
- ▶ **Top tunnelling performances:** 36m/day, 179m/week, 705m/month.

(7) Sissi, Herrenknecht Gripper TBM S-210, Ø 8.83m
(8) Heidi, Herrenknecht Gripper TBM S-211, Ø 8.83m

- ▶ **January and February 2003:** Start of regular tunnelling.
- ▶ **2003:** After just 200 meters the tunnellers unexpectedly encountered unstable kakirites. This slows down tunnelling for 6 months, since every meter of tunnel must be secured in a complex process.
- ▶ **2004 to 2006:** Stable rock alternates with brittle, squeezing rock.
- ▶ **September 6 and October 26, 2006:** Successful breakthroughs at the Faïdo underground multifunctional station.
- ▶ **Top tunnelling performances:** 38m/day, 190m/week, 619m/month.

Gotthard base tunnel, lot 360



About the Gotthard base tunnel - lot 360:

• Project: 2 x 8 km single tube rail tunnel

- Shotcrete Dramix® RC-65/35-BN
- Fire protection: Duomix® M6 Fire

• Production: Underground batching plant

- logistic cooperation with Holcim

High Performance!

- high energy absorption
- ductile concrete with improved load capacity
- high impact and fatigue strength
- improved crack control

Financial Benefits!

- no need for mesh or expensive reinforcement frame
- reduced concrete consumption
- fast easy application

Benefits from our Service:

- Bekaerts Lab
- On site support
- Quality control
- Most economical and qualitative end result
- Global expert

Crossrail faces GBP1bn cut

GREAT BRITAIN

Cuts of GBP1bn (USD1.6bn) have been made to London's Crossrail project in a drive to bring down the total GBP15.9bn cost. The cuts will delay completion of the project by 12 months.

As part of the recent Comprehensive Spending Review the UK government announced the funding available to the project had been reduced by some GBP1bn and, thanks to savings found through a cost review, the project delivery cost was not expected to exceed GBP14.5bn.

Crossrail played down the cuts.

Speaking on the day the Comprehensive Spending Review was published Crossrail chairman Terry Morgan said, "We welcome today's strong statement by the government of its firm support for the project. Today's decision removes any remaining doubt that Crossrail is going ahead and that it will be built in its entirety."

A spokesman for Transport for London, one of the financiers for the project, told *T&T*, "Throughout 2010, started by the previous government, Crossrail has been going through a cost-saving process looking for any efficiencies that can be made. The government then noted in the

spending review that Crossrail had made savings of GBP1bn."

Crossrail claimed the savings can be found in 'engineering-led solutions' and the 'reprogramming of the central tunnels programme' and, as a result, the project is not suffering any cutback in terms of scope.

The spokesman added, "The final delivery cost is still not known and won't be known until the main tunnel contracts have been awarded."

The awarding of the central running tunnel contracts was delayed earlier this year to be awarded at the start of 2011. At the time of the delay there were fears that the spending review

would impact on these tunnelling contracts.

It is anticipated that Crossrail will add GBP42bn (USD66bn) to the economy, GBP6bn more than previously thought. With this comes GBP17bn (USD27bn) worth of tax generation, 14 000-21 000 jobs created at the peak of construction and the extension of a 45-minute London business commute to a further 1.5 million people.

Crossrail currently costs between GBP50M and GBP100M a month. The UK taxpayer has so far paid out some GBP2bn, including GBP400M to get the Crossrail Bill through Parliament.

Breakthrough



SWITZERLAND

Breakthrough was made on the Gotthard base tunnel under the Swiss Alps on 15 October. The 57km rail tunnel is the world's longest.

Drilling from the Faudo section in the east tunnel, a TBM broke through the last metre of rock on the route to Sedrun. The location was 30km from the north portal and 27km from the south portal.

AlpTransit said the tunnel breakthrough was highly accurate. "At 8cm horizontally and 1cm vertically, the deviation

was very small."

About 200 people witnessed the breakthrough, and around 3,500 miners, engineers, surveyors and others watched on big screens at other locations nearby.

Completion of the USD-9bn project is expected for 2017, and it will be the longest road or railway tunnel in the world.

For complete coverage of the entire Gotthard base tunnel project, see the *Tunnels & Tunnelling* Gotthard supplement, included with all regular subscriptions this November.

Christie cancels ARC tunnel again

NEW JERSEY

New Jersey governor Chris Christie called off the USD-8.7bn Access to the Region's Core (ARC) Tunnel permanently on 27 October after a 2-week reprieve to find other funding for the project.

After considering different options for funding with US transportation secretary Ray LaHood during a the reprieve period —options Christie said still didn't take New Jersey's taxpayers off the hook—he cancelled the tunnel project.

"For me, it is a dollar and cents issue," he said. "In the end, my decision is not changed." Further to this, he cited cost overruns potentially as high as USD5bn.

The 6.5km single-track twin tunnels would have connected New Jersey to New York under the Hudson River.

The tunnel's funding was to be shared by the Port Authority of New York and New Jersey, both of which would be contributing USD 3bn. The federal government

would also be contributing a further USD3bn. New Jersey would cover the final USD2.7bn, plus any overruns.

Options considered in the 2-week reprieve included securing a public-private partnership, a loan through the Federal Rail Administration and increased contributions from all partners of USD378M.

Senator Frank Lautenberg (Democrat-NJ) launched an investigation into the cancellation the next day to determine "the circumstances, actions and motivations that led to the largest loss of federal transportation resources in New Jersey history."

He said, "It is critical that the public know what happened and how we can prevent this from happening in the future."

A preliminary report will be released before the end of this year and a final report will be delivered to the public within the next six months.

For more on the ARC cancellation, see *T&T's* News in Depth on page 16.

Footscray West Link tunnel route proposed

AUSTRALIA

The Australian government last month released the proposed route for the four-kilometre Footscray tunnel in Melbourne. Roads Minister Tim Pallas announced that the AUD 5bn (USD 4.9bn) tunnel would begin at the Port of Melbourne and emerge in an industrial area in West Footscray.

The project will avoid all residential areas but up to 80 businesses could be affected by freeway construction.

Potentially paid for in part by the Federal Government as a 'nation building' endeavour, the Department of Transport had entered into 27 contracts with consultancy firms by June. Construction is unlikely to begin on this portion tunnel before 2013. It

is part of a larger, 30-year Melbourne transport project that plans to overhaul the existing infrastructure.

The situation has drawn political attention. Promoted by Pallas and fellow Labor Party MP for Footscray, Marsha Thomson, as a means of reducing local congestion, particularly from HGVs, the Green candidate, Janet Rice, has questioned these views. "If the tunnel is not tolled, it will take the traffic off the Calder, the City Link and from the suburban growth areas and funnel them straight down residential Ashley Street and Dempster Street," Ms. Rice said. "If the tunnel is tolled, trucks won't use it, so they'll still be hurtling through Footscray and clogging up the Westgate."

The project is in public consultation until 19 November.



News in brief

ACS to build 72nd Street Station

Spain's ACS won a USD-447M contract to build the 72nd Street station for the 2nd Avenue Subway line in New York. The station's main cavern is 322m long, 22m wide and more than 30m below ground level. ACS will deliver the contract through its subsidiaries Dragados and Schiavone.

Sri Lanka to open its longest tunnel

President Mahinda Rajapakse will inspect the longest tunnel constructed in Sri Lanka on 4 November at the Upper Kotmale hydropower plant. Measuring 12.9 km long with a 5.2km diameter, the LKR 37bn (USD 331M) tunnel will divert water from the Kotmale reservoir, and is expected to add more than 150 megawatts of power to the national grid.

Beverly Hills unhappy with LA Subway extension

CALIFORNIA

The Los Angeles County Metropolitan Transportation Authority (Metro) approved the draft environmental impact reports for the USD 4.2bn Westside Subway Extension on the city's Purple Line on 28 October.

This also confirmed the locally preferred alternative route recommended by Metro staff, which includes the approximately 9-mile (14.5-km) extension to

Westwood/VA Hospital along busy Wilshire corridor. Stops are proposed at Fairfax Avenue, La Cienega Boulevard, Century City, Westwood-UCLA and the Veterans Affairs' campus.

Beverly Hills officials and residents are concerned about tunnelling under the city's high school and homes, but had expressed support for the Westside Extension, just not this particular route as Metro had been considering four other options.

"We want to work with the experts and do everything we can," said Lisa Korbatov, the school board's vice president, after it had been confirmed the district had hired a lawyer. "But if it comes down to a lawsuit, we won't shy away from it."

Construction could begin in 2013, with completion of the subway to the Westwood area by 2022 if Metro is successful in securing advance federal funding.

At the same time, Metro

approved the recommended route for the USD 1.25bn Regional Connector Project, a nearly 2-mile (3.2-km) fully underground light rail line connecting the Gold, Blue and future Expo Lines through downtown LA. Construction could begin in 2014 and be completed by 2019, again depending on funding.

Both projects will now enter final environmental review and preliminary engineering.

Seven killed in Chinese rail tunnel collapse

CHINA

A tunnel collapse in northern China killed seven people in mid-October during construction of a 280km railway line.

Four workers died on site, while

another three workers passed away at a hospital. The cause of the accident is still unidentified though an investigation has been launched. Results of this investigation have not yet been announced.

Mr. Yue, a safety official, who only gave his last name as he was unauthorised to comment, revealed that another three workers were injured as a result of the collapse. There have so far been no announcements from officials.

The line will connect Chifeng, Inner Mongolia, to Jinzhou, Liaoning Province. This provides an important link between mineral-rich Chifeng with China's northernmost seaport (at Jinzhou).

China railways gets big boost

CHINA

The China Minister of Railways, Liu Zhijun, has just (1 November) signed an agreement with Jianxi province governor Wu Xiniong to accelerate railway infrastructure development in the region. The stated objective is the guaranteed sound and fast development of the economic and social infrastructure in the region. This follows a similar agreement with Jilin Province.

So far Jiangxi Province has 2900km of railways but the agreement will increase this to

6000km by 2020. Liu Zhijun praised all parties involved in the remarkable achievements of railway modernisation so far. The 'Twelfth Five Year Plan' is to concentrate on north-south routes as soon as possible, within an overall 'four vertical and four horizontal' railway network.

Wu-hsiung pointed out that Chang 'Ninetown' was only 40 minutes away following the opening of the Nachang to Jiujiang high-speed rail route, and said they wanted the Ministry to perform its duties and play local strengths to advance railway construction in Jiangxi.

Koralm tunnel to start construction in 2011

AUSTRIA

A Strabag-led consortium with Jaeger Bau has signed a EUR-570M (USD-800M) contract to build the Koralm Tunnel in Austria, with work beginning in early 2011.

The project will see the construction of two parallel, single-track bores each measuring 20km in length. Two 9.9m-diameter TBMs will be used to excavate the tunnels. The 8.5M tonnes of excavated material will be used to produce 1Mm³ of concrete for the inner lining of the tunnel.

The work represents a particular

technical challenge as the only possible access to the underground construction site is through a 60m access shaft near Deutschlandsberg in southern Styria, said Strabag.

Part of the new Koralm Railway, the tunnel is the main section between Graz and Klagenfurt. The railway is part of the Baltic-Adriatic axis of TEN Corridor No. 23 between Gdansk, Warsaw, Vienna and Bologna.

Upon completion, expected by late 2018, the Koralm Tunnel will be 32.5 km long, making it the longest railway tunnel in Austria and one of the longest in the world.

Developer fined for Delhi metro delays

INDIA

Continued delays in the opening of the Delhi Airport Express metro service (otherwise known as the IGI line after Indira Gandhi International airport, or Orange Line) resulted in a fine on the developer early last month. The 'last straw' appeared to be the failure to obtain the mandatory safety clearances from the Commissioner of Metro Rail Safety before the line could be allowed to operate.

The Delhi Metro Rail Corporation (DMRC) as client ordered penalties amounting to INR 11.25 crore (USD2.53M) on the developer and contractor for the PPP scheme, Delhi Airport Metro Express (DAMEPL), a subsidiary of Reliance Infrastructure.

DAMEPL had been awarded a 30-year concession to operate the line once completed, although DMRC is paying for half the construction costs and is responsible for the tunnelling and other civils works. There was provision for penalties for failure to complete by the set date (31 August) under the concession contract clause 16.4. It is understood that penalties can increase to about INR 75 lakh (USD 169 000) a day after 31 October and DMRC could terminate the contract if operations don't begin. The dispute between DMRC and DAMEPL has become increasingly heated.

The Airport Express was another item of Delhi infrastructure not completed in time for the Commonwealth Games held in October, but the delays were somewhat overshadowed by the more publicised problems with direct preparations for the Games. Although the original scheduled opening date was 31 July and postponed at least twice until September, it is now believed that the service should begin this month, if safety tests can be passed.

The estimated value of the project is INR 2885 crore (USD 654.9M). The 24.2km line goes from Connaught Place, New Delhi to the airport with 15.7km of the route underground. There is a planned extension past the airport to Dwarka Sector 21 and possible connection to the existing Blue Line and Indian Railways route to the South-East and Rewari. Airport Metro Express trains will travel at 135 km/h instead of the 80km/h adopted for the rest of the metro network.

Although different in concept from the rest of the metro network, the airport express is in Phase II of the overall scheme.

A further two phases are planned for overall completion in 2020. Currently the network serves Delhi, Gurgaon and Noida with six lines of 156km total length. This includes 132 stations of which 31 are underground. The railways are in both broad and standard gauge.

News in brief

■ Northern Gateway

Enbridge proposed drilling two 1.7-km tunnels beneath the Morice River in British Columbia for the 1,172km Northern Gateway pipeline. Directional drilling has been proposed after concerns were-

raised about the CAD 5.5-bn (USD-5.42 bn) project's impact on salmon in the river. The tunnels would be up to 95m below the Morice's river bed.

■ Azerbaijan tunnel complex

A complex with multiple tunnels and underpasses will be built at the Ganjlik underground station in Baku, Azerbaijan, within two

years. The complex will reportedly consist of six tunnels, two underpasses, one underground 3-storey station and two additional entrances for the Ganjlik underground station.

■ Amman tunnel completed

The Greater Amman Municipality (GAM) has

completed both sides of the upper tunnel, each with three lanes, of Prince Hussein bin Abdullah II Square in Amman, Jordan. Work in the two-lane lower tunnel from Prince Hussein bin Abdullah II Street to the airport is more than 70 per cent complete. The project started in February 2009 with a cost of JOD 23M (USD 32.5M).



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GRANDS PROJETS

Second Avenue Subway shakes buildings' foundations

USA

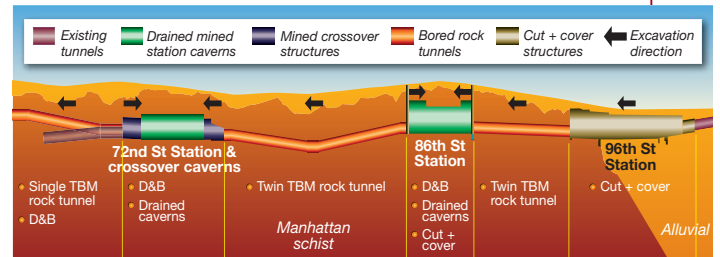
Some 51 buildings are 'too fragile' to withstand Second Avenue Subway tunnelling works. MTA Capital Construction has completed its survey of the 225 buildings on Second Avenue, New York that could be affected by tunnel works, assessing that one in four of the buildings require reinforcement.

The work will be undertaken by MTA itself, at an anticipated cost for both works and relocation of residents of around USD6-8M.

The tunnel itself isn't the issue, said MTA spokesman Aaron Donovan. "There has been no indication of any vibration or settlement associated with the TBM

operation. The area in which the building reinforcement has occurred is in the TBM launch box area, which is a braced cut-and-cover excavation and is approximately 70ft wide by 70ft deep by 800ft long (21m x 21m x 244m). The outside walls are either slurry wall (where the 96th Street Station will be built) or secant piles (where the walls are temporary for TBM launch purposes only). The adjacent 4-5-storey brick masonry buildings are typically on shallow foundations supported on soil or timber piles."

Repairs have been completed on 12 of the 80-100-year-old buildings already and involved cellar ties between front foundation walls and bearing walls where none existed already, though this is only



Below: Construction methods along Phase 1

undertaken if a certain level of settlement is reached said Donovan. He added that in some cases where facade tilting is of concern, the front walls are being 'anchored' by steel plates and ties to floor joist trusses.

The tunnel is being bored by a -485t, 140m-long, hard rock TBM. Phase one is scheduled for

completion at the end of 2016. However, MTA initially predicted a progress of 50ft (15m) per day. Actual progress is slower than this. TBM excavation has only achieved a rate of 40ft (12m) per day.

The subway will serve approximately 200 000 people per day upon completion.

Dulles Corridor breakthrough

USA

Excavation of a half-mile (approx. 0.8km) tunnel in Tysons Corner, Washington DC achieved breakthrough last week. The tunnel, which was under construction for 13 months and cost USD85M, is the most expensive section of the 23-mile

(37-km) Dulles Corridor Metrorail Extension.

It is 29ft (8.8m) in diameter and lies 40ft (12m) below a heavily congested section of road. The tunnel will connect passengers to two of the four planned rail stations in Tysons Corner.

Bechtel was the contractor chosen to handle tunnelling

works, which were the preferred solution to the 515ft (157m) Slope in Tysons.

Progress was difficult as the subterranean environs of Tysons Corner are littered with gas and water pipes. However, Dominic Cerulli, an engineer working for Bechtel, announced that they are still weeks ahead of schedule.

Malta calls for EU backing of flood-protection network

MALTA

Malta has called for EU support in an attempt to resurrect the National Flood Relief Project. The project, which will protect the region from frequent flooding, will start next year, said Maltese finance minister Tonio Fenech.

The estimated EUR56M (USD-78.5M) endeavour calls for the construction of a series of tunnels

and will require 85 per cent funding by the EU.

People living in the 12 areas intended to benefit from the proposed tunnel network (Balzan, Lija, Attard, Iklin, Birkirkara, Gzira, Msida, Zebbug, Qormi, Marsa, Zabbar and Marsascala) will avoid raising their hopes too high, however as this project has been touted and subsequently shelved on several occasions since its inception 15 years ago.

