

NOVEMBER 2009

tunnels & tunnelling INTERNATIONAL



ALPINE FOCUS

Reports on tunnelling Austria's Brenner Pass and mucking out Zurich's railway

CONSUMABLES

T&TI reviews disc cutter developments as the technology approaches maturity



THROUGH THE FINNE IN 17 MONTHS.

The first tube of the Finne Tunnel has been completed. Using the Herrenknecht Mixshield S-419 (Ø 10,820mm) the tunnel workers reached their target near Bad Bibra on September 30, 2009 – after almost 7 kilometers and only 17 months of tunnelling. The tunnelling teams of the consortium "ARGE Finnetunnel" celebrated the breakthrough six months earlier than planned, reaching top values of up to 202 meters of new railway tunnel per week.

The S-419 used for the North Tunnel, like the identical S-420 in the parallel South Tunnel, is a convertible Mixshield and, as such, constitutes the high-tech solution for the challenges faced in large-scale projects like this. The design, developed by Herrenknecht's engineers, allowed the machine to be converted from one operating mode to another so that the two different geologies on the route could be mastered by one machine. Safe and quick tunnelling was possible both in the slurry mode when drilling up to 40 meters beneath the groundwater level on the first 1,500 meters, and in the open mode for the second section, after the conversion of the machine in the tunnel. The concrete segments for the lining of the tunnel are produced on site by the lining segment production plant which was delivered by Herrenknecht Formwork.

The Finne Tunnel is the core part of the currently largest railway construction project in Germany. It is scheduled that, from 2015 onwards, the train journey from Munich to Berlin on the intercity express train route between Erfurt and Leipzig/Halle will only take 4 hours.

FINNE TUNNEL | GERMANY

PROJECT DATA



S-419, S-420
 2x Mixshield (convertible)
 Diameter: 10,820mm
 Cutterhead power: 3,800kW
 Tunnel length: 6,825m
 Geology: sandstone, mudstone

CONTRACTOR

ARGE Finnetunnel:
 Wayss & Freytag AG,
 Max Bögl Bauunternehmung GmbH
 & Co. KG,
 Porr Technobau und Umwelt AG



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After three years of frantic tunnelling, South Africa's high speed rail Gautrain achieved final breakthrough on the last tunnel drive, all in time for the World Cup (p23).

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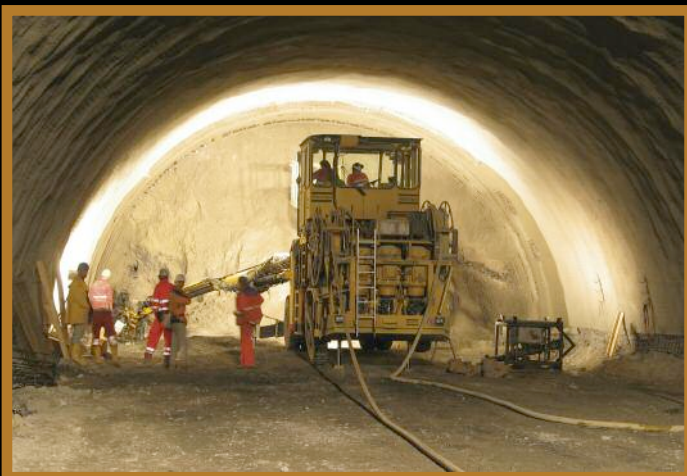
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On the up

Things are looking up. If recent news reports are to be believed the recession could be over by Christmas. A good spending splurge over the holiday season could be the final capital injection the global economy needs.

US shoppers are hitting the streets once again to indulge their whims. Banks and manufacturers have started clearing their debts ahead of schedule and with China and the US promising to work closely together in solving the world's problems spirits seem high.

Perhaps it is finally safe to say – without jinxing the industry – that tunnelling is a robust, recession resistant if not always recession proof business.

There have been a few casualties in our ranks. Some US government projects, like Detroit's Upper Rouge tunnels, hit funding crises and have been shelved. Industry players with a lot invested in the mining sector have taken a greater hit than others.

But the past two recession years have also seen their victors. New York's Trans-Hudson Express won funding from the Early Systems Work Agreement and broke ground earlier this year. And Crossrail got its official green light in the first days of the banking crisis.

Measured against the economy as a whole and tunnelling has fared well.

T&T has forty years under its belt covering these highs and lows. From the great breakthroughs of the Chunnel, the SMART tunnel and the ongoing Gotthard base tunnel, to the learning curves of the Mont Blanc fire, the Heathrow collapse and more recently the Sao Paulo sinkhole.