The storms responsible for the flooding resulted in a particularly high level (87.3mm) of rainfall. However, not everyone is convinced that expensive tunnelling works should or even could be used effectively in the flood-prone regions. Geologist Peter Gatt said earlier prevention methods could be more effective, such as construction of additional dams to supplement the current stock.

News in brief

▼ Lushan tunnel suspended

Construction of the Lushan Mountain Tunnel in China, announced by the Jiujiang City Bureau for Urban Planning earlier this year, has been suspended. The National Development and Reform Commission (NDRC) halted the project, claiming that it had not examined or approved the plans. These complications come during a public outcry against projects in the area.

▼ Albanian PM pushes for tunnel tender

An international tender for building the Tirana-Elbasan road tunnel would open this month, said Albanian Prime Minister Sali Berisha at a meeting for the Democratic Party Parliamentary Group on 1 November. Though he couldn't say when the works would start, he confirmed the deadline for completion would be 18 months after the contract is signed.

TBM launched in Faroe Islands

FAROE ISLANDS

A 3.35m diameter Robbins Main Beam machine is being used to build an 8.4km collector tunnel for the hydropower plant in the Faroe Islands.

The project is an extension for the Eidi II plant on Eysturoy Island. Once the tunnel is complete it will collect water from 25 streams, increasing the annual capacity of the plant from about 43GWh to about 60GWh.

Contractors MT Hojgaard and J&K Petersen are constructing the extension for utility agency Streymoy, Eysturoy and Vagoy (SEV), which owns the machine.

Launched in September, the TBM had originally been purchased in 1984 and had excavated about 25km of tunnel for the Eidi Hydropower Plant. Prior to working on Eidi II it has undergone refurbishment on the gearboxes, main bearing, lube system, and hydraulic hoses.

"We are looking into using the machine for additional projects in the next five to ten years," said



Above: A worker okays checks the tunnel face on the Eysturoy Island project

Anders Nedergaard-Hansen, head of the Power Production Department for SEV.

By October, several hundred metres of basalt rock were

excavated with no problems.

The Faroes receive an average of 250 days of rainfall annually, creating significant runoff, ideal for small hydropower plants that

use collector tunnels to transport rainwater. It's the only TBM to have been used at the islands, said Robbins. March 2013 should see the completion of tunnelling.

Jerusalem gate project calls for tunnel

ISRAEL

The Jerusalem Municipal Planning and Construction Committee has given its approval to plans to build the first new gate in the Old City for over 100 years.

The plan calls for the construction of a tunnel that will run underneath the wall between the Dung Gate and the Zion Gate.

The tunnel will incorporate an underground auditorium, visitors' centre and classrooms, as well as an archeological exhibition centre. This will improve access to the Western Wall (which the Municipality of Jerusalem predicts will experience twice its current tourist figures in the next 10 years) and will also spur renovation of the

Jewish Quarter.

Aside from the high cost associated with tunnelling through the solid rock beneath the wall, the main obstacle to construction is the anticipated Palestinian backlash against any construction projects located inside the Old City.

The most memorable such incident of recent times being the 1996 riot in response to the announcement by then Prime Minister of Netanyahu that he would open a new entrance to an archeological tunnel near holy ground. The riot caused 80 deaths.

The last gate was constructed in 1898 for the outsize retinue of Kaiser Wilhelm II and involved the demolition of the wall next to Jaffa Gate.

Tunnel refurbishment to create UK's 'safest roads'

UNITED KINGDOM

The 1967 Tyne Tunnel has begun fire prevention work as part of the GBP 260M (USD 417M) New Tyne Crossing Project.

The fire safety designs include new panelling, a fixed fire suppression system and a new emergency escape passage.

In February 2011, once the new tunnel is open, the original tunnel will finally close for the construction of the separate emergency escape passage.

According to the Tyne Tunnel Concessionaire, this will involve the realigning of traffic lanes and, along with the planned fire suppression systems, will make

the Tyne Tunnels the safest road tunnels in the country.

This is particularly important as the original tunnel, designed to accommodate 24,000 vehicles passing through each day, currently deals with approximately 38,000.

The work will be undertaken between 9pm and 5am every weeknight until the end of the year, enabling regular traffic flow to continue during the day.

At night there may be minor delays due to single lane closures and traffic management systems, during which time motorists will be granted a rare opportunity, being able to view the tunnel refurbishment works in progress as they drive past.



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Equipment orders see rise

ECONOMY

German construction equipment supply association, VDMA, has announced a recovery in sales of machinery. The orders for equipment have increased by 60 per cent during the period January to August 2010, compared to the same period in 2009.

However, revenues belie this vast increase in activity. Sebastian Popp, economic expert of the Construction Equipment and Building Machinery Association of VDMA announced that the current level

of turnover is at best equivalent to the level enjoyed in 2005.

If revenues continue to accrue at the present rate, however, VDMA will rise above their own predicted increase of five per cent by the end of the year.

This recovery is expected to continue at least into the next year. IHS Global Insight predicts that the worldwide construction industry will grow by about four per cent a year from 2009 to 2014.

Asia has been targeted as a large factor in this, with growth estimated at around 8 per cent, the Asian Development Bank (ADB) anticipates that Asian growth will,

in 2010, constitute around 46 per cent of the global total.

South America is also identified as a promising future market. Brazil, in particular, is planning to invest USD 480bn in energy supply, housing construction and infrastructure over the next four years.

The construction industry in the country is worth approximately USD 100bn, or, 5 per cent of GDP. Indeed, the Brazilian construction machinery association Sobratema has anticipated sales of construction machines will increase by more than 24 per cent in 2010.

Asia boosts BASF profits

PROFITS

Buoyed by growth in Asia, chemical manufacturer BASF expects to generate sales and profit next year exceeding the record levels predicted for 2010.

There has also been a strong demand for plastics as well, so it is anticipated that sales volumes will increase in the fourth quarter, according to board member Martin Brudermueller.

"The dynamics of demand took us by surprise. The majority of our plants are operating close to full

capacity, especially in Asia."

In the fourth quarter, sales are set to increase from EUR 13.2bn (USD 18.5bn) to around EUR 15.6bn (USD 21.9bn) a year, according to BASF.

"We see no signs of business activity weakening," he said. "2011 will also be a growth year for BASF, with sales and earnings rising."

China alone will add around EUR 300bn (USD 419bn) in chemical industry sales by 2020. BASF has added 21 per cent this year, valuing it at more than EUR 48bn (USD 67.3bn).

With the company's 2010 outlook, it predicts a rise of nearly 65 per cent in earnings before interest and taxes EUR 8bn (USD 11.2bn). Revenue is forecasted to rise to EUR 63bn (USD 88.4bn) from EUR 50.7bn (USD 71.1bn).

Kurt Bock, chief financial officer, will take over the top job following BASF's annual general meeting on May 6. Like Bock, Brudermueller's promotion to second in command is coinciding with a rebound in markets that spans BASF's more commodity-based plastics like styrene, an area he also oversees.

News in brief

Parsons Brinckerhoff acquires Halsall

The Halsall Group, comprising Halsall Associates, Pivotal Projects and Loop Initiatives has become the Canadian operating company of Parsons Brinckerhoff, it was announced in October. Halsall specialises in infrastructure planning, design and construction management.

US Department of Transportation funds high-speed rail

The Federal Railroad Administration announced USD 2.4bn of funding for 54 high-speed rail projects in 23 states. The agency said it received 132 applications from 32 states, seeking a total of USD 8.8bn. Awards include USD 901m to California, USD 800m to Florida, USD 230 to Iowa and USD 161M to Michigan.

Bids in for Alaskan Way Viaduct

Washington governor Chris Gregoire announced both bids submitted to design and build the SR 99 bored tunnel in Seattle were at or below the contract price limit. The submittals were from two teams of national and international tunneling firms. Total cost of the proposed bored tunnel is estimated at USD 1.96bn, and includes design, right of way, construction management and more than USD 200M set aside for risk.

VolkerFitzpatrick to construct Crossrail academy

VolkerFitzpatrick has been awarded the GBP 6M (USD 9.6M) contract to construct the new Crossrail Tunnelling and Underground Construction Academy (TUCA), which will be built at Aldersbrook Sidings close to Ilford town centre in London. The Department of Business Innovation and Skills have provided GBP 5M (USD 8M) of funding for TUCA.

Costain wins National Grid tunnelling contract

CONTRACT

National Grid has awarded Costain the GBP 200M (USD 321.9M) contract for 32km of tunnel beneath London. The tunnel will carry power cables that will enable National Grid to deal with increased demand and better handle rising energy flows across the city.

The project calls for two tunnels, each between 3 and 4m in

diameter and approximately 20 to 60m below ground. The first, at 20km, will run from the National Grid substation in Willesden via Kensal Green, St. John's Wood and Islington to the substation in Hackney. The shorter 12km tunnel will run from Kensal Green to Wimbledon. Work on the tunnels will commence in late 2010 and is expected to be finished by the end of 2014. The energisation of the new cables is anticipated to have

taken place by November 2018.

Construction director of National Grid, Michael Dyke has said that the new programme will be built below the existing network 'minimising disruption'. The contract also includes the design and build of associated head-houses and installation of ventilation equipment.

Programme and project management contracts were awarded to Arup and Mott McDonald earlier this year.



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:



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Calling off ARC

USA

New Jersey Governor Chris Christie killed the Access to the Region's Core (ARC) tunnel project on 27 October over the risk of covering cost overruns.

Also known as the Trans-Hudson Express Tunnel, the USD 8.7bn ARC tunnel would have been the second commuter rail line to connect New Jersey to Manhattan. The project called for two, 6.5-km, single-track tunnels under the Hudson River—bringing some 6000 jobs to the state of New Jersey and doubling the number of trains travelling into the city daily.

The project had been on thin ice with Christie (Republican) for nearly two months after he had called a 30-day suspension on 10 September to review costs.

Christie, elected in November 2009, had inherited the project from the former New Jersey governor, Jon Corzine (Democrat). It was during Corzine's tenure that federal funding for the tunnel had been applied for through the Federal Transit Administration (FTA)'s New Starts programme.

Both the Federal Government and the Port Authority of New York and New Jersey had each dedicated USD3bn to the project. New Jersey would pay the remaining USD2.7bn and any overruns.

The FTA required New Jersey to guarantee all costs over the USD8.7bn to qualify for the USD3bn portion of federal funds. The governor had confirmed this in February 2010. His office pointed out the first cost range, of USD10.9-13.7bn, was presented by FTA on 16 August.

"The potential for USD 2bn-5bn cost overruns was something that was unacceptable for me to contemplate, knowing that it was just the beginning, potentially, of what this project would cost," Christie said.

At the end of the 30-day suspension, he announced his cancellation of the project on 7 October saying it was too risky (T&T October page 5).

US transportation secretary Ray LaHood met with Christie the next day to discuss options for saving the tunnel and the governor agreed to a 2-week reprieve. At this point, federal officials updated the project cost to a low-end estimate of USD9.8bn ranging up to USD12.7bn.

Not included in the original cost was the USD775-M Portal Bridge South, required as part of ARC. This would be covered by the state of New Jersey.

Christie and LaHood met again 24 October, and the federal government proposed four approaches based on the assumption that total cost would



Above: Governor Chris Christie

be a mid-range USD 11.7bn. The four approaches included one or more of the following:

- Cutting back ARC by USD700M;
 - A loan from Railroad
- Rehabilitation and Improvement Financing (RRIF), which can provide direct loans and loan guarantees up to USD35bn with repayment not commencing for six years after first drawdown of the loan;
- A Public-Private-Partnership (PPP) of USD1.85bn—the difference between the current budget and the low-end cost estimate (USD9.8bn) plus money for the Portal Bridge South;
- Additional USD378M contributions from all parties involved—the Federal

Government, Port Authority and the state—to fund the difference between the current budget and the low-end estimate.

Christie said none of the proposals eliminated the state's exposure to cost overruns.

"In the end my decision has not changed," he said. "I cannot place upon the citizens of the State of New Jersey an open-ended letter of credit. And that's what this project represents."

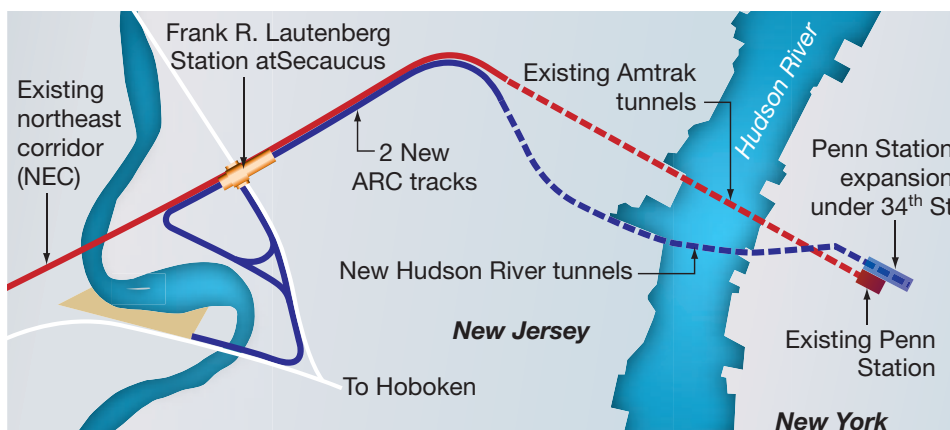
Senator Frank Lautenberg (Democrat-NJ), who has been a strong critic of Christie's decisions the past two months, disagreed. "The governor was presented with a proposal from the Department of Transportation that would shield New Jersey from the risk of cost overruns," he said of the PPP proposal. "It was clear from the beginning that Governor Christie planned to kill the ARC Tunnel no matter what."

Opponents to the cancellation have questioned Christie's decisions as not taking taxpayers off the hook, as he said, but rather as playing at partisan politics in a mid-term election.

In the past two months constituents have alternately lambasted Christie, or applauded his decisions on what is sometimes nicknamed the 'tunnel to Macy's'.

Nicole Robinson

Below: The existing and the recently cancelled Trans-Hudson tunnel routes



Blanka tunnel collapse

Dear Sir,

The August issue of Tunnels and Tunnelling International contained, on page 14 in the News column, an article by Kris Mole titled: Questions asked as Blanka Tunnel collapses for third time.

The ITA-AITES Czech Tunnelling Association supposes that it must let you know about its opinion on the content of the above-mentioned article.

A third collapse of a mined tunnel on a single tunnelling project is certainly a serious matter. Nevertheless, it is necessary to know that the Blanka Complex of Tunnels project is exceptionally extensive and has been implemented in very difficult and variable geotechnical conditions. The third collapse of the tunnel cover took place in a part of the construction which completely differed from the location in which the two preceding collapses had occurred.

We fully respect your right to

inform about this exceptional event in Tunnels and Tunnelling International journal. However, we suppose that the fact that the author drew solely from more or less lay opinions of a member of an interest group called the Club for Ancient Prague, an employee (a preservationist) of a public organisation, the National Heritage Institute, and a member of the Green Party was not appropriate for your renowned and professional journal. The opinions of all of the quoted gentlemen were unprofessional. In addition, they were highly populist, containing political undertones.

First of all, the allegation of the above-mentioned preservationist that the Blanka complex of tunnels will not improve the Prague environment and will conduct the main traffic into the city centre is highly misinforming. The contrary is true. Prague has been building a modern circle road system. The main components of the system are two circles: an outer motorway

route encircling the city of Prague and an inner city circle road. The Blanka complex of tunnels will form a part of the City Circle Road. Surely, the solution comprising two circles interconnected by radial roads will protect historic parts of Prague against transit traffic and terminating traffic. Several years ago, when the section of the City Circle Road containing the

Mrázovka and Strahov tunnels was inaugurated and opened to traffic, automobile traffic flow in adjacent parts of the city was significantly reduced.

Nor the opinions of the Green Party member can be considered to be objective. This party, which is in opposition in Prague, is seeking any opportunity for criticising the current city government today, in the period which will soon end by the city council election. Experience shows that opinions of politicians on similar technical matters are usually not focused on the root of the trouble. They are rather

motivated by other, usually partisan interests. It is probably improper for a technical journal to publish them.

In conclusion, we take the liberty of drawing your attention to the fact that members of the ITA-AITES CzTA have repeatedly published problems of the Blanka complex of tunnels construction in conference papers and technical magazines, including objective analyses of the two incidents the investigation into which has already been concluded. Since the expert investigation into the third collapse by relevant organisations has not been finished yet and its results are not known, all preliminary standpoints must be considered to be personal opinions.

Miloslav Novotny
Secretary of the ITA-AITES Czech Tunnelling Association

T&TI makes every effort to contact all parties relevant to a story to give them opportunity to respond. In this instance not all responses were forthcoming as T&TI was going to press. - Ed



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Spending heads south

Mexico, Panama and Chile are seeing tunnelling for many of their infrastructure projects, and they're not alone in the region, Nicole Robinson reports

Compared to wealthier countries, such as the UK and US, the recession and economic woes of the past few years did not have as severe an effect on those in Latin America. Couple that with the need to build much of their infrastructure, and there are plenty of opportunities for tunnelling, but with their own hurdles.

When asked how the financial crisis has

affected tunnelling in Mexico, project manager for the District Federal, Enrique Horcasitas says he isn't so sure there is even a crisis, as there are several EPB machines working in and around Mexico City. "We've never had this many. This sounds like a boom."

He's overseeing construction of the city's Metro Line 12. A 10.2m diameter Robbins EPB machine will bore 7.8km and cross seven underground stations of the 25km alignment (page 21). The approximately USD 1.4bn contract awarded to Mexican construction firm Ingenieros Civiles Asociados (ICA), in a consortium with Carso and Alstom, calls for construction to be completed in 2012, when the city's

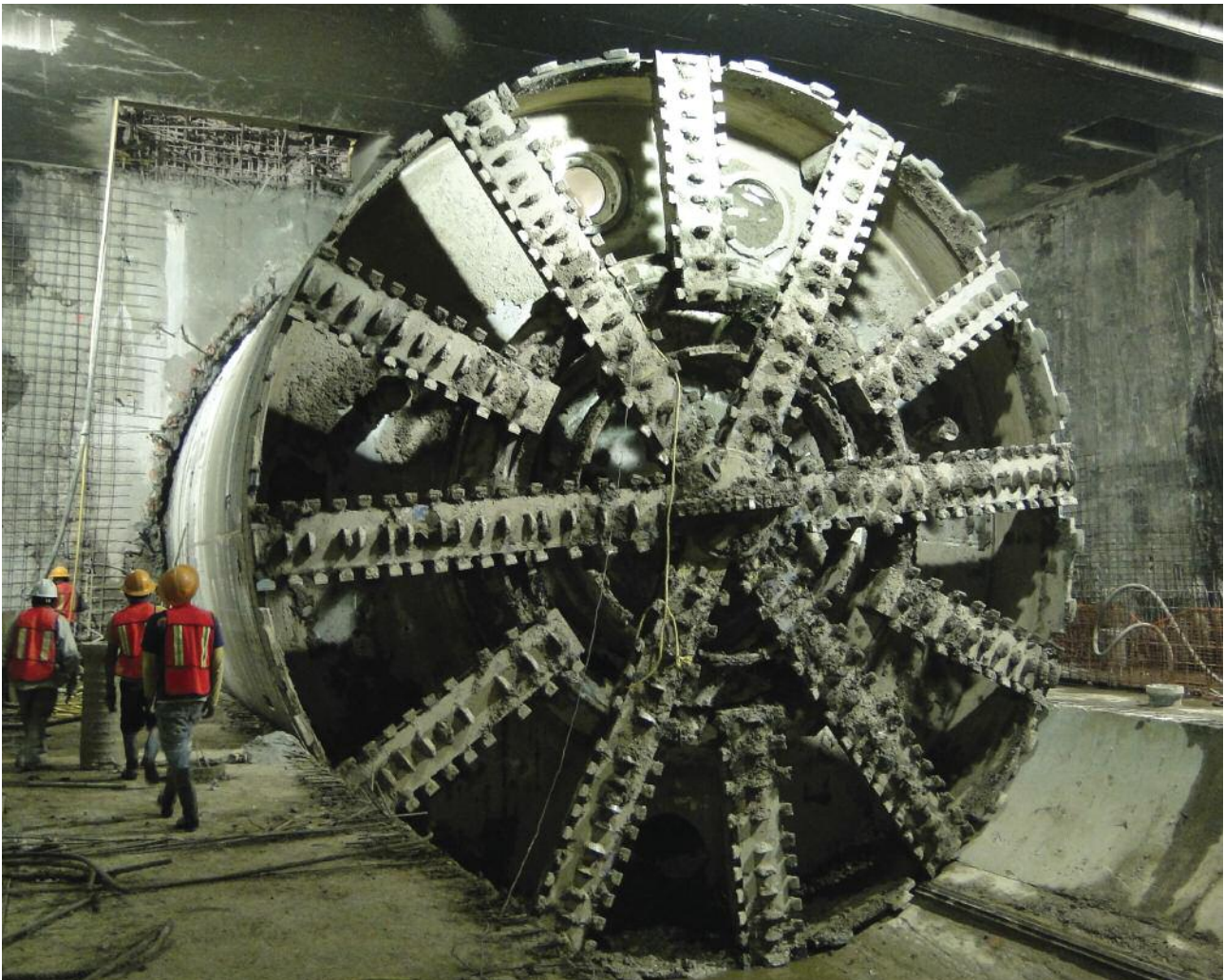
mayor's term ends.

It's the first time in 10 years that Mexico City is doing underground construction for its metro system. While Horcasitas explains the project is partly related to politics—the current city government is pro-tunnels—the topic of climate change has had influence as well, helping gain a positive public perception.

"The tunnels market in Mexico is lower mainly due to the lack of building important infrastructure," says Horcasitas. However, he points out, "infrastructure development in Mexico seems to be growing."

There are currently major construction projects, but there are also challenges to overcome in the short term. Besides Line

Below: The 10.2m Robbins EPB TBM will spearhead the Mexico City tunnelling





12, Mexico City's metro network has plans for five more lines to be built, giving a total of 483km. Currently the city has 215km of lines, and Line 12 will bring that up to 240km. These lines are needed, but so is the budget to build them. There is also the 62-km wastewater Tunel Emisor del Oriente (TEO), rock tunnels of about 14m x 14m for La Yesca hydroelectric dam and several highway tunnels.

One project under construction is the modernisation of the Durango-Mazatlan highway crossing the Sierra Madre Occidental mountain range, which currently includes a more treacherous passage nicknamed the Devil's Backbone. Around 60 tunnels in varying lengths are included in plans for the new highway and upon completion (expected in 2012) it will reduce journeys by up to three hours and be much safer.

Early this summer, Spanish tunnelling contractor Proacon signed a contract for more than 200M pesos (USD 16M) from the Mexican Federal Government's Ministry of Communications and Transport for six new tunnels, in addition to 14 tunnels already in progress by Proacon on the project. In total, the six tunnels measure 2053m long, the shortest of which is 123m, and the longest 710m. They have a common section of 110m² and 130m² of excavation. The contract also included single-bore Baluarte Tunnel, notable for accommodating four lanes of traffic and located in front of Baluarte Bridge. This also under construction as part of the project and will be the longest in Latin America.

Around the region there was a hesitation to see what would happen with the crisis, says Andrei Olivares, project engineer for Robbins Mexico. "But tunnelling is emerging again," he says. "There is activity in Colombia, Argentina has some projects, and there is a metro line in the Dominican Republic."

Cities across the region are planning, tendering and or executing metro projects, including Caracas in Venezuela, Santiago in Chile and both Sao Paulo and Rio de Janeiro of Brazil. The later, besides the increasing transportation demands day-to-day, is set to host both the 2014 World Cup and the 2016 Summer Olympics, putting further pressure on both cities. Elsewhere these projects include extensions, entirely new lines or even new networks as some governments have only begun building subway infrastructure.

The Dominican Republic's government transport authority, called Opret by its Spanish acronym, has a master plan for



Above: San Cristobal is a twin-tube tunnel in Santiago by Hochtief and ACS Dragados

phased construction of the capital city Santo Domingo's metro system. Line 1 started commercial operations in January 2009, with the service running north and south. A Dosco Mk3A roadheader was delivered to the project this April to work on Line 2, which will run east to west across the city under John F. Kennedy Avenue, entirely underground. There are plans for Line 3, but a timeline has not been confirmed.

Panama City is currently in the bidding process for the design, build, equipping and commissioning of its first subway line. An announcement is due at the end of October to see which of two final bids will be awarded the 14km Line 1. Consortium Linea Uno (lead by Construtora Norberto Odebrecht (CNO)) and Grupo Italiano Metro Panama (lead by Impregilo) were the only two submitted bids for the 31 August deadline. A second line is being studied by the government.

That's not all for country with a population of nearly 3.4 million. Elsewhere, CNO is constructing the 8km interceptor tunnel for the Panama City Wastewater Treatment Plant using a Herrenknecht EPB shield with a 3.67m diameter. The machine was delivered in August and started boring in early October. Funding for the project comes from the Inter-American Development Bank in the form of a USD-45M loan to the Panamanian Ministry of Health.

Next year, Panama will also see two very similar EPB TBMs launched on sister drives through lahar, a variable volcanic rock (page 26). The projects are on the

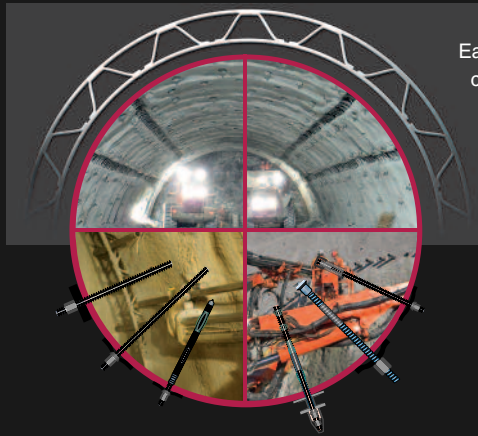
Chiriqui Viejo River, close to the border with Costa Rica. Each machine will be used to construct a headrace tunnel, one of 7878m for the Monte Lirio hydropower plant and the other, just up stream, of 5161m for the Pando plant. Seli was awarded a USD-105M engineering-procurement-construction (EPC) contract for the two tunnels by Electron Investment, and it will undertake the work through a subsidiary, Seli Panama, which it established in November last year.

As *T&T* went to press, opening ceremonies were held for hydropower stations in Chile (La Higuera and La Confluencia) while the Chacayes hydropower project is being constructed in adjacent Cachapoal Valley for 2011 (page 28).

Originally a consortium of Astaldi and Fe Grande was awarded an EPC contract worth USD 282M in October 2008 for the Chacayes project, which includes 6km of tunnels. This was consolidated to 27.3 per cent in jv with Pacific Hyrdo in May 2009.

The capital city, Santiago, has also seen tunnelling for other transport. The San Cristobal 1.8-km, twin-tube road tunnel is part of a larger 4-km construction project connecting two districts in the east of the city to two others in the north through the San Cristobal Hill. Construction started in May 2006 using drill and blast. The toll road opened in 2008, though with restricted services. Germany's Hochtief and Spain's ACS Dragados have a 50-50 share in the build, operate, transfer project until 2037.

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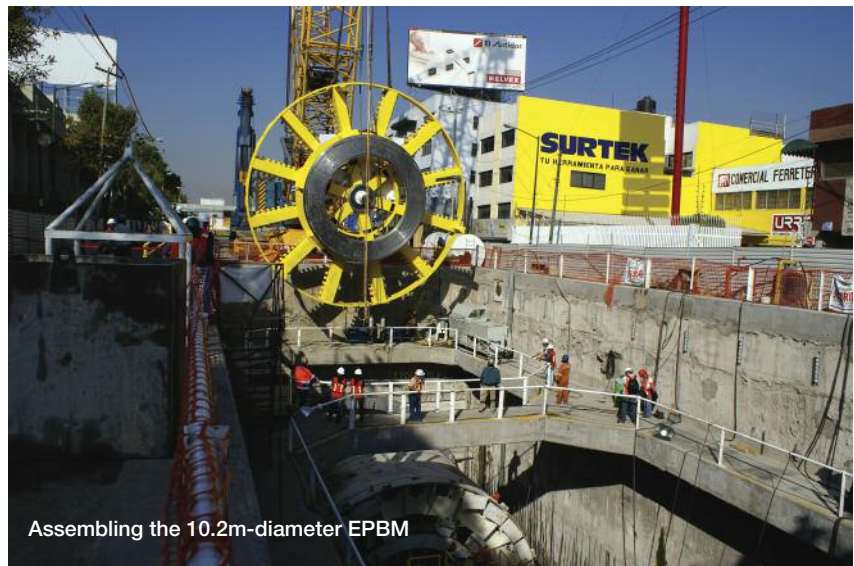
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A master plan for metro expansion

Tunnelling on Mexico City's Metro Line 12 started this year, and it's the first time a metro project makes use of an EPBM for its clay soil. This project will improve transportation options for hundreds of thousands of people daily, as Mexico City makes good on a master plan developed nearly 50 years ago, Nicole Robinson finds



Assembling the 10.2m-diameter EPBM

Of the entire metro system of Mexico City, some 215km, the new Line 12 is being built in the most difficult ground conditions. The geology is mainly clay with sand containing boulders up to 800mm in diameter. For this a 10.2m diameter Robbins EBP TBM is being used, the first ever in the city. However, that wasn't always the plan, looking back to the project's inception.

All other metro lines in the city have been built using cut-and-cover and have been in better ground, explains Ismail Benamar, project manager with Ingenieros Civiles Asociados (ICA), which is not only the contractor for this project—in a consortium with Grupo CARSO and Alstom—but has also built many of those metro lines. In fact his company did much of the groundwork paving the way for the whole system.

In the 1960s, the president of ICA started doing studies of subterranean Mexico City. Around 10 years later, ICA gave the mayor a gift: plans for an executive project to build a metro system underground. General director of the project for the Mexican

Federal District (the official name for the city), Enrique Horcasitas, explains the ICA basically told the mayor of Mexico City: An underground metro is a necessity, whether or not we are the contractor to build it, so here is the master plan for its construction.

Complete with ground surveys, feasibility studies, alignments and so forth, this plan for some 300km of metro lines is reviewed on a 10-year basis—most

recently in 1996. In early 2007, the Federal District decided to build the 25.1-km Line 12, based on its costs and benefits when considering the network as a whole, with some funding assistance from the federal government. With strong support from the city's mayor, whose term ends in 2012—at about the same time as the project—the contract was tendered as design and build, another first for the city's metro.



Right: Figure 1: The Line 12 alignment and geological conditions

**Table 1: Construction methods of Line 12**

	First phase	2nd phase	Line total
Bored tunnel	0.0km	8.7km	8.7km
Cut and cover	1.0km	2.0km	3.0km
Ground level	1.9km	0.0km	1.9km
Elevated	11.5km	0.0km	11.5km
Total	14.4km	10.7km	25.1km

Right, top: Figure 2 – Underground construction for Line 12

Right, bottom: Surface level work for Ermita Station

Volcanoes and lakes

In the distance from sprawling Mexico City, one can make out the faint arc of mountain ranges. Forming a border around the modern city, long ago these created the basin for the now drained Lake Texcoco, where the city was founded. Many of these mountains saw volcanic activity that deposited ash into the lake, forming the clay soil for which the city is known.

The valley is occupied by hills composed of hard floors such as tuff and alluvium – the latter is a result of rivers that flowed to the lake. These areas generally occur at the periphery of Lake Texcoco but are also located within the lakes themselves, such as Hill of Estrella, amongst others. Viscous basalt eruptions from the volcanoes of the nearby Xitle hills led to the formation of basalt and other rocks in the area of the city where Line 12 is being built (Figure 1).

A low transition zone south of the alignment marks a junction of the lake and hills that formed a gradual beach between hard floors and the soft clays of the lake. Further west, to the south of Mixcoac Station, an area of high transition signifies more extensive beaches or those with a more abrupt thickness formed by alluvial soils mixed with the lake's soft clay.

These clays have a variable thickness and in some cases are up to 80m long and have water content up to 500 per cent. With the area's lakeside origin, the water table is currently detected between 2m and 3m deep. "Which means that these clays are saturated, are highly deformed and have low shear strength," explains Horcasitas. So geotechnical studies were aimed at defining the following:

- Determine the thickness of soft layers and define their mechanical properties by defining their shear strength and deformability.



- Determine water pressure within the clay mass.
- Determine the regional subsidence along the axis of Line 12 to consider its long-term effect on the design of the line.

The established alignment

Line 12 had originally been specified as having cut-and-cover construction along its entire 26.1km length, much like the rest of the network. However, in this overcrowded city, occupying the streets and disrupting utilities would be a major problem and pose a time constraint with the 2012 deadline. Technical and economic studies also showed cut and cover would cost MXN19.5bn (USD1.57bn), which was over budget.

ICA offered to build Line 12 for around MXN17.58bn (USD1.41bn) using four different procedures—at ground level, elevated, cut and cover and with the EPB TBM. The tunnel would be up to 19m

deep, run for 7.7km and include eight underground stations (Figure 2). This divided the project into two phases; that above ground and below ground (Table 1).

In phase two, tunnelling a single, large tube with the EPB TBM was favourable to take advantage of the soil, making it the faster and more economical choice. Compared to cities like London, there isn't much other underground infrastructure in Mexico City, leaving plenty of room for the 10.2m-diameter tube, though the route does pass within 1.5km of a 4m-diameter collector sewer, 2m of building foundations and 3.5m below metro Lines 2 and 3.

In phase one, the above-ground portion of the alignment, there are rockier ground conditions, not favourable for an EPB machine. Rather than cut and cover, the elevated and at ground level construction methods were chosen to save time, money and disruption at the surface.



Monitoring measures

Currently, in the approximately 1200m excavated with EPB TBM monitoring, the behaviour of the neighbouring structures hasn't indicated any major distortions that may risk of stability or affect municipal facilities, Horcasitas reports.

ICA brought in a permanent team in charge of instrumentation, and monitoring the software it has developed that allows the team to monitor everything in real time.

For example, this instrumentation measures horizontal and vertical deformation, water pressure in the subsurface and topographic measurement in the surface and surrounding structures.

In addition to the preliminary geotechnical report, ICA completed boreholes along the alignment and other geotechnical studies, finding nothing of significance. "We also take into account that all the underground stations are now under construction so we can see, on a big scale, what they are finding underground and it's more or less what we expected," says Benamar.

Left: The EPB TBM installs a segmental lining as it excavates the Line 12 tunnel

for the machine's launch in February. The machine build finished in about 10 weeks using Robbin's Onsite First Time Assembly. Components were lowered into and assembled in the 34m by 14m and 17m deep pit. At start-up the machine excavated the first 70m using umbilical cables connected to back-up gantries at the surface. (See *T&T* March 2010 for more on the assembly and launch).

One third at a time

Tunnelling has been divided into three more or less equal-sized parts, from the launching shaft to Ermita Station, from Ermita to Parque de Los Venados Station and from there to the exit shaft. The three walk-in access shafts will change as each third completes its tunnelling.

It should take about one month for

The alignment's only digression from the master plan was in phase one, moving part of the line and its workshop from Acoxta to Tlahuac, where there was more demand for public transportation, explains Horcasitas. This was decided by a public survey.

move the launch shaft east of Mexicaltzingo by 500m, because the station was still being excavated and waiting for its completion would have required a 3-month delay, says ICA's Benamar.

EPBM assembly started in October 2009

Where to launch

For the tunnelling, the launch shaft was originally to be located at the western end, where there is harder ground. However, there were issues with properties on the surface that created too much of a delay in the construction of Mixcoac station—work that only started three weeks ago.

That wasn't entirely the case on the eastern end of the tunnelling portion (though similar property problems had delayed construction on Mexicaltzingo Station), at least not to the same extent. ICA decided to

Table 2: Distances for Line 12's underground stations

Stations (east to west)	Station length	Distance between next station (east to west)
Mexicaltzingo	193m	1,761m
Ermita	194m	870m
Eje Central	154m	1,277m
Parque de Los Venados	154m	520m
Zapata	231m	409m
20 de Noviembre	154m	721m
Insurgentes Sur	154m	738m
Mixcoac	209m	-



Right: The Robbins EPB TBM after its breakthrough to Mexicaltzingo Station

everything to be dismantled and the portion of completed tunnel cleaned and ready for fitting out, while setting up again at the next point, explained Benamar. "Doing more than 7km of tunnelling from one launching shaft to the exit can be done, but it's a big investment on all the equipment," he says.