For nearly ten years former editor Tris Thomas charted the industry and celebrated it through *T&T*. As Tris passes the baton on to me I look forward to delivering the news, site reports and technical papers that have made *T&T* the first read for tunnellers worldwide.

New challenges, pitfalls and successes lay ahead of us as the projects become longer, deeper and more complex. New players are entering the market as emerging economies become global leaders. And a new *T&T* team is in place to track these developments.

Maurice Jones, who many of you may be familiar with as a former *T&T* editor, has rejoined the team as technical editor to keep us all abreast of the latest technological leaps.

With your support, I look forward to applauding the industry's project successes and marvelling at its technological breakthroughs as the economy and the industry emerges from the recession stronger than before.

Jon Young



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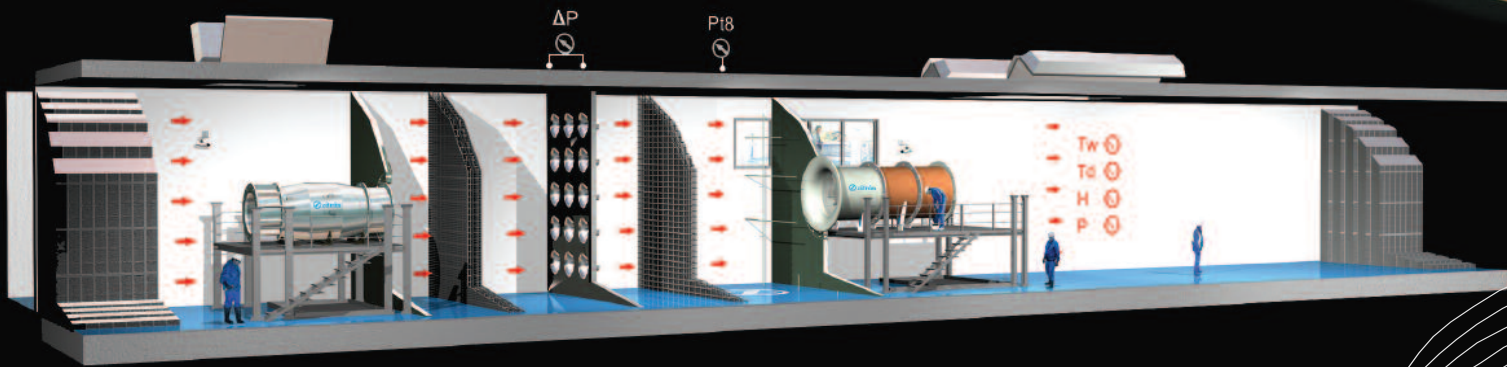
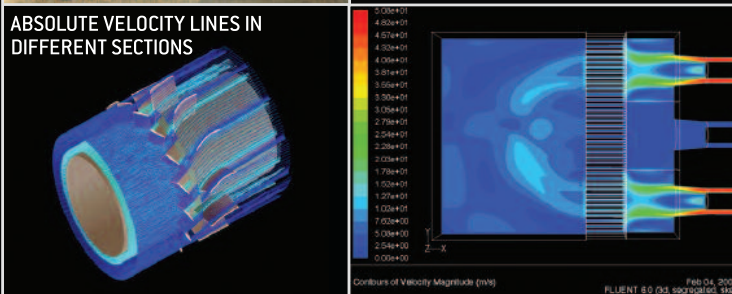
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Telephone: +34 98 516 81 32
Fax: +34 98 516 80 47
E-Mail: zitron@zitron.com



Ground movement disturbs Belfast street

Engineers in Belfast are working to repair the ground on Cromac Street after tunnelling disturbed a void beneath the surface causing the ground to sag. Northern Ireland Water has confirmed that the depression is located above a new storm water tunnel, which is part of the Belfast Sewers Project.

Remedial work is now underway and as T&T went to press a reinforced concrete road base slab had been poured which needed several days to achieve the required strength. After this new black top surfacing will be laid.

The new tunnel under Cromac St was constructed in November 2008 using an EPBM excavating through sandstone overlain by glacial clays and alluvial sand.

Paul Ronicle Project Manager for the project contractor Morgan=Est Farran said: "The ground in Belfast is mostly sandstone which has been eroded due to glaciation. There is a layer of dolomite at the bottom with softer rock at the top which makes for difficult tunnelling situations. We grouted the area to refusal, around 4.5 – 5 bar and have monitored the surface ever since."