As mentioned earlier, time is of the essence for this project—and this decision is coincidentally a particular time saver. "We decided to put the second lining in the softest ground, which is subject to very high natural subsidence," says Benamar. This can start only after the tunnelling and first lining is complete.

The EPB TBMM is installing a 400mm thick, rebar-reinforced concrete segmental lining with seven plus one configuration as it advances. These segments are manufactured by ICA outside of the city and trucked in. It's possible to carry the components that make up one ring in each truckload. In the beginning, the TBM progress was averaging three rings per 12-hour shift and it took about a month and a half to reach the fastest speed, said Stefano Petris of Robbins, who trains the machine's operators. In September and October the machine has been completing 10 to 11 rings in a single shift.

To control subsidence, there is a soil additive injected in front of the machine, and a 2-component backfilling system of cement and accelerant that hardens rapidly to fill the gap between the excavation and the segments. "The gel time is very quick, maybe 15 seconds," says Roberto Gonzalez of Robbins. "There is very little settlement. Right now they say the limit is 70mm and the machine is behaving well under the parameters."

But there are concerns that the tunnels and station will have different degrees of settlement. ICA will use a continuously cast concrete, reinforced with rebar 20cm thick that will be applied for about 1km from the launching shaft to 500m east of Mexicaltzingo Station.

By the end of April, the machine had completed the first 500m to breakthrough at Mexicaltzingo Station. At the time of T&T's site visit, the machine was only 200m away from an early November breakthrough at Ermita station. This will complete the project's longest drive, about 1800m, and will mark the end of the first third of tunnelling, requiring a new access shaft (Table 2). Application of the second lining will start soon after, before the end of the year.



Stations and their excavations

The upper slab of each underground station will be 2-3m below street level; all stations are underneath one of the city's roads. With the harder ground on the western end of the alignment, Insurgentes Sur and Mixcoac Stations are being built with secant piles, rather than diaphragm walls as are being used in the other six stations.

After installing the walls, about 3m is excavated and then a slab is placed on top, leaving two windows of space from which the rest of the station is excavated and where equipment can be lowered down. These windows are located roughly where the TBM will enter, measuring 8 by 10m and an exit measuring 16 by 10m to accommodate the launching frame.

In the seven stations that the TBM must cross, existing ground, mostly clay, is removed and replaced with cemented ground for better stability where the machine will enter and exit. While in the stations, two segments are installed on the tunnel invert to push through. There is also scheduled TBM maintenance at each station including cleaning, and checking the cutting tools.

The spoke-type cutterhead has tungsten carbide, knife-edge teeth of 120mm, and so far none of them have needed changing, as the ground is so soft. From January 2011 that won't necessarily be the case. After the breakthrough at Ermita in early November, plus roughly two weeks of maintenance, the machine will start its 870m drive to Eje Central Station, with arrival expected by the end of the year.

Changing geology

So far excavations through the soft ground have used a sludge pump to remove the clay through a series of pipes along the tunnel, up to a collection point on the surface at the access shaft. The material is taken by truck to an approved area, 35km out of the city.

From Eje Central Station the ground improves says Benamar and a conveyor

will be used for muck removal instead of the pumps. The TBM is equipped with two 1200-mm screw conveyors. The first is a ribbon-type that allows boulders to be transported to the top and taken out on a collection gate. The second can handle more liquid material. "So you have here two very high-powered pumps that work over 100bars," says Gonzalez.

In this same area, the TBM will complete two 250m-radius curves to the right and then left, before crossing the last four stations. The machine is designed to provide more articulation in curves for precise construction of the segmental lining. It successfully completed right and left curves earlier this year in the drive to Mexicaltzingo Station.

The distances between stations are shorter once the curves are completed. A 15x12m exit pit is already constructed equidistant between Insurgentes Sur and Mixcoac Stations where the TBM is expected to arrive in August 2011. While there aren't definite plans after it's removed, Benamar hopes it may be used again on a tunnelling project in Mexico City.

Future tunnelling

Part of the master plan calls for an extension on Line 12, and this is almost decided says Horcasitas. This would include two more stations and 1400m of tunnel going west from Mixcoac station, using the New Austrian Tunnelling Method. The only factor standing in the way of the project is the funding. Paperwork has been filed and is waiting approval by the Legislative Assembly of the District Federal. A decision is expected on 15 November.

Building a new line, or any project, is very much related to politics Horcasitas explained but there are plans for five other lines to be built (Lines 10, 11, 13, C and D).

It's no coincidence when a project ends at the same time as a government official's term. With the city's master plan in place, and 6-year terms, it may not be too long until Mexico City's metro is seeing tunnelling again. ■



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Growth in Chile

Tunnelling activity is growing in Chile with key hydro, road and mining projects and combinations of equity and construction involvement by foreign firms. Report by Patrick Reynolds

Chile has seen a number of tunnelling projects over the years and activity has been growing more recently with excavations in the hydro and road sector, and also a TBM in a mine.

Key projects of late, some still being excavated and others having already come into service, include the La Higuera, La Confluencia, Chacayes and Angostura hydro schemes as well as the San Cristobal toll road tunnel and copper mine development at Los Bronces.

What is notable of these recent projects is

the presence of Australian, Norwegian, Italian, German and Brazilian firms in development of the projects. The companies range from energy utilities Pacific Hydro and SN Power to construction groups Astaldi, Seli, Impregilo, Hochtief, ACS Dragados and Queiroz Galvao Group.

Chilean companies involved are Tecsa and its Constructora Fe Grande unit.

A focus of interest among a number of the foreign firms also has been to help make the projects happen in the first place, and taking equity stakes, though some are focused on straight construction services. Hochtief and Astaldi, though, have done both.

La Confluencia & La Higuera

La Confluencia and La Higuera are sister hydro projects in the Tinguiririca river basin, about 150km south of Santiago, and they have involved significant tunnelling works. The projects have been developed by Pacific Hydro in co-operation with SN Power, now majority owned by Norwegian utility Statkraft. The utilities joint venture to develop and operate the projects is Tinguiririca Energia.

The turnkey civils contractor for La Confluencia is a 70:30 JV of Hochtief Construction and Tecsa. The 158-MW project was officially inaugurated at the end of last month. Turnkey civils works for La Higuera were performed by

Constructora Queiroz Galvao Sucursal Chile SA, which is part of the Brazil's Queiroz Galvao Group, and the 155-MW plant also recently came into service, though later than previously scheduled.

Upstream lies the La Confluencia project, which has two branch tunnels supplying waters from the Tinguiririca and the Portillo/Azufre rivers to a surface powerhouse. The discharged flows enter into the head of the La Higuera conveyance system.

There are three main tunnels across the two hydropower projects – the Tinguiririca and Portillo branch tunnels which are 9.3km and 11km long respectively, generally about 7m wide and excavated by drill and blast using six Sandvik jumbos; and, La Higuera's dominant tunnel, which is a 5m diameter, almost 17.5km long transfer tube, also excavated by drill and blast. In addition, upstream of each powerhouse is a surge shaft.

Chacayes

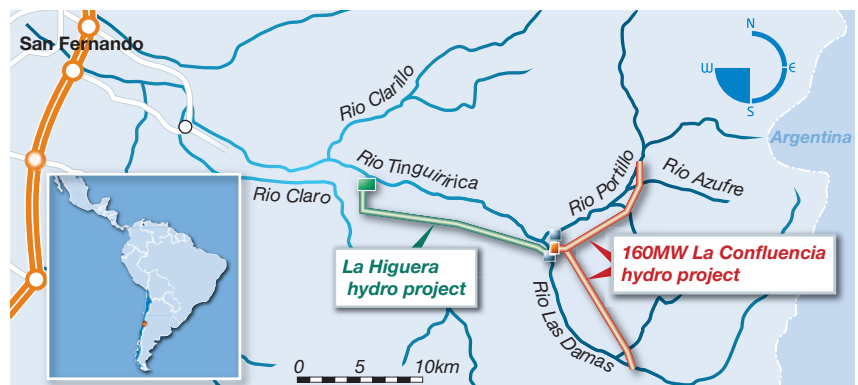
Development of the Chacayes hydropower project involves Pacific Hydro, once again, but this time with Astaldi as both an equity and construction partner.

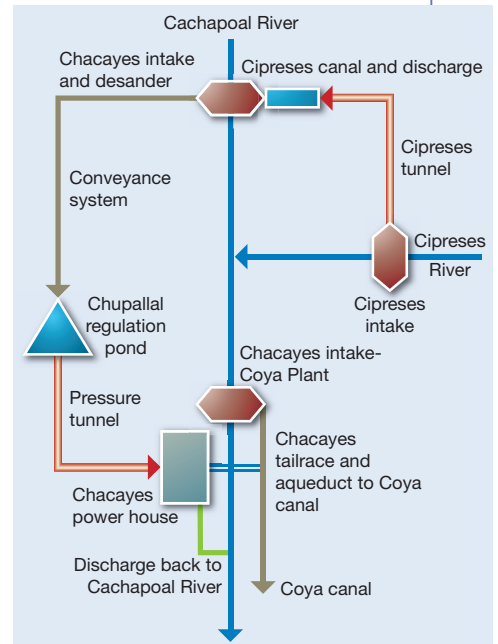
The run-of-river scheme involves construction of a surge shaft and more than 6km of tunnels split into three sections – the Cipreses transfer tunnel, which taps the Cipreses River; two short transfer tunnels, including the Peralitas tube, part of a conveyance system including canals, culverts and a 2.6km long headrace tunnel running down the Cachapoal River to the



Left: Map of some key recent and ongoing projects involving tunnelling works in Chile

Below: Layout of the La Higuera and La Confluencia headrace tunnels





surface powerhouse. The works are at a late advanced stage.

A jv between Astaldi (95 per cent) and Chilean firm Fe Grande was awarded an engineering-procurement-construction (EPC) contract two years ago. Then in mid-2009, the year after Astaldi entered into a development agreement with Pacific Hydro to look at potential projects in the river basin, the Italian firm took a 27.3 per cent equity stake in the company undertaking the 111-MW development – Pacific Hydro Chacayes. The project is due to be completed next year.

Astaldi's first entry to Chile was in the late 1980s with construction of tunnels on the Alfafal hydro project on the Colorado River

Los Bronces

For the Los Bronces copper mine, the owner, Anglo American Chile, wants to investigate how to optimise development of the deposit, and called upon TBM technology to do so.

The probe tunnel is being excavated by joint venture contractor Dragados-Belsaco using a 4.5m-diameter compact double-shield universal (DSU) machine, which was manufactured by Seli to order for the mine owner. Slightly more than 8.1km of tunnel is to be bored at the Los Sulfatos prospect, over an estimated two years.

Seli's simpler, shorter DSU shield with 27 (no.) 19-in. (483-mm) discs was launched in late 2009 from a cavern opened up by drill and blast. By the middle of last month the TBM had advanced 2716m with a best monthly progress rate of 363.5m (August). The following month progress was almost

as good, at 351.9m.

The first 3150m of the drive is in quartz monzonite, to be followed by a short section of rhyodacite porphyry, 1300m of andesite and then other sequences.

San Cristobal

The 1.8km long twin tubes of San Cristobal toll road tunnel in the northern part of Santiago were opened to traffic over 2008-9 by the concessionaire on the public-private-partnership (PPP) scheme; a jv of Hochtief and ACS Dragados. Eight cross passages connect the tubes.

Tunnelling was performed by a combination of drill and blast and mechanical excavation for the 10m wide tubes. The bores holed through in 2007 and the first lining was completed and services installed the following year.

Construction work on the project was undertaken for the concessionaire by construction partners including Hochtief, ACS Dragados, Brotec and Belfi with Geocontrol as consultant.

The PPP concession was awarded in 2005, and Hochtief's stake is held by Hochtief Concessions.

Angostura

The Angostura hydropower project is just getting underway in the Bio-Bio region, approximately 600km south of Santiago. The project involves excavation of diversion tunnels on the Bio Bio River and a large underground powerhouse.

In the second quarter, a jv of Impregilo with local firm Fe Grande was awarded a construction contract valued at

Above: Schematic of the separate Cipreses transfer tunnel and headrace on the Chacayes hydro project
Left, top: Finishing touches to a tunnel for the recently inaugurated La Confluencia hydropower project
Left, bottom: A 4.5m-diameter Seli compact TBM is driving an exploratory bore at Los Bronces copper mine

approximately Euro 200M (USD 275M) by local utility Colbun to undertake the civil engineering works. The utility has a budget of USD 657M for the entire project, and it expects the 316MW plant to be completed by early 2013.

Impregilo said the award marked a return to the Chile while it has been already active elsewhere in Latin America, both on hydropower projects, and as part of a consortium to widen the Panama Canal.

Fe Grande is working on the Chacayes hydro project with Astaldi.

More Ahead

Hydropower is providing the majority of the tunnelling work in Chile at present, with a number of projects in development, including those under study by Astaldi along with Pacific Hydro. This may provide the Italian with both more construction and equity opportunities. While its compatriot has made a return to Chile, Impregilo remains on a construction-only focus.

Chile looks set to present both opportunities and further challenges for tunnellers in the next decade with the possibilities for further civils and underground works.



Panama power

EPB TBMs are to drive through highly variable, lahar volcanic rock to bore headrace tunnels for a string of small hydro plants in Panama. Report by Patrick Reynolds

By this month, Seli will have tested and delivered at its factory in Aprilia, Italy, the second of two very similar EPB TBMs to be launched shortly in Panama on sister drives through lahar, a variable volcanic rock rarely met by tunnellers.

Each machine will be used to construct a headrace tunnel, one for the Monte Lirio hydropower plant and the other for the Pando project, just upstream. The run-of-river projects are on the Chiriqui Viejo River, which runs west in Chiriqui province, close to the border with Costa Rica.

The first of the mixed-face EPBMs was tested last month, and is now being shipped to Central America for a January launch on the 7878-m long headrace for



Above: Location of the neighbouring Pando and Monte Lirio hydro projects in western Panama and the layout of their headrace tunnels

Below: Seli is supplying two EPB TBMs under an EPC contract to drive the Pando and Monte Lirio headrace tunnels. Excavation starts in January





the Monte Lirio project. Then, in February, the second machine is to start boring the 5161m-long Pando drive.

To all intents the machines are almost twins, except for the very slight difference in diameter—3.92m for the Monte Lirio TBM and 3.72m for the machine on the Pando drive. Aside from the slightly differing inner diameters of 3.2m and 3.0m, the pre-cast concrete tunnel lining, too, is almost the same—1.2m long rings with five-plus-one 250mm-thick segments.

What has brought the similarities in tunnelling equipment and lining is the close geographic relationship between the two projects, which have, in effect, a hydro cascade arrangement, the same uncommon lahar geology, and Seli being appointed the engineering, procurement and construction (EPC) contractor for both headraces. The drives are below groundwater level.

The project clustering extends further—Seli was just last month awarded a separate contract to build the headrace for the El Alto project, the next plant downstream in the Chiriqui Viejo cascade. However, a bigger EPB TBM—6.79m in diameter—is required for that project, which is being developed by a different group, a local joint venture of Hydro Caisan and Panama Power Holdings.

Pando-Monte Lirio scheme

Located in the mid-upper stretch of the river, the Pando-Monte Lirio scheme is one of many hydropower projects planned for the Chiriqui Viejo valley. It is being developed by Electron Investment, which won a 50-year electricity generation concession that was awarded by the state regulator, Autoridad Nacional de los Servicios Públicos (ASEP).

Electron Investment is responsible for the design, construction, operation, maintenance and funding of the projects as well as a transmission link to the Central American grid. Pando (approximate rating 32MW) is to be commissioned in mid-2012 and Monte Lirio (approximately 52MW) by the end of that year. The scheme will have a total installed capacity of 83.3MW (firm capacity of 57.5MW), and is expected to generate 450GWh of electricity per year, which will be split between utility and spot market sales.

The hydropower scheme is estimated to cost USD292M, and a 63:37 debt-to-equity ratio is planned. Funding for the project is coming from multilateral lenders such as the International Finance Corporation (IFC), the arm of the World Bank Group dealing with private projects and the Inter-American Development Bank (IADB). Hatch Mott MacDonald undertook a project

assessment for IFC.

Equity is being provided to the scheme by its two sponsors—the Spanish investment firm Inveravante Inversiones Universales, which is owned by entrepreneur Manuel Jove Capellan, and Fundacio Fernando Eleta Almaran, an investment vehicle owned by the local Eleta family. They jointly own Electron Investment, which is a special purpose company established in Panama. The Spanish investor holds 51 per cent, which is to rise to 65 per cent.

Seli was awarded a USD105M engineering, procurement and construction (EPC) contract for the two tunnels by Electron Investment in the third quarter of 2009. It will undertake the work through a subsidiary, Seli Panama, which it established in November last year.

Lahars

Chiquiri Viejo river valley is steep-sided and runs in the geomorphological border formed of detritus from separate collapses, millions of years ago, of the Baru and Colorado volcanoes in the early Tertiary Period and the more recent Quaternary Period. In the project area the geological formations comprise detritus flows, lahars and landslides. The headraces will be bored mainly through lahars.

Lahars, which are common to the Pacific Rim, originate as volcanic slurries, often with significant water content, especially if the gravity flow is produced from an area involving crater or sub-glacial lakes. The powerful slurries can also result from pyroclastic flows becoming mixed with either running or bodies of water, or snow and ice.

Phreatic explosions, or steam blasts, from volcanic activity can also trigger the soil and rock mass to merge with water. Other mechanisms include land shifts or avalanche collapses, from seismic activity. However, in tropical regions there can also be lahars generated by heavy rain falling on recently ejected pyroclastic debris on the slopes of a volcano.

The mudflows can have high bulk density, such as more than 1400kg/m³ or almost two-thirds the density of normal concrete and the matrix can include a wide range of debris, from dust, ash and fragments to stones and boulders, some of which can be several metres wide.

The heterogeneous, unsteady mass can run on a laminar boundary layer at the base, which reduces the resistance to flow and leads to the slurry sliding great distances to wreak widespread damage along the valley channels that they follow, and there can be significant loss of life. The

Lahar at La Joya

Working in an Italian joint venture with Ghella, Seli undertook the tunnelling works on the La Joya hydropower project in Costa Rica and while lahar was encountered it was a relatively small part of the drive and proved to be stable.

The 50-MW hydropower project was developed by Spanish power company Union Fenosa Generadora and was completed just over four years ago on the Reventazon River in the mountainous Central Valley region.