He said that when the tunnel was first mined, the ground initially moved 3mm. "But there was no further movement. In hindsight, I think we took a little more material

than we should have," he said.

Staff from project consultant Atkins have been on site and have been working with NI Water and Morgan Est Farrans to carry out investigations of the soil/rock condition over the tunnel to fully determine the cause of the road depression and establish the

extent of the problem. Inspections of the tunnel lining and existing surface monitoring have indicated no further signs of movement or material ingress.

Remedial work will include repairs to an existing local storm water sewer and man holes, infilling and carriageway repair; no other

utility services have been affected and unlike a similar incident in Cairo recently, there was no civil disruption or reports of vehicles being consumed by the crater.

The new Belfast Tunnel is unaffected and remains on schedule to open toward the end of the year.

Tunnelling complete in Colorado

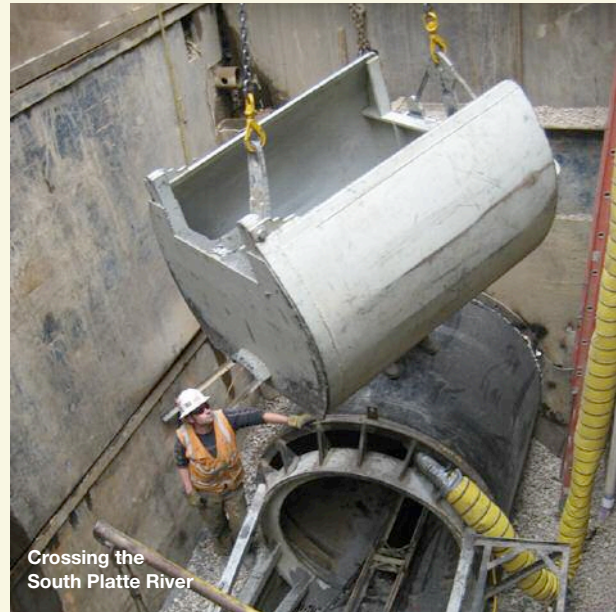
US firm BT Trenchless (a subsidiary of BT Construction) has this month completed 1277m of tunnels on the \$754M Aurora Prairie Waters project in Colorado. It used a range of methods to drive the tunnels including seven microtunnels, four TBMs, two hammer bores and six auger bores. Diameters ranged between 1.5m and 2m.

The Prairie Waters project for the City of Aurora, Colorado, is the first large-scale water re-use project in Colorado's history. Slated for completion in 2010, water will be pumped from the South Platte River, undergo a six-step treatment process, and ultimately replenish the diminishing drinking water supply.

One of the most challenging milestones was to break through the bedrock on the east side of the South Platte River to complete a challenging river crossing. A crew of about 10 worked 12-hour shifts

drilling a 78-inch (1.98m) diameter hole through the bedrock under

the river in only 7 days. Client is Aurora Water.



Crossing the South Platte River

NFM TBM finishes Spain rail bore

NFM Technologies' shield on the Pajares-Sotiello high-speed rail project in Spain has holed through on a 5.9km long hard rock drive.

The contractor, a JV of FCC and Acciona, completed the drive on Lot 5 of Pajares with the 9.88m diameter TBM, named 'Via Carisa', at the end of September after less than eight months of excavation.

Geology along the alignment was shale, limestone and

sandstone. The TBM was equipped with a methane gas detection system designed by NFM.

The tunnel lining is precast concrete with 320mm thick segments – thinner than the 500mm segments used on Lot 1 of the Pajares project where the TBM was previously employed.

The maximum advance in a month on Lot 5 was achieved in July when the TBM bored 1,140m – ahead of the previous record

held for a hard rock drive in Spain, which NFM said it held and was 1,012m. The previous advance was by the 'La Adelantada' TBM and was achieved on the Madrid metro in 1996.

The contractors will retain the hard rock TBM for future tunnelling projects.

On Lot 1 the TBM had experienced prolonged downtime due to problems with complex geology, including groundwater

and methane. The machine bored 9,847m in 20 months and finished its drive – one of two parallel tubes – in mid-2007. The remainder of the 10,400m long tube was completed by conventional means.

The Pajares high-speed rail project is being developed by Administrador de Infraestructuras Ferroviarias (ADIF). The rail link will be 49.5km long and include 24.7km of twin tunnels.

Push for nuclear waste research

Two key steps were taken early this month to back research and development efforts on deep burial of high-level radioactive waste (HLW) and spent nuclear fuel in Europe.