Seli bored a 7900m long headrace with geology along the alignment comprising lavas, breccia and other volcanic deposits, such as lahars. The tunnel crosses faults as well as long and continuous sections of completely weathered rock with no residual cohesion and high groundwater inflows. Overburden varied from 50-600m, and watertable was 60-120m over the crown with a mean of 80m.

Ground conditions were different to those indicated in the tender documents, says Seli in an RETC 2007 paper. To build the 5.60m (i.d.) headrace it selected a 6.18m diameter Robbins double-shield TBM with 43 (no.) 17-in. (approx. 430 mm) back-loading cutters, a maximum cutterhead thrust of 10750kN, torque of 3440kN (4470kN breakout), and rotational speed of up to 7.2 rev/min. The power was 1440kW (8 x 180kW).

The lining was formed of 200mm-thick, hexagonal honeycomb segments (four per ring). The contract also involved two surge tanks and a penstock.

Apart from the generally well-cemented and stable lahars, the geology was much worse than predicted and very poor in general—almost 2.2km in Class V and a further 545m in even more difficult ground with low cohesion and offering less than a few minutes of face stability.

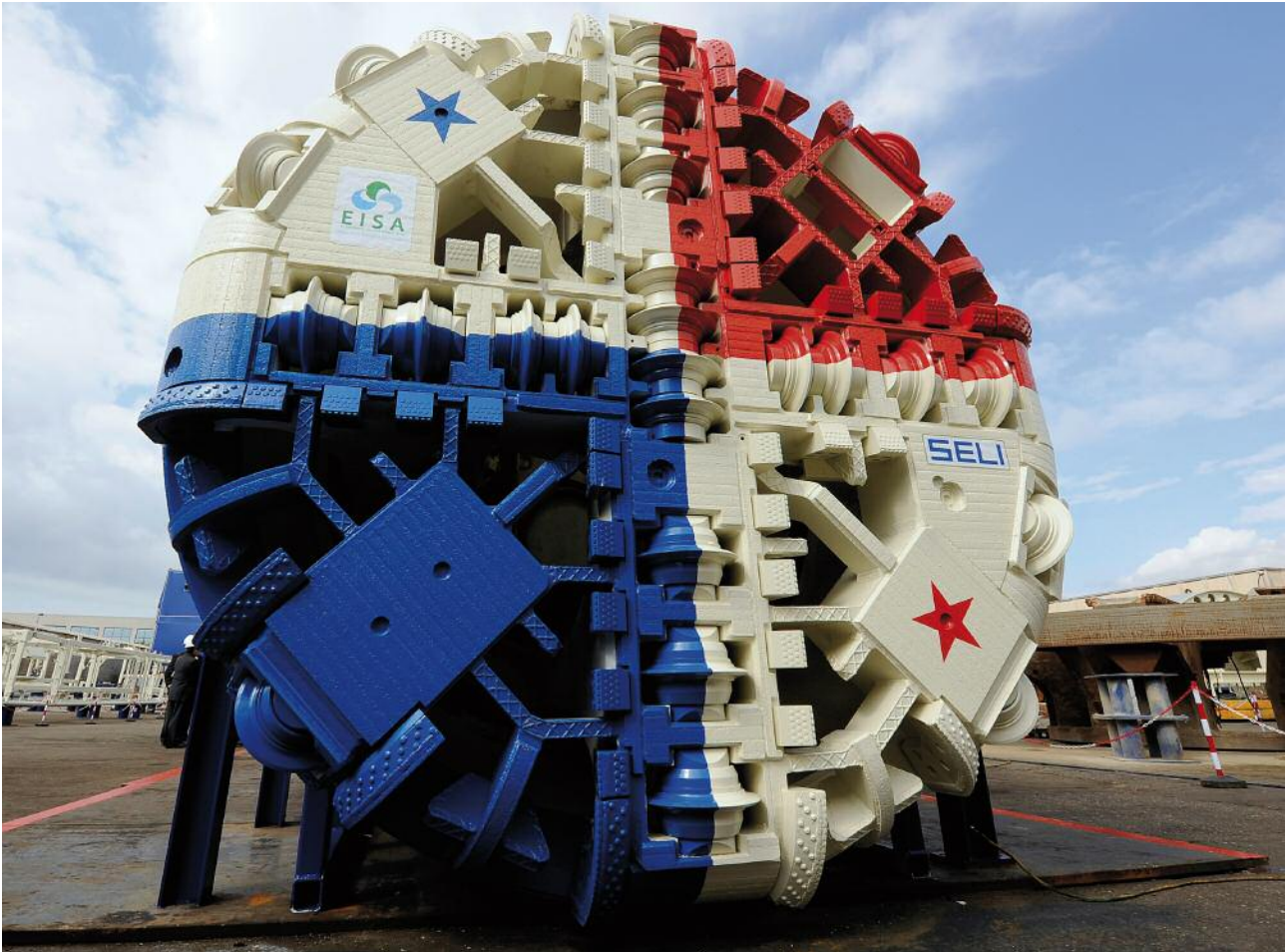
Seli developed special procedures to keep the TBM operating, probing as well as seismic and geoelectric scans ahead of the TBM; grouting with chemical foam injection to stabilise the face and constructing some small bypass tunnels in the crown to help the advance in some stretches.

boundary can also keep large debris, such as boulders, within the fine-grained matrix, despite gravity.

Once solidified, the flows form mixed rocks of highly variable properties. The boundary layer from the base of the flow can often be seen in the hardened mass as a fine-grained band.

Tunnelling

Excavating the Pando and Monte Lirio tunnels will be a big challenge due to the complex and variable characteristics of the dominant lahar rock, says Seli. While uncommon in tunnelling, the contractor has had marginal experience with the rock type,



next door in Costa Rica, on the La Joya project (see box).

From site visits at Pando-Monte Lirio, Seli says, the lahar formation has been classified into two types—matrix-supported or clast-supported—the difference being the relative percentage of fines and grading, there being more content and better grading for the former. Typical classification of lahars into either cohesive or non-cohesive does not appear to be appropriate, it notes.

Seli adds that laboratory tests showed surprisingly uniform residual and peak frictional characteristics, such as the normal stress range (up to 8MPa) having coefficients of residual internal friction about 0.62MPa. Peak friction values for pre-loaded materials could be up to 0.76MPa-0.80MPa.

In terms of groundwater flow, permeability is generally low in the matrix-supported lahars. However, where there are diminished fines then there could be a degree of water flow, and also with water-bearing strata or connate water.

Seli says that, in its opinion, only an EPB machine would give reliability in this kind of

Above: The EPB TBMs will drive mostly through lahars, which are uncommon in tunnelling and are variable, solidified former slurries generated by volcanic activity

'soil-rock' formation, especially as the alignments are below the water table.

The machines are equipped with 17-in. discs and rippers. The maximum cutterhead thrust is 13 560kN and the cutterhead speed is up to 4 rev/min. The drive power for the cutterhead is 600kW (4 x 150kW).

The TBMs are designed to operate in both closed and open modes without modifying the machine arrangement. The EPBMs are expected to operate in open mode in the presence of rock mass, including highly dense lahar and ancient lava flows, says Seli, adding that closed mode would be used in case of an unstable face or loose ground.

In principle though, there will be no probing of the ground ahead of the machines and nor, therefore, is ground treatment to be called upon. Spoil is to be removed by loco-hauled transport.

In line with local regulations, Seli plans to work a three-shift daily pattern for each drive. At each project site the contractor should have about 80 workers, it says.

The Italian firm is supplying moulds to Euroconcretos, in Costa Rica, to cast the concrete segments. The majority of the tunnels will have the single, segmental rings, except for near the outlets that will also have an inner lining of fibreglass pipe due to high water pressure but relatively small overburden, meaning the concrete lining is not sufficient.

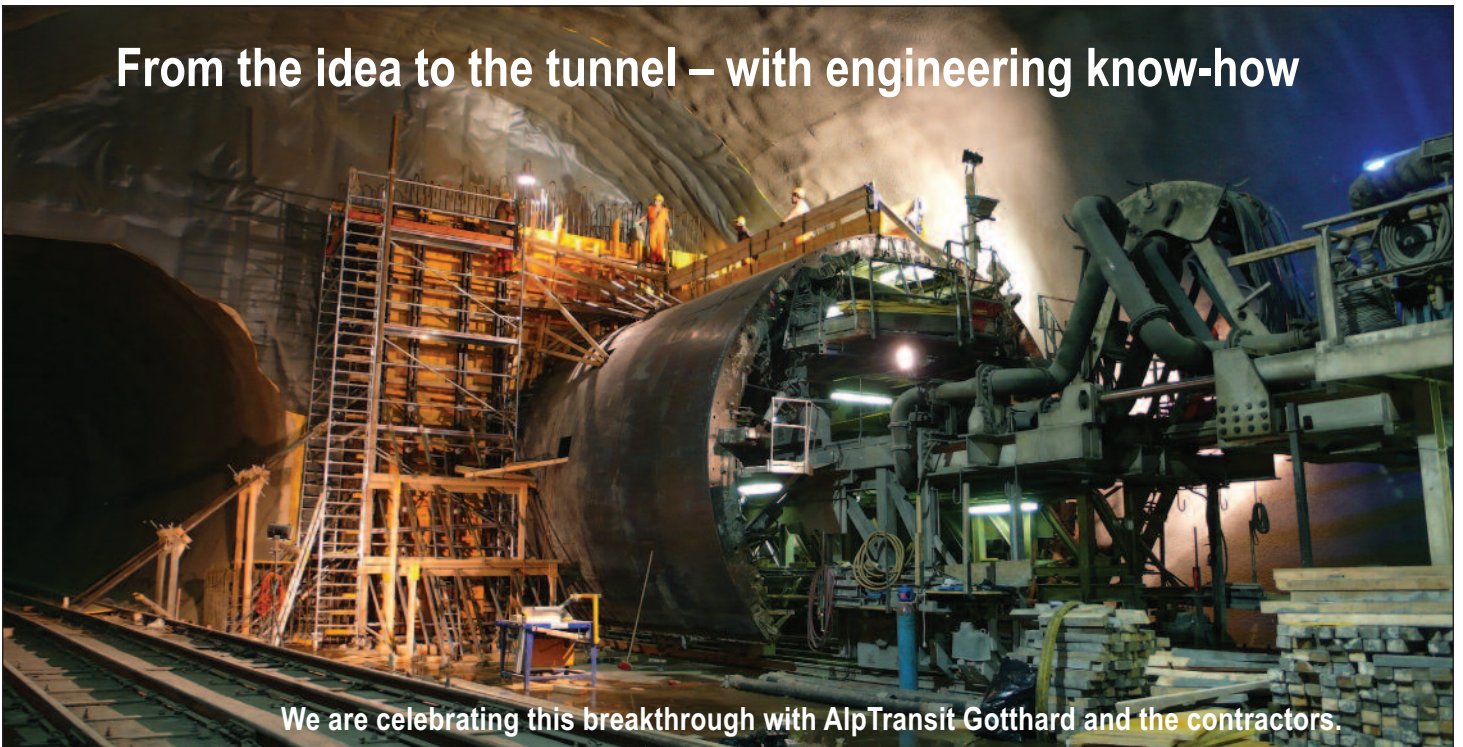
El Alto

To be built immediately downstream of Monte Lirio, the El Alto project calls for construction of a 3.24km-long headrace tunnel plus surge tanks, a 96m shaft and 368m-long penstock.

Seli was awarded a USD46M EPC contract to execute the underground works for the project, which is to be commissioned in 2013.

Hydro Caisan, part of the JV developer, has a 50-year concession on the 60-MW (24.7MW firm) project. It is majority-owned by Netherlands-based Tahal Group International, held by the Kardan Group. ■

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Finesse in tough environments

Technologies employed underground to ensure positional accuracy have advanced at great pace over recent years. The portable computer, data processor and laser have all but replaced the tape, notepad and pencil. These, together with the introduction of lasers as reference axes and the toughening of electronics, have led to major benefits in productivity. Maurice Jones reviews some of the latest developments

Theodolites are synonymous with precision surveying, but, apart from the telescope and tribrach, modern versions have little in common with their predecessors, featuring, as they do, digital readouts, multiple automatic functions and laser-based accurate distance measurement that does away with the tape. Whereas early electronic systems were limited by their fragility and excessive weight of power sources, modern instruments can be set up in most tough tunnelling environments and, in many cases, left to operate remotely in a protected position due to the introduction of motorised functions.

It is remote-controlled, motorised and automatic functions of high accuracy that have enabled the broader use of theodolites, particularly in monitoring of small movements in the ground or what is connected to it including tunnel profiles, surface subsidence and heave and movements of related structures such as building being tunnelled under. Their robotic operations allow a large number of stations to be covered in each sweep, much more than would be practical in conventional surveying. This makes it more likely to pick up problem areas that could otherwise be missed. Dedicated data processing with specific reporting functions of warning and alarm situations brings important values to the attention of surveyors and project managers.

Underground rapidly operated or automatic instruments sited in carefully planned locations mean that survey teams need rarely, if ever, have to interfere with the progress of tunnelling, and vice versa. Thus the productivity of tunnelling as well as surveying is improved.

Theodolites & scanning

The precision and reliability of Leica Geosystems instruments means they are found in a wide variety of tunnel projects for both underground measurements and monitoring for any disturbance at the surface. The Leica range are direct descendents of the Wild Heerbrugg theodolites that have been widely used

underground. Applications range from sewer work (see separate article p38 this issue) in East London, to the recent breakthrough of the world's longest rail tunnel, the Gotthard Base Tunnel. Leica instruments have been used in a wide range of activities throughout the Gotthard project.

The Gotthard tunnel client's surveyor, Vermessungsingenieure Gotthard-Basistunnel (VI-GBT), has had the main task of ensuring the correct positioning of the tunnel bores with set-out and check surveys using Leica total stations, digital levels and optical plummets. "Put simply, our duty was to see that the hole was built in the right place," commented Ivo Schaetti, senior engineer with VI-GBT. The client, AlpTransit Gotthard, required an accuracy of 100mm transversely and 50mm vertically over the whole length of the 57-km tunnel.

An extension of the application of laser theodolites was the development of underground excavation profiling, pioneered by Amberg Technologies. Something of an advanced development curiosity in early days, profiling and scanning have become important techniques to increase tunnelling efficiency, especially in larger projects, both in terms of overall size and the dimensions of the excavations. This has come about by a successful integration of Amberg software and instruments that have lately been

developed into reflectorless and robotic total stations and 3-D scanners using advanced lasers.

A latest application has been New York's (see general report in T&T North America Sep 2010 p9) No.7 Line metro extension including its major caverns under the congested urban environment of Manhattan. The S3II Tunnel Constructors JV of Shea, Skanska and Schiavone employed an Amberg 5003 Profiler. This is a high-speed laser scanner that employs the Amberg Positioning method (APM).

The Amberg TMS (Tunnel Measurement Systems) Solution offers several dedicated tunnel construction functions in software from setting out and check surveys to complete dimensional data. An extension of TMS Setout is TMS Setout Plus that enables the tunnelling crew to perform routing set out tasks themselves, removing the need for frequent surveyor site visits. The established TMS Profile enables the excavation profile to be checked accurately, whilst TMS Tunnelscan uses the latest scanner technology meets full dimensional data requirements with full mapping of the excavation surfaces at maximum speeds.

Amberg continues to break sales records for TMS Tunnelscan system. This instrument package is a laser-based scanning system of modular structure,

Below: Surveying the Gotthard Base Tunnel with Leica instruments



combining hardware and software to scan the excavated surface to check of accuracy including, as examples, overbreak and underbreak in drill-and-blast tunnelling and the amount of sprayed concrete required to meet specified dimensions. Data output provides comprehensive documentation as has been shown in Helsinki Airport's Ring Rail Line where it enabled precise invoicing of the tunnelling work and efficient use of time for data acquisition to processing and output.

Leica's latest development of its ScanStation is the C10 all-in-one platform. The compact unit now includes a tilt sensor, battery, controller, data storage, auto-adjusting video camera and a laser plummet as well as the scanner itself. The addition of the new Smart X-mirror allows the operator to use its spinning mirror to perform a full-dome scan in a few minutes, thus affording major productivity advances.

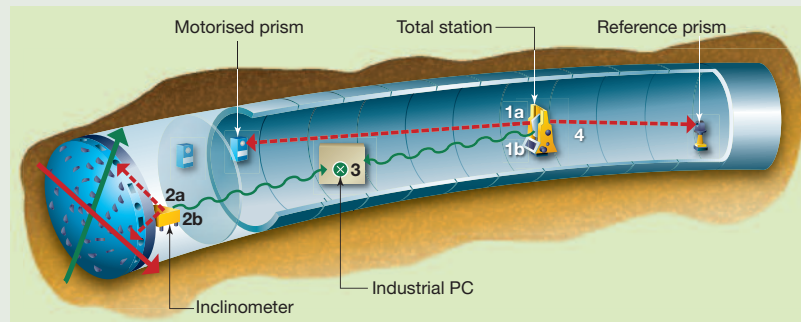
The latest digital laser theodolites from Topcon (DT-200 series) feature the same absolute circle reading technology as employed in Topcon's total stations, for high accuracy and reliability.

Sokkia has released a new range of robotic total stations, the SRX, designed mainly for autotracking and distance measurement. The four models feature a



PPS TBM Guidance system

Diagrammatic view of the main components of the PPS TBM guidance system used on the Linthal 2015 hydropower project



MAJOR COMPONENTS FOR FOUR STEPS OF MEASUREMENT AND DATA TRANSFER

1 TOTAL STATION

1a & 1b Measurement prisms 1 and 2; sends data to industrial PC

2 INCLINOMETERS

2a & 2b Measures roll and pitch; sends data to industrial PC

3 INDUSTRIAL PC

Visualises BM position update on screen

4 TOTAL STATION

Measures to reference prism(s) periodically

new laser system for increased reliability in prism tracking, plus new motors and drive mechanism.

Guidance

In addition to distance measurement, lasers have had another major effect on underground surveying, that of providing a semi-permanent reference of direction. As lasers became more robust and accurate, that simple reference for direction could be used for additional functions to replace manual marking out of excavations. Now laser-based guidance can be used to guide not only TBMs, but now also roadheaders and to provide a reference for drill hole patterns in drill-and-blast tunnelling.

ZED has been a leading developer of TBM guidance systems from 1975, originally based on a laser beam striking an active target. In the basic system, curves are negotiated by manual inputting of precalculated offsets. Further levels of sophistication use global co-ordinates in three dimensions with the required tunnel path defined by pre-programming the co-ordinates throughout, using the laser beam and distance travelled as reference.

Now there are several more companies offering increasingly sophisticated guidance and related measuring systems that, in some

Left: Sokkia's new LDT520 laser theodolite is claimed to have the world's longest beam range at 600m

cases, can now be integrated into complete TBM control and management packages.

Very often a basic guidance system has to be modified to suit the particular circumstances of the project (see the separate article by Manfred Messing of VMT on p41, this issue, to see how techniques originally employed for smaller diameter pipejack work have been used to guide TBMs on the Gotthard Base Tunnel). VMT has developed a wide range of systems not only for TBM guidance but also roadheader guidance, segmental lining erection planning, segment ring movement monitoring and complete TBM management systems.

Another example of special guidance design is the Linthal 2015 hydropower project in Switzerland where PPS (Poltinger Precision Systems) provided a guidance system for an Aker Wirth TBM to bore at a constant inclination of 24 per cent over 3800m. Since the TBM is of 8m diameter, the guidance and steering must maintain exceptional accuracy since the previous maximum diameter for steeped inclined TBM drives has only been 6m.

Quirin Poltinger explained, "This project underlines two main characteristics of PPS; customer-orientated and flexible adaption to specific project needs. To meet customers' expectations not only the hardware but also the software have been improved to fit the needs of the specially designed TBM.

In another recent application of PPS

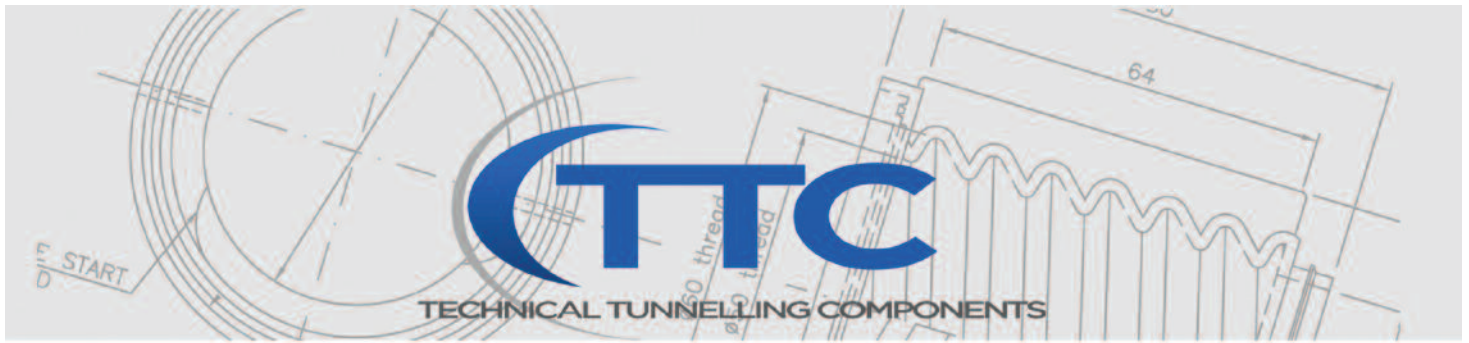


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guidance technology, its roadheader system used on the Devil's Slide road tunnel project in California (see T&T North America March International 2010 p8) achieved offsets within 10mm with respect to the tunnel axis at the roadheader's recent breakthrough.

Other established manufacturers and suppliers of excavation guidance systems include taccs with the acs system and its news lining support ring development view in TBM control, and Geodata of Austria with its Tauros TBM and roadheader guidance systems amongst a range of surveying solutions. Recently, Geodata has entered into a partnership with Sokkia to offer combined expertise in optical 3-D monitoring, setting out and profile management in tunnelling.

Geodata has also been a leading participant in research and development projects within the Europe-wide Tunconstruct project including the Underground Construction Information Systems (UCIS) with Geodata's Kronos package, plus the advanced concept of virtual reality visualisation of data.

An alternative approach is the heart of TEDSS (Tunnels Engineers Directional Survey System) promoted by Alignment Surveys and is currently being used by Costain in the Ovingdean drives of the new Brighton & Hove Wastewater Treatment project. The system uses a gyro theodolite over the 1700-m drive. At approximately 700m, Costain survey manager Nigel Drayton commented, "TEDSS has proven to be simple to use and maintain, and require minimal training for the engineers and surveyors. It has shown itself to be well suited for use in a small diameter TBM (2.44m i.d. in this case), where space is a critical issue. Being able to switch prisms on the curves has proved to be a major advantage. I would recommend TEDSS for similar small TBM-bored tunnels having small diameters, tight radius bends and limited survey windows.

Previously TEDSS had been used on the last major Belfast Sewer Project with similar application advantages in avoiding frequent moves of a laser system on curves. Project manager Paul Ronicle said, "The gyro system allows multiple targets, which allows greater flexibility, especially when negotiating a succession of curves. The system gave us better productivity, was accurate and extremely reliable."

Ground instrumentation

Ground instrumentation for tunnelling projects has a more established position in the principle of remote, passive

monitoring, but still has a vital role to play in providing project managers with an overall picture of what is going on with the ground and linked structures. In spatial ground and structure monitoring, instruments such as inclinometers and extensometers provide information that would be laborious or impossible to obtain by conventional surveying.

Another activity in which inclinometers play an important role is in borehole surveying, whether for site investigation or long-hole probing. Sherborne Sensors was set up in 2002 by managing director Mike Baker and sales & marketing director Robin Butler to offer small, high-precision instruments including inclinometers and accelerometers. Both men have backgrounds in manufacturing such devices for international markets in industrial, aerospace and military applications where, in the latter case, environmental conditions could not be more demanding. Therefore, although pitching to small-diameter borehole and seismic surveying applications for the first time, the T820 series of inclinometers has been developed for equally demanding conditions.

This is another sector in which miniaturisation has major application advantages. Sherborne's T820 gravity referenced, dual axis inclinometer is only 23mm in diameter (the company's smallest) and 161mm long.

Robin Butler explained to *T&T* that the instrument's stainless steel housing makes it more rigid and therefore less prone to angular errors than the main alternative of aluminium alloy. The measuring range is +14 to +60 degrees, and normal operating temperature range -18 to 70 degrees C, perhaps opening up its use for groundfreezing conditions. Connections can be totally sealed (to IP67), as in the T823, or equipped with solder pin terminals as in the T825.

The inclinometer is housed with other instruments in a surveying probe for use between drilling operations, or is robust enough to work with MWD (measurement while drilling) as has been proven in larger diameter geometric studies in Russia at depths to 12,000m where retraction of the drill string is prohibitively expensive. The T820 series has a 1000G shock resistance claims Butler.

Mike Baker explained, "The T820 series has been designed to operate in the smallest of areas and can withstand high levels of mechanical shock without any degradation in performance."

Custom design is a Sherborne speciality with around 50 per cent customised and 55 per cent exported. The new inclinometers



Above, top: Above, bottom: Dr Janes of Alignment Surveys checks total station settings during work on the recent Belfast sewer project by the Morgan Est-Farrans JV using the TEDSS alignment system

Above, bottom: Sherborne Sensors' new T820 2-axis inclinometer

can be used in any hard-to-access area, for example behind reinforcement, to check for uneven movement.

Tilting

The latest instrument in the wide Geokon range is the 6165 MEMS tilt beam (MEMS = MicroElectricalMechanical System). This is designed to measure any tilting or differential subsidence by being attached to structures, whether horizontally or vertically. Tilt beams can be coupled together in long horizontal strings if differential settlement over a longer distance needs to be checked such as on embankments, along existing tunnels, railways etc. Vertical strings can be used to measure wall or piling deformation.

Recent applications of Geokon tilt beams and other spatial instrumentation include the Blackfriars Station redevelopment project in London, the Busan Subway 308 in South Korea and the FCC metro Line 7 in Madrid.

Headquartered in Lucknow, India, Encardio-Rite manufactures a wide range of instrumentation of all types. Exports have been made not only to Asia but also to Europe and elsewhere. Project involvement includes installation and monitoring of the instrumentation packages.

Recent projects involving Encardio-Rite inclinometers and extensometers include the Red and Green Lines of the Dubai Metro, the Udhampur-Srinagar-Baramulla Rail Link (USBRL) in Jammu & Kashmir and the Delhi Metro. ■

Monitoring Stratford

Careful monitoring of potential surface movements under railways was required as part of the West Ham Flood Alleviation Scheme for Thames Water in East London. Stewart Harrison, survey consultant for rail and tunnels with SCCS, describes the advanced methodology of survey operations employed

As part of the West Ham Flood Alleviation Scheme, Thames Water commissioned the construction of a tunnel that passed approximately 15-20m below the south end of the Stratford Market London Underground depot train stabling roads, Jubilee Line running lines into Stratford Station, the spur line into the depot and the Dockland Light Railway Abbey Road construction site. As a result of the construction of this flood alleviation tunnel some vertical surface ground movement was expected, which potentially could have had an adverse effect on the infrastructure above and the safe operation of the railway systems. Consequently a programme of precise survey monitoring was required to check for any movement.

The tunnel was driven by contractor Costain using a Lovat M132 Series 25000 Earth-Pressure-Balance (EPB) TBM with an outer diameter of 3.35m and an internal diameter of 2.87m. A Tacs guidance system was fitted to the TBM using a Leica 1201 total station with telescope-mounted laser for positional information. The total length of the tunnel drive was 3.3km, the TBM being launched from the 12.5m-diameter T1 shaft at Abbey Mills pumping station and arriving

at the reception shaft T5 after passing through shafts T2, T3, and T4.

A surface survey network was observed using Leica 1201 instruments and calculated using the Star*Net adjustment package to produce a 'least squares networks' solution. A level traverse was run on the surface along the tunnel route using a Leica DNA03 with invar staff, which was used to strengthen the vertical aspect of the control network. After the TBM passed through each intermediate shaft a wire drop was carried out to verify the tunnel survey control by means of a Weisbach triangle method – a method of joining over ground and under ground control networks.

Monitoring

In order to ensure that any potential ground movement would be identified, Costain Engineering, the contractor undertaking the tunnelling work, consulted and worked closely with London Underground and Tube Lines Infrastructure Protection Department (now both part of Transport for London (TFL)). Tube Lines is responsible for Jubilee Line infrastructure. Costain implemented a 'real time' and manual precise deformation system covering all of the areas likely to be influenced by the tunnel construction. The Deformation Monitoring Package was awarded to Survey Associates (SAL), which was responsible for the design, installation and implementation of both the automated and precise 3-D monitoring undertaken for the duration of the contract.

Implementation of the deformation monitoring scheme was to determine the extent of any ground movement and to ensure that the London Underground and Docklands Light Railway assets were protected. Tube Lines had specified that deformation monitoring of specific areas of the depot was to be carried out during the pre-construction, construction and post-construction phases of tunnel construction.

The basis of the automated systems was to set up arrays of 3-D points along the tunnel alignment in order to produce classic

settlement curves. Resulting measurements were then processed and presented through Leica's GeoMoS monitoring software.

This software is composed of two main applications called 'Monitor' and 'Analyzer'. Monitor is the online application responsible for the sensor control, collection of data, computation and event management. Analyzer is the offline application responsible for the analysis, visualisation and post-processing of data.

Leica GeoMoS stores all measurements and results in an open SQL database. The data can be accessed both locally and remotely using Leica GeoMoS Analyzer, Leica GeoMoS Adjustment or third party software. The GeoMoS system proved to be very versatile and configured to ensure that deliverables were precisely as required.

Survey Associates commented, "The GeoMoS software's ease of use and open source database structure allowed us to create bespoke deliverables".

To cover the 'live' area in construction a 'fluid' system of five permanent automated total stations and one 'roving' total station was used. This enabled 'real-time' analysis of the effect of tunnel construction on the surface and the relevant infrastructure.

Lyndon Preece, Costain Project Manager, confirmed the importance of such monitoring. "Monitoring enabled the ground levels to be analysed in real time, which helped minimise surface settlement", he said.

High-precision automated surveying equipment was used in the survey observations: Leica TCA1201, TCA2003 and TCA1800 total stations and GPH1P precision reflectors with Leica 'L' Bar Mini optical monitoring prisms. This all enabled the surface to be monitored accurately to an accuracy of +/-1mm.

In addition to manual and automated systems Survey Associates utilised the high-precision Track Quality Measurement Trolley (TQM) on sections of the Jubilee Line track. This enabled real-time check surveys to be undertaken of the running rails ensuring that all rail and safety parameters were maintained during the passage of the TBM beneath. The (TQM) is a portable



Left: One of the six Leica total stations used for subsidence monitoring surveys

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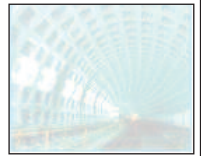
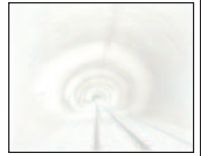


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Left, top: The Track Quality Measurement trolley (TQM) for precise checking of rail-track dimensions that may be affected by tunnelling

Left, bottom: The TQM in use



trolley delivering full track quality at 0.100mm intervals reporting for both 35m and 70m wavelengths based on the following recorded track geometry parameters: horizontal and vertical versines, cross level, longitudinal level, gauge and distance measured against exchangeable chord length bases.

Real-time

In order to ensure that the results of the monitoring were available to the Costain Engineering and Tube Lines engineers, Survey Associates ensured that all data was presented in a clear and concise manner via an office-based server system. Access to the system to review the monitoring data was available in real time to all persons approved by Costain Engineering.

In addition to the real-time data, Survey Associates implemented an early warning system based on settlement trigger values, agreed with Tube Lines Infrastructure Protection Dept. This automatically e-mails or sends SMS texts to appointed persons if 'amber'/'red' trigger values are breached. Automatic notifications enable corrective actions to be taken by Costain Engineering tunnelling engineers. Alert triggers can be set up as absolute triggers, eg; if a point has dropped 5mm, or as relative triggers, eg; a point has dropped 5mm in 24h.

Processed

All data was presented in graphical and numeric format to clearly indicate heave and settlement prior to the arrival of the TBM, during tunnelling through the zone, and post construction of the tunnel. In addition to ensuring that data was available to enable the Tube Lines engineers to ensure the safe operation of the Jubilee Line and depot Costain Engineering engineers were able to derive useful data from the settlement information to substantiate the face-loss measurements that they were taken in the tunnel. Both sets of data were available for comparison. The tunnelling construction progressed as planned with overall surface settlement figures being less than or comparing very favourably with those expected.

Ultimately the deformation monitoring of the Jubilee Line roads, the Stratford Market depot fan roads, Docklands Light Railway Abbey Road Station, de-icing facility and the EDF and signalling buildings undertaken by Survey Associates was a complete success. The monitoring scheme they designed, installed and operated made a highly accurate, consistently reliable 3-D deformation monitoring system available to all interested parties. This presented clear and unambiguous monitoring data to the engineers.

Conclusions

The availability of 'off the shelf' automated systems, such as Leica GeoMos, has brought sophisticated methodology into use both in terms of cost and ease of use. The application of the technology by expert survey contractors means the monitoring can be brought together and used to enable the engineering technology to lessen effects on the environment.

As discussed previously, the main success of the monitoring scheme can be attributed to the way in which Survey Associates presented and made available the deformation data in a way that related directly to the tunnel construction process. Having the data delivered and presented in this way allowed for efficient analysis and reaction of the effects of the construction process on its surroundings. This in turn allows for cost savings; letting engineers to concentrate fully on the construction process with full confidence in the monitoring measurements. The close relationship of the monitoring contractor with the tunnelling contractor enabled the whole system to be created using standard 'off the shelf' survey elements applied expertly to produce a bespoke monitoring system with groundbreaking deliverables.

Deliverables included a Base Excel spreadsheet, updated on an hourly basis by uploading the latest data from an ftp web portal, showing the client the latest data and a summary of the last 24 hours. The location of the tunnel heading was updated, being shown graphically on an aerial plan. The plan allowed the nearest monitoring points to be identified and simply by clicking on the relevant arrays (longitudinal and transverse to the alignment) an A3 graphical and numerical plot is automatically created for analysis.

In conclusion Preece commented, "GeoMos along with Survey Associate's visual report allowed ground movements and the TBM position to be visualised simply and effectively."

Acknowledgment

Stewart Harrison is survey consultant for rail and tunnels with SCCS of Eaton Socon, Cambridgeshire; UK supplier of Leica instrumentation and GeoMoS monitoring software. SCCS is also the UK agent for Amberg Technologies (see main article). ■
All illustrations are by Survey Associates (SAL).

Guidance at Gotthard

Special requirements for the construction of the running tunnel drives of the Gotthard Base Tunnel meant high demands on the navigation systems of the four TBMs. Due to the need for tunnel works to be carried out in line with the advance, various factors such as line-of-sight, dust, heat and vibration prevented a normal measuring operation. This article by VMT managing director Manfred Messing shows how VMT produced secure navigation of the TBMs by the selection of suitable equipment and a change of measuring methods

The guidance of a tunnel boring machine (TBM) is comparable with the navigation of a super-tanker: it takes a long time before the effect of a course correction is visible.

Skilled machine drivers know the performance of their machine in different geological conditions. Therefore a precise and reliable determination of the TBM's position is the most important information for steering control. Although the TBM moves slowly it is possible that the machine bears away from the planned course and exceeds the requested precision of 100mm radius from the given axis. It is a real challenge to eliminate these deviations in a tunnel drive as long as those in the Gotthard Base Tunnel, which can only be met with perfect co-ordination between surveying and machine driving.

All geodetic information must be carried out by a polygonal process from outside the tunnel right up to the machine's cutterhead. For this purpose there is normally a dedicated clear area or laser window available throughout the complete area of the machine, along the tunnel wall and through trailing gear.

One special characteristic of the Gotthard project was that various tunnelling activities needed to be done concurrently with the advance and consequently the machine and trailer assembly was designed accordingly. Therefore the navigation system has to be adapted to this situation too.