The European Commission (EC) has called for proposals for in situ demonstration projects in underground repository laboratories under its "Fission" scheme, operated by the Euratom unit. Deadline for submission of proposals to the EC is April 2010.

Separately, this month, leading radioactive waste management organisations launched a document that aims to bring greater co-ordination, knowledge sharing and training for "geological disposal", as deep burial has been termed.

Their 'vision document' aims to establish a "technology platform" to gain such systematic benefits among partners in Europe. As a result, they hope the effort will help co-ordinate the remaining R&D needed in Europe to help establish the world's first deep repository.

Tunnel complexes as deep repository structures are being partly developed on-site in

Finland or planned in Sweden and France.

The on-off progress with the long sought repository at Yucca mountain in the US is out of political favour at present, but research work continues at a reduced level.

Research for a repository in Germany was started in a salt dome at Gorleben but politics led to a moratorium. However, the change of government in the federal election, in September, might lead to some changes.

Currently, the UK has no active research underway at a specifically favoured site for a repository.

The EC's call for proposals is the fourth to be made under its current funding period but marks a strong push towards on-site implementation of concepts and technologies in deep repositories.

It is anticipated that about €12M (US\$18M) will be made available by the EC for approved demonstration projects and other support work related to geological disposal. Matching funds may lead to the total budget for the repository research being double the EC's indicative figure, as has

happened with previous work on dealing with disposal of radioactive waste.

While the funding call centres on tunnel complexes as repository structures, separately there is some, albeit minority, interest in the alternative possibility of disposal in deep

boreholes, approximately 3km-5km in depth.

The option was also raised among others at the "Nuclear Waste: The Challenge of Underground Storage and Disposal" conference, in London, this month which was organised by Progressive Media Group.

Beles headrace final breakthrough

Final breakthrough on the tunnelling for the headrace of Beles Multipurpose ("Beles II") project, in Ethiopia, was achieved early this month.

Seli completed the tailrace tunnel last year but the headrace was longer and more difficult drive. Both tunnels have been excavated under subcontract to Salini Costruttori.

Geology along the alignment of the headrace was mostly basalt of up to UCS 350MPa but there is a zone of almost 2km of local faults and loose, lake deposits.

The 12km long tunnel was excavated with a 8.1m diameter double shield universal TBM designed also by Seli for EPB mode excavation.

The TBM is one of the company's most advanced shields, capable of switching from DSU to EPB mode in the complex ground. In addition to usual DSU functions, the design provides ability to handle squeezing ground and face treatment. The switchover in excavation mode

takes between two and three weeks.

Progress achieved by the EPB-DSU shield through the loose soils was up to 15m-20m per day. Tunnel lining was precast concrete rings (6+1) with segments of 300mm thickness.

The EPB-DSU shield started excavation on the headrace in late 2006. Finishing works on the headrace are due to be completed by January next year.

Separately, Seli used a conventional, 8.03m diameter DSU to bore the 7km long tailrace tunnel through basalt. The TBM was launched in the second quarter of 2007 and holed through in May 2008. The tailrace will discharge into the Blue Nile river (T&T, August 2008, p4). In addition to the two TBMs, Seli also supplied backups, rolling stock and ancillary equipment for the drives.

The client is the Ethiopian Electric Power Corp. It awarded the EPC contract to Salini in 2005.

Trio of Robbins TBMs team up in Kuala Lumpur

Three Robbins main beam TBMs are to be used on the 44.6km Pahang-Selangor Raw Water Tunnel in Malaysia. The Ministry of Energy, Green Technology and Water has commissioned the tunnel to transfer water from the Semantan River in Pahang State to the Selangor / Kuala Lumpur region, traveling as far as 1,200m (3,900ft) beneath the Titiwangsa mountain range. Excavation is scheduled to begin in late 2010.

The 5.2m (17.2ft) diameter machines and continuous conveyor systems will be provided to the SNUI JV, a consortium led by Shimizu Corporation and Nishimatsu

Construction of Japan, along with local companies IJM Corp and UEM Builders Bhd.

After shop assembly, the three machines are scheduled to begin boring between October and December 2010. "Robbins' experience in hard rock ground conditions, along with their willingness to work together and be a reliable partner with us, were the main factors in choosing the Main Beam machines," said Mr. Kawata, Project Manager for the SNUI JV.

TBMs 1, 2, and 3 will be used to excavate sections of tunnel 11.6km, 11.6km, and 11.2km in length, respectively. The three machines will be

assembled outside their particular adits, then 'walked' down a 12% grade for launch from NATM-excavated starter tunnels.

TBM 3 will be launched first from an intermediate adit, followed by TBM 1 boring in the same direction. TBM 2 will be launched last, boring in the opposite direction towards TBM 3. Conventional drill and blast headings will complete the remaining tunnel sections.

The back-loading cutterheads are the smallest ever designed using 19-inch disc cutters—a disc size that will allow for longer cutter life in hard rock. Geologic conditions are expected to

consist of 200 MPa (29,000 psi) UCS granite, with moderate squeezing ground and fault zones.

During excavation, ring beams and rock bolts will be used in addition to shotcrete, which can be applied from working platforms directly behind the cutterhead.

If unstable ground is encountered, invert thrust systems can be utilized to avoid gripping against the tunnel walls.

Once complete in 2013, the tunnel will convey approximately 27.6 cu meters of water per second (7,300 gallons per second) for use in domestic and industrial applications.



Left: The Vesalius arrived on the back of a 110metre long by 45metre wide submersible deck cargo barge, the "Eide Barge 33" which was towed by the 78metre long tug vessel the "Eide Wrestler"

Dredger arrives on the Tyne

The cutter suction dredger, Vesalius arrived on the River Tyne in early November ready to begin dredging a channel for the second vehicle tunnel under the river.

The start of dredging marks a crucial milestone for the New Tyne Crossing project. Four 90m long reinforced concrete tunnel elements have already been

constructed at Walker Dry Dock ready for immersion into the dredged trench early next year.

The 93m long Vesalius will be berthed at Riverside Quay, South Shields while preparations are made to the vessel to enable it to begin dredging operations. It will be moved to the site of the new vehicle tunnel, between Howdon Basin in the north and Jarrow

Riverside Park in the south, on Sunday 8th November to begin dredging operations.

Nicolas Caille, Project Managing Director for Bouygues Travaux Publics, the main design and build contractor, said: "The arrival of the

dredger is a very visible sign that the key part of this project is about to begin.

"Progress on the land tunnels is right on target, with excavations for all the cut and cover sections complete, and floor and roof slabs for the new tunnel already built in parts of Jarrow and East Howdon. What we need now is that vital connection between the north and south land tunnels, and with dredging due to start we can look forward to making that connection a reality in a matter of months."

Extra shaft to prevent delays in Brisbane

The Brisbane Airport Link and Northern Busway project has been given permission to sink an extra 42m deep shaft to avoid a potential eight-month delay to the construction programme after unexpectedly poor ground was met in part of the project.

The Government of Queensland, Australia, last month gave the green light for the additional, 15m dia. shaft to be sunk at Woolloowin, on a state-owned site set aside for a future road upgrade.

JV contractor Thiess-John Holland plans to have two roadheaders working from the shaft, taking the total number of machines at Kedron to six. The roadheaders will bore the permanent access ramps and open up two junction caverns to the main tunnels.

Kedron is about halfway along the main tunnel alignment and the caverns need to be completed before the TBMs arrive at the location. Two 12.48m diameter Herrenknecht TBMs are scheduled to be launched in mid-2010, in Clayfield.

The original plan was to use the ramps to open up the caverns and also provide access for final concrete lining works. However,

due to the more extensive ground support needed in weaker strata, continuing with the plan would have severely delayed cavern construction with a knock-on to the TBM drives and completion of the entire project.

The JV began excavation work early this year on the fixed-price, fixed-term contract to complete all construction by 2012. The project involves construction of 11.8km of main tunnel, including 5.7km long twin tubes.

In layout, all the project's ramps require four cavern junctions to link to the two tubes of the main tunnel – two in the Kedron area and two at Chalk St, where the TBMs will eventually be dismantled. Only the Kedron caverns are affected by the change to construction plans.

Generally, the geology in the overall project area is mainly regionally metamorphosed rocks, including hardened shales, greywackes and quartzites.

At Kedron, the anticipated strata ranged from Brisbane Tuff at the cavern invert (high strength) and crown (low to high strength). In between the early data suggested intersecting sediments and Tuff, overlain by highly weathered material and residual soils. Above the crown the low strength

HCC holes through on Mumbai bore

Hindustan Construction Co (HCC) has holed through on excavation of the 5.8km long Maroshi-Vakola section of a major water tunnel project in Mumbai.

Tunnelling on the 3.6m diameter bore