System demands

A guidance system is equivalent to a navigation system. It provides information for starting a directional control or course correction. Therefore it is indispensable that the actual position of the TBM in relation to the planned tunnel axis is continuously present and displayed. As a 98 per cent availability of the TBM position is required, continuous measurement of the TBM position is necessary as well as the pitch and roll values of the TBM, which are all

collected and displayed. A status indication of all relevant sensor components of the guidance system is requested as well as automated directional control.

Normally the well-known navigation systems are working with GPS, but in a tunnel there is no satellite reception. So, the determination of position is carried out in the classic (back sight) method with the help of motorised measuring instruments.

Gotthard system

In the Gotthard tunnels two different trailing gear concepts were in use for the north and south drives (from Amsteg and Bodio respectively). To cope with these circumstances different navigation systems had to be designed but using the same hardware components, including motorised total stations, inclinometers and also software-controlled shuttered prisms marking the key machine measurement points. Additionally geometric machine data (including ram extensions) from the TBM's programmable logic controller (plc) were stored and used in the calculation of the actual position. Concurrently with the advance, various works needed to be done:

initial shotcreting, erection of wire mesh, arch mounting and rock bolt drilling and insertion, which caused heavy interference with the line of sight to the machine measurement points. Therefore a standard measuring method couldn't be applied. Extreme vibrations would also affect hardware components from the total station and computer up to the shuttered prisms.

Gotthard North – Amsteg

In the North Section the first three trailing sections were pulled together continuously along rails during the advance. The following units hung on roller-brackets mounted on the segmental lining and were pulled only after the advance. The area around the last trailing units was stable for a short time and could be used for measuring the cutterhead position, albeit only in the lower laser window. The coordinates and orientation for the automatic total station in the lower section had to be determined again after each advance. In this section it has been accomplished by carrying forward key machine measuring points in the invert area. For measuring the tracks on which the first trailer section was

Below: Fig. 1 – The shielded total station used in Gotthard North TBM guidance





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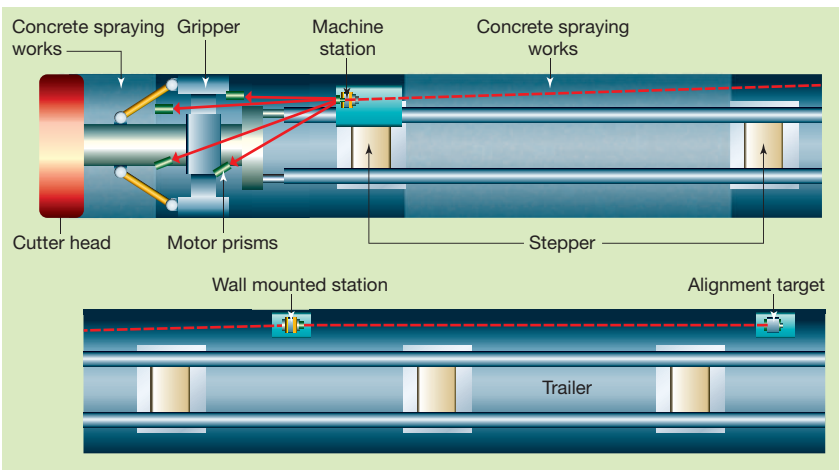
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Left, top: Fig. 2 – Installed shutter prisms (closed)

Left, middle: Fig. 3: Section (top) and plan of the TBM train assembly and guidance instrumentation concept on south Gotthard TBMs from Bodio]

Left, bottom: Fig. 4: Shuttered prisms on machine frame



pulled forward these points had to be pegged out anyway. They were also used for the automatic measurement of a 'free chainage' of the total station (see figure 1).

After each advance this trailing gear area was pulled forward, whereby the co-ordinates and the orientation of the total station changed. After the grippers were engaged again, a signal was sent to the control computer which started the automatic measurement of the total station with the new key machine measurement points. If the co-ordinates and the orientation of the total station were known, the TBM position could be measured by using the automatic machine prism at the cutterhead (see figure 2). The total station was mounted at a self-levelling tribrach (AD-12) which compensated for any roll and pitch of the trailer and automatically levelled the total station.

Gotthard South - Bodio

In the southern section the trailing gear was advanced using the two grippers that were secured during the advance. After the advance these grippers were contracted and moved forward. Here the grippers could be assumed to be of temporary stable construction (see figure 3).

Four motorised, shuttered prisms (machine prisms) were mounted on the machine frame (see figure 4) and measured on the machine axis. This 'local' co-ordinate system was incorporated into the computer calculations. During the advance the machine framework moves forward.

The machine station (a motorised total station on an automatic tribrach AD-12) was mounted on a divert frame which was connected to the gripper and so independent from the trailing gear (see figure 5).

During the advance the gripper does not move, only being pulled forward after the advance. With the temporarily stable machine station, the motorised prisms were measured and the global co-ordinates calculated during the measurement cycle. The TBM's position was determined by a special transformation (see figure 6). As the TBM stays in advance mode within these measuring cycles, a track correction is added to the measurements of the motor prisms (dynamic transformation).





Left, top: Fig. 5 – Divert frame with machine station;

Left, bottom: Fig. 6 – Operator screen showing TBM position in relation to the planned tunnel axis calculated by transformation

Display of TBM position

On the monitor (see figure 6) all the data relevant for control are displayed for the machine driver.

Besides the deviations from the planned axis (horizontal and vertical), the roll and pitch are also shown. Indication of the operational status of the connected sensor system is displayed as well as the station and the advance number. From the same display the directional control and a display of the last (historical) shield drive can be activated. The latter acts primarily for identification of the TBM performance directly influencing the control.

Conclusion

The adaptation of the navigation system to the special drive operations was doubtless a big technical challenge. The components and materials used were subject to very problematic conditions such as vibration, dust and heat.

The operating mode of the navigation system has to be fully orientated to these drive operations as the driving process should be in no way affected. Several times during the advance not only were geometric system adaptations necessary but also changes in some hardware components. For example the controller unit (data conversion and network) had to be cooled with compressed air as well as conforming to the IP62 protection category as a minimum.

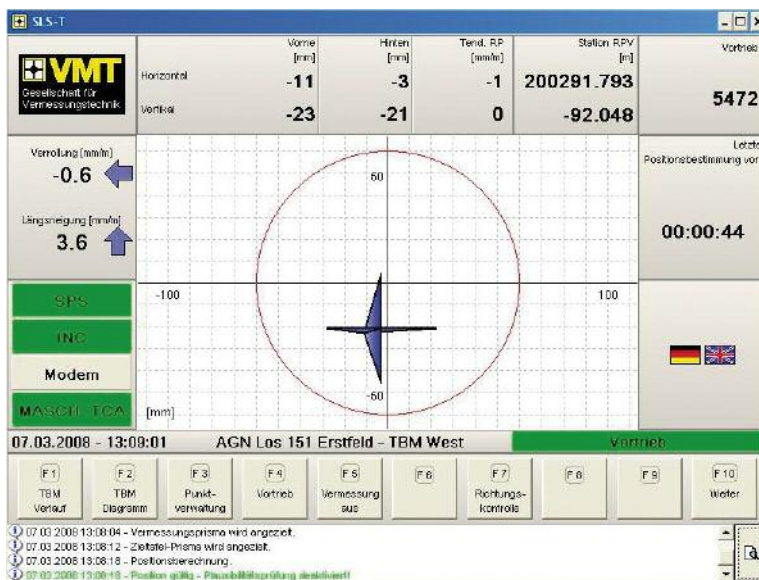
The use of similar hardware components and a modular software system in all systems was beneficial as all the necessary adaptations could be done with relatively low effort.

Things didn't always flow smoothly – therefore sincere thanks are given to all parties involved, for their patience and understanding during the set up of the system and the necessary revisionary phases.

All things considered, this project has accounted for the enhancements of the technique and methods in many respects from which many future projects will benefit.

Acknowledgement

This article is adapted by T&I from a translation of the original German version supplied by VMT. ■



As with the Gotthard North system, the co-ordinates and orientation of the machine station were only stable for a short time. This means they changed with each advance.

When an advance was made, the grippers were contracted, moved forward and afterwards extended again on the

tunnel wall. A signal was then given by the TBM to the control computer, which started the measuring of the machine station from the wall-station mounted in the rear. The measuring operation took about two minutes.

Afterwards the shotcrete work in the backup area could continue.

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Atlantic Ocean tunnels in Norway

At the June British Tunnelling Society meeting, Prof. Eivind Grov, former vice-president of the International Tunnelling Association and president of the Norwegian Tunnelling Society gave a presentation on road tunnels being built along Norway's western coast

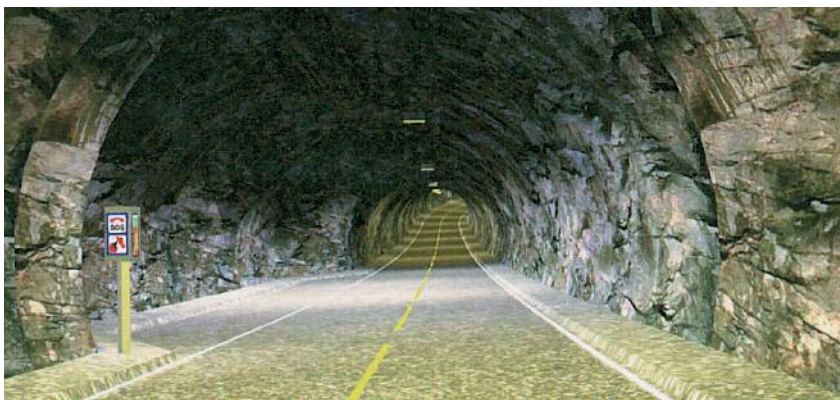
Norway is a remotely populated country with a coastline of some 57 000km, which, including islands and fjords, is greater than the circumference of the earth at the equator. The Norwegian government has made a commitment to the connection of these remote islands to facilitate the development of business. Many projects have been implemented

over the past 20 to 30 years to connect islands with populations as small as a few hundred inhabitants. Many options have been considered for connections of islands and crossing of these straits, fjords, etc., including immersed tubes, rock tunnels, bridges, new ferries and submerged floating tunnels. The presentation concentrated solely on tunnels located in rock.

Over the past 30 years there have been 28 subsea road tunnels constructed in Norway through bedrock, representing a total length in excess of 100km. All of these are single-tube tunnels with cross sectional areas varying from 43 to 78m². Depth below sea level is up to almost 300m. Table 1 provides a summary of some of the key statistics of some of these Norwegian tunnels. The first tunnel was Vardo which was opened in 1983 and is 2.6km in length. In addition eight subsea tunnels have been built for the oil industry as shore approaches and pipeline tunnels and another eight for water supply and sewerage.

All these tunnels are excavated entirely in bedrock by drilling and blasting. Throughout Scandinavia, general rock mass conditions are favourable for such methods. The geological setting is dominated by igneous rock types such as granite, together with metamorphic rocks of various types and origins such as gneiss, shale and in some places basalt. The host rock is intersected by weak zones, which may have an intense tectonic jointing, hydrothermal alteration or be faulted and sheared, constituting significant weaknesses in the rock and making the rock mass far from homogenous. These conditions may require rock strengthening measures.

The host rock in Scandinavia generally varies from poor or very poor to extremely good rock quality, according to the Q-system. The zones of weakness can exhibit great variation in quality, their Q-classification ranging from 'extremely poor' rock mass at the lower end of the scale, to 'good', with their width extending from only a few centimetres to tens of metres. The



Norwegian sub sea road tunnels - key data/characteristics of some projects

Project	Year	Cross section m ²	Geology	Length (km)	Min. rock cover (m)	Max. depth (m.b.s.l.)	AADT
Vardo	1981	53	Shale/sandst.	2.6	28	-88	670
Ellingsøy	1987	68	Gneiss	3.5	42	-140	2700
Kvalsund	1988	43	Gneiss	1.6	23	-56	500
Godøy	1989	52	Gneiss	3.8	33	-153	725
Nappstraumen	1990	55	Gneiss	1.8	27	-60	600
Freifjord	1992	70	Gneiss	5.2	30	-100	1850
Byfjorden	1992	70	Phyllite	5.8	34	-223	2800
Hitra	1994	70	Gneiss	5.6	38	-264	635
North Cape	1999	50	Shale/sandst.	6.8	49	-212	300
Oslofjord	2000	78	Gneiss	7.2	32	-130	4000
Frøya	2000	52	Gneiss	5.2	41	-157	530
Børmlafjord	2000	78	Gneiss/schist	7.9	35	-260	2500
Skatestraum	2002	52	Gneiss	1.9	40	-80	
Eiksund	2007	71	Gneiss/gabbro/limestone	7.8	50	-287	

Total number: 28

Above left: Typical Norway road tunnel in rock; Left: Table 1 – Subsea road tunnels

Right: Figure 1 – major features of subsea tunnels in Norway

stand-up time of many of these zones may be limited to only a few hours. The great challenge in Norway, and in particular subsea tunnels, is dealing with these changing ground conditions and due to the location and depth of the tunnels having limited methods available that allow a detailed investigation of the rock mass to be undertaken prior to tunnelling.

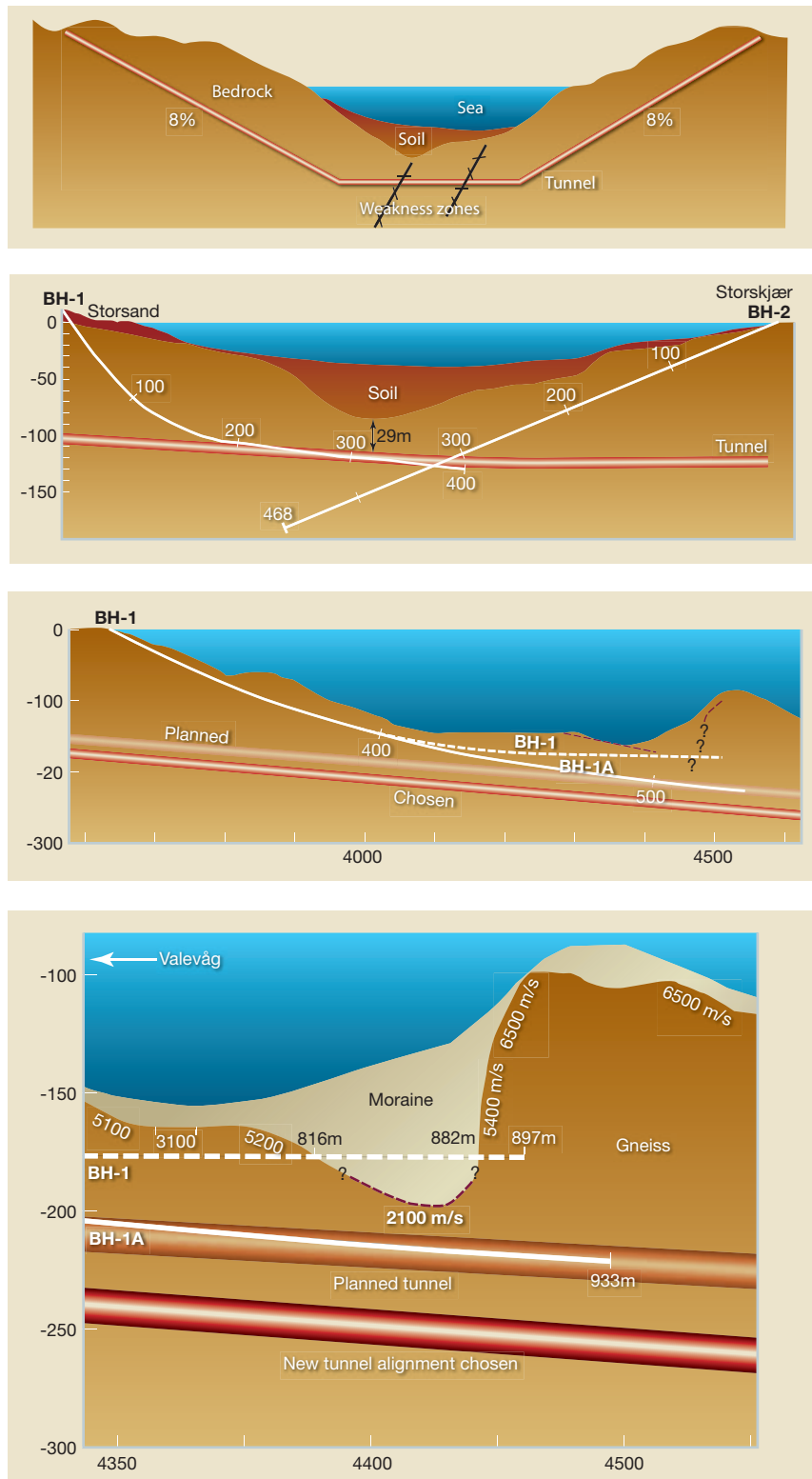
Figure 1 details schematically the major features of subsea tunnels. The tunnels may have an incline and a decline of up to 8 per cent. Additionally there is a saline body of water that is a reservoir for water infiltration in the tunnel that, combined with exhaust fumes in operation, provides a very harsh environment for which all of the rock support needs to be designed for.

One of the most important parameters in the design of subsea tunnels in Norway is the depth of rock cover above the tunnel. The Norwegian public road organisation has specified that the cover should be a minimum of 50m unless you can prove and document that there are very good rock conditions along the route of the tunnel. Many of the tunnels in Norway are between 25 to 40m and the cover is generally determined on a risk-based approach relating to water ingress to the tunnel and piping to the sea.

Pre-investigations are undertaken in five stages and the aim is to build a geological model with sufficient confidence on which predictions for aspects such as cost, programme, rock support and grouting can be made. The stages are:

1. Initial stage that includes bathymetric surveys and geological references;
2. Feasibility study including desk study, geological surface mapping, acoustic survey and some refraction lines;
3. Detailed feasibility study that includes comprehensive refraction seismic and core drilling;
4. Detailed design using directional core drilling, detailed refraction lines for a particular route and tomography in particular areas;
5. Tender stage where a geological summary report is prepared on the geological model.

The main aim of the pre-investigations is to establish a geological model with sufficient confidence. The geological model shall form the basis on which predictions for time scheduling, cost assessments, tunnelling prognosis, rock support and grout estimates shall be



Above - top to bottom: Figure 1: Major challenges facing a typical fjord crossing tunnel construction project

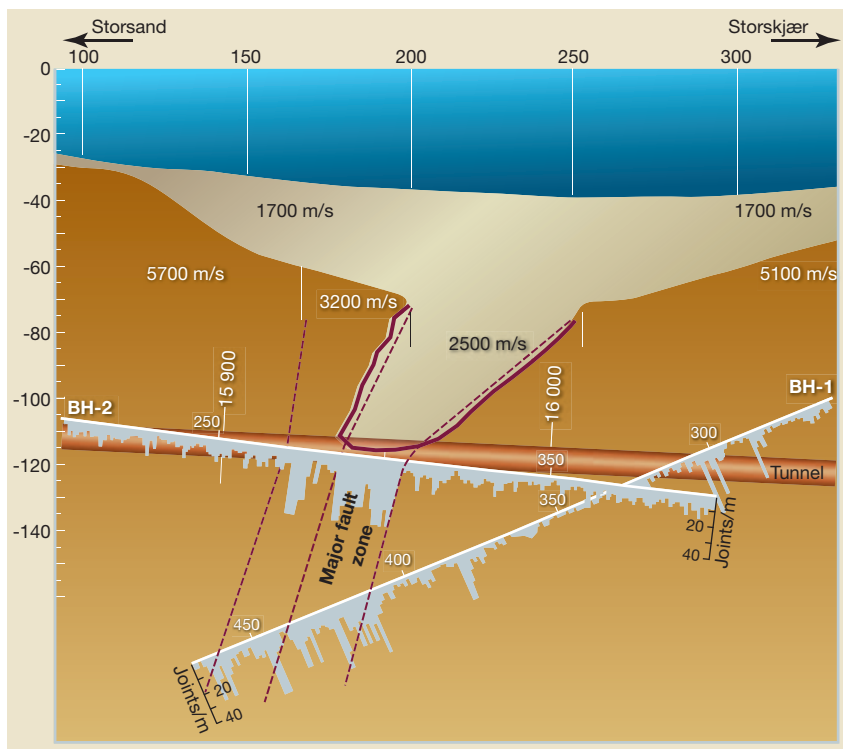
Figure 2: In construction of the Oslojord tunnel, the filled erosion channel was much deeper than expected as detected by probe drilling, necessitating a bypass tunnel
Figures 3 and 4: A similar situation in the Bomlafordtunnel project was detected and avoided by lowering the alignment by 30m

made. Pre-investigations highlight the following elements:

- Cost effective methods aimed at determining the variability of the rock mass
- Critical areas call for specific investigations
- Probe-drilling ahead of the tunnel face

Below, top: Face instability of the Atlanterhavstunnelen (2006-2009) at the deepest point delayed the project by a year and necessitated a concrete plug, extensive pregrouting and other major support measures;

Below, bottom: Figure 5: The eroded channel at the deepest point of the Oslofjord tunnel showing position of borehole surveys through fault zone



acknowledged as a reliable investigation method while tunnelling.

To obtain information about features that are in the subsea part of the tunnel vertical holes can be drilled on the land sites. Refraction is generally used on the subsea section, however where this identifies concerns it is becoming increasingly common to undertake directional drilling along the proposed alignment. Directional drilling has been undertaken up to about 1000m long for Norwegian subsea tunnels to hit the actual area where more information is required. Notwithstanding this, based on the knowledge during pre-investigation and tunnel excavation, probing ahead of the tunnel face is generally undertaken on a systematic basis with two, three, six, or even more holes (if required) with a length of 30-35m ahead of the tunnel face to gain more information about the conditions ahead of the face.

The established practice of site investigations has proven to be reliable, but exceptions have occurred. In the Oslofjord tunnel, despite an extensive program of seismics, directional core-drilling, hole-to-bottom seismics and seismic tomographic interpretations, the glacial erosion along a known depression along the bottom of the fjord proved to be much deeper than interpreted, and left the tunnel without rock cover over a short section. This was detected by probe drilling during construction; a by-pass tunnel was prepared to allow continued tunnelling under the fjord. The soil filled section was frozen (at 120m water pressure, or 13 bar) and excavated through. Figure 2 demonstrates that if the directional drill hole had been placed above the tunnel alignment, not within the cross section and below, the eroded channel could have been avoided by lowering the alignment of the tunnel.

A similar situation was close to occurring at the Bomlafjord tunnel. A 900m long directional core hole towards a low point in the bedrock (not the deepest) hit moraine where rock was expected. This was checked by further directional core drilling and the tunnel alignment was adjusted (from a 7.0 to an 8.5 per cent slope) to pass in the bedrock below the moraine deposit. This resulted in the tunnel alignment being lowered by approximately 30m thus saving costly remedial measures in the form of ground freezing and a by-pass tunnel.

Excavation and rock support

All subsea tunnels in Norway have been excavated by drill and blast. This method

provides great flexibility and adaptability to varying rock mass conditions and is cost effective. The most difficult rock mass conditions often occur in fault zones along the deepest parts of the fjord where any uncontrolled major water inflow will have severe consequences.

The systematic percussive probe drilling by the drilling jumbo is the single most important element for safety, and a limit of 30 litres per minute per 100m length of tunnel for water inflow is generally set for all subsea tunnels in Norway. The water is collected at the low point and pumped to the surface for discharge. All rock support structures are drained, whether they are made of sprayed concrete (prime support measure), sprayed concrete ribs or in the worst case, cast-in-place concrete (mostly horseshoe) lining. Sprayed concrete is dominantly applied as wet mix and is steel-fibre reinforced. The use of sprayed concrete has been increasing gradually to about 1.5-2m³ of sprayed concrete per metre of tunnel. Traditional methods such as mechanical and hand scaling and rockbolting are still in use and the number of rockbolts is in the range of three to six per metre of tunnel. Various types of inner lining are often used, with the main purpose to prevent water entering the traffic areas (including frost protection), rather than providing structural support for the tunnel.

One of the most significant differences between the design of road tunnels in Norway and the UK is the tunnel classification system. In Norway, the design uses the NPRA Handbook 021 where the tunnel relates to the annual and daily traffic flow in the tunnel irrespective of the tunnel length.

However in the UK, BD78/99 (Design of Tunnels standard) also references the length of the tunnel. This means that for tunnels in excess of 2km in the UK, the volume of traffic is not a consideration in the size of the tunnel. In Norway however, where tunnels are used to connect remote islands producing small traffic density (often with an annual average daily traffic of under 1000 vehicles) it is important that the traffic flows are considered when the viability of constructing these tunnels is in question.

Risk and contractual practice

Tunnelling and underground works are inevitably associated with a certain amount of risk taking. No matter the extent of the pre-investigations, a certain level of risk remains. Identification of risk and risk

allocation is important. Norwegian tunnelling involves standard unit rate contracts with risk allocation and contractual handling as follows in an ideal risk sharing model:

- The Owner carries the risk for the rock mass conditions as they occur,
 - The Contractor carries the risk for the appropriate and efficient handling of the works and focus on improving his technical and organisational performance,
 - The Owner is responsible for the collection of information on ground conditions. All information is disclosed to the tendering contractors for their own interpretation.
 - The Owner's engineers provide their interpretation of the situation in terms of presenting their estimate on quantities on rock support, rock mass grouting etc and all expected measures are quantified in the tenders and contracts.
 - The contracts include regulations for extension of construction time based on actually performed quantities.
- If these unforeseen or unexpected conditions occur it would be the owner who is the risk holder, no matter the type of contract used.

Operational aspects

Operation and maintenance of the tunnels is a very topical issue in Norway. Based on a review of information from some Norwegian subsea tunnels at 2010 costs, it is estimated that maintenance of the tunnels is approximately an average of EUR100 (USD140) per metre.

Typically lightweight installations such as lights and fire extinguishers have, in such corrosive environments, a design life of 10-15 years. Experience of the tunnels has also shown that over time the water inflow reduces indicating there is a tendency towards the rock mass self tightening itself.

A study of the accidents that occurred in road tunnels was undertaken in 1997. We have started to divide these tunnels into different zones. What we see is that we have most of the accidents just outside of the portal. We then have accidents following in the next 50m, while in the mid part of the tunnels we have the lowest number of accidents. This could be the fact that, because you are driving in daylight, for example, you are entering a very dark area or you are coming from a dark area and entering daylight.

Questions from the floor

Richard Brown

Q: Are there any provisions for cyclists or pedestrians for the typical tunnels in Norway?

A: No allowance is made for pedestrians or cyclists and they are generally banned from the tunnels. It could be done but would require separation from the traffic area and a lot more ventilation and illumination.

Colin McKenzie – Retired

Q: Coming from a remote Island community in the Outer Hebrides of Scotland, what is the smallest population that you have connected with a tunnel? Secondly, when deciding the size of the tunnel is there a standard cross section?

A: The tunnel with the lowest annual average daily traffic is 300 vehicles. I think the population then would be probably less than 1000. There are standard cross sections and normally the smallest one has a width of 8.5m, which is quite typical for remote tunnels. To reduce the cross section further there has been some discussion on a single lane tunnel of say 5m width however this would require sophisticated control systems.

Neville Harrison – Retired.

Q: How are these tunnels financed?

A: The majority of these projects are funded by the Government and toll payment.

Martin Knights - Halcrow

Q: There is an 8 per cent gradient in the

tunnels. Are there psychological problems in dealing with such a steep gradient in tunnels like that for the public and does this increase the accident statistics?

A: In Norway people are more accustomed to driving in road tunnels but of course accidents where vehicles drive into the rear of others are frequent. However, when it comes to the overall picture as far as accidents are concerned, the tunnel accident statistics are similar to open roads.

Tony Rock – Mac McDonald

Q: My question follows on from Martin's and it's to do with the gradient. Now the length of your tunnels and the steepness of the gradient must pose a very big challenge for ventilation in the case of a fire, do you have any comment please?

A: The main dimensional criteria of the ventilation fans is related to smoke and pushing smoke out of the tunnel up against a steep gradient. There is a preferred ventilation direction because all emergency cars/vehicles would preferably arrive the scene from one side. The ventilation system requires a minimum speed of air flow which is 2m per second. In the EU regulations there is a leeway on the gradient as 5 per cent is the maximum, unless geographical or topographical conditions restrict this, which is why in Norway the gradients are increased for subsea tunnels.

Rapporteur Damian McGirr

Making Mexico's Metro



Above: The man: Alfredo Garrido
Left: His machine: an EPBM

For Alfredo Garrido, one of the more interesting challenges in his day-to-day duties is checking up everything and interacting with his co-workers on the field service team. His job experience has taken him from China to the United States, Russia and now to Mexico.

He's been in Mexico City for seven months working on the 10.2m diameter EPBM that is boring a 7.7km tunnel for the city's new metro Line 12 (page 21). For Alfredo, who is from Spain, this job offers him the unique opportunity of working in a country that shares his native language.

"It's very easy for me," he says. "But in China for example, at first communication is difficult, but later you make a connection and the people who are mechanics, who don't speak English, understand the system and I understand the system, so it's easy. But here in Mexico it's very easy."

Alfredo is originally from Asturias in the northern part of Spain. Working in tunnelling wasn't something he immediately started out doing, or something he had planned on doing.

He attended a technical school, focusing

on welding and hydraulics. At one point he was doing hydraulic work for a Spanish company on a contract with Mitsubishi, which had two TBMs at a site near his home. When that contract finished and the company didn't have many jobs lined up, he interviewed with Robbins. It's been seven years now that he's worked with the US-based manufacturing company—first fixing cutters on the Abdalajis tunnel project on Spain's high speed rail known as the AVE, now a field service manager.

Line 12 in Mexico City is Alfredo's first tunnel project using an EPBM. He started with a double-shield TBM on the 7.1km twin tunnel Abdalajis project and has worked with single shield and smaller machines in Spain as well.

In China he worked on the Jinping-II Hydroelectric project where two main beam TBMs are excavating two of four 16.7km headrace tunnels (the other two are drill and blast). He also worked on the two 6.36m diameter main beam TBMs that are being used to excavate Line 6 for Chongqing Metro in China.

He says he enjoys working with hard rock TBMs because that's what he's used

to, but the EPBM has its advantages too.

"Before in the Chongqing metro it was a main beam and you don't have assembly. It's only the rock so you have a lot of water and a lot of dust. Here it is very clean," he says. "And normally for a metro it's only for one line, and this is for two lines, so it's very big. You have space in the machine."

Working with him on the EPBM are three other Robbins field service staff and communication is important. "This job is continuous. Every day I'm checking all the hydraulic systems, the pressure, the flow, the cylinders," he says. Keeping updated with everyone is a necessity if there are any problems and for planned maintenance at the end of each week.

It's been four years now that Alfredo has worked around the world. Though he does miss his house in Spain where he enjoys fishing and hunting in his spare time—hobbies that aren't easy to pursue in an urban environment—he is fortunate to have his wife and three-year-old son living with him in Mexico City.

"We live about 5km from the job site in a nice neighbourhood called Coyoacan," he says, explaining that it's one of the benefits of working on a metro project in a city. "They never travel with me because sometimes you have to live in a camp and it's not good for a family."

With tunnelling scheduled to end on the Line 12 project by August 2011, Alfredo will be in Mexico City for about half a year more. ■

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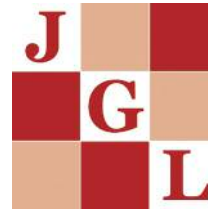
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dates & events

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

24 - 25 NOVEMBER 2010

Tunnel Design & Construction North East Asia

Some 22 leading tunnel designers, geotechnical experts, EPC firms and asset owners are speaking, notably Mr. Liu Ka Ding, Chief Engineer of Shenzhen Metro Line 3, who will be presenting the latest on using composite structures for better service life of tunnels. Also featuring a masterclass on cost efficiency by Mr. Joseph Lo, AECOM and Mr. Alexander Mackay, SMEC.
Email: enquiry@iqpc.com.sg
Tel: +65 6722 9388

29 NOVEMBER - 1 DECEMBER 2010 The 10th Anniversary Australian Tunnelling Conference

The agenda will centre around key current project updates and announcements on future project developments. Great variety of issues to be explored, featuring case studies of California's Silicon Valley Rapid Transit Project and the Guangzhou-Shenzhen-Hong Kong Express Rail Link.
Contact: Informa Conferences
GPO Box 2728, Sydney NSW 2001
Email: registration@informa.com.au
Tel: (+61 2) 9080 4307

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

9 - 11 NOVEMBER 2010

Harkany 2010 - Tunnel Construction and Civil Engineering Conference

Design and construction experiences from the tunnels on the M6 motorway. Design and construction experiences of the National Radioactive Waste Repository at Bataapáti Foresight, the near and the distant future, the vision for tunnel construction and civil engineering. Contact: Dr Tibor Horváth;
Tel: +36 26 319 368; Email: geovil@geovil.hu

17 - 19 NOVEMBER 2010

6th conference of international Society on Underground Freight Transport (ISUFT2010)

The objective of ISUFT2010 is to provide a forum for discussion of the state-of-the-art, opportunities and challenges in underground freight transport.
Contact: Prof.Chen Zhilong Email: isuft2010@163.com

22 - 23 NOVEMBER 2010

BTS underground health and safety course

Following the success of underground health and safety course in 2009 it has been decided to repeat the two day format of last year to allow more time on specific subjects and include more discussion and debate. Contact: The BTS Secretary; tel: +44 (0)20 7665 2229; email: bts@britishtunnelling.org.uk; web: www.britishtunnelling.org.uk

23 - 26 NOVEMBER 2010

Bauma China 2010, Shanghai New International Expo Centre, Shanghai, China

The Bauma trade show is famous for it's German event once every three years and the China show is rapidly growing to meet its bigger brother. Contact: Messe Muenchen bauma, China Exhibition Management Messegelaende, 81823 Muenchen, Germany; Tel: +49 89 949-20251; fax: +49 89 949-20259; Email: info@bauma-china.com

25 - 29 NOVEMBER 2010

7th WBI-International Shortcourse on Rock Mechanics, Stability and Design of Tunnels and Slopes, Aachen, Germany

Trade event for underground utility construction focused exclusively on installation and rehabilitation of the underground infrastructure.
Tel: +1-301-694-5243; Fax: 1-301-694-5124;
Web: www.uctonline.com; UCT P.O. Box 941669, Houston, TX 77094-8669

25 - 27 JANUARY 2011

Underground Construction Technology International Conference & Exhibition, Houston, Texas

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1 - 3 MARCH 2011

International conference and exhibition on tunnelling and trenchless technology, Selangor, Malaysia

The 2011 conference organised by the Tunnelling & Underground Space Technical Division (TUSTD) at The Institution of Engineers, Malaysia (IEM), will focus on tunnelling in South East Asia, future challenges and management of safety and risk. Tel: +(603) 7968-4001 / 4002; Fax: +(603) 7957-7678; Email: Tunnel2011@iem.org.my
Website: www.iem.org.my

BRITISH TUNNELLING SOCIETY

18 NOVEMBER 2010: Pittsburgh Northshore Connector

Stephen Woodrow and Andy Miller of Faber Maunsell (AECOM) will deliver this talk on the light rail tunnels in mixed ground conditions with challenging vertical alignment. The tunnelling works for the Northshore Connector Project in Pittsburgh, USA, involved several engineering challenges. The construction included 6.5m i.d. bore tunnels, 660m long passing under the Allegheny River. ICE, 5.30pm for 6pm start.

16 DECEMBER 2010: Baggage tunnel design and construction at Heathrow Airport

Andrew Stephenson of BAA, Enrique Blanco of Ferrovial and Athur Darby of Mott MacDonald give details on the challenges of constructing the tunnel under one of the world's busiest airports. ICE, 5.30pm for 6pm start.

20 JANUARY 2011: East Side Access Project, New York

The USD 7.3bn East Side Access Project currently under construction in the heart of Manhattan by the New York Metropolitan Transportation Authority Capital Construction Company is the largest federally funded infrastructure project in the USA. This talk will also present an overview of the multitude of tunnelling methods being used, including the first use of slurry TBMs in New York to excavate the 50,000 linear feet of tunnel.

17 FEBRUARY 2011: Lesotho Highlands Tunnels - BTS / MinSouth Joint Event

The Ingula Pumped Storage Scheme is the largest tunnelling project in South Africa. The location is just south of Johannesburg and just north of Lesotho. 12 km of 9.4m dia tunnels, 4 shafts (20m dia x 150m deep), 2 caverns, 200m x 20m spans.

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, 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.

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', John Carpenter House, 7 Carmelite Street, London, EC4Y 0BS, United Kingdom.

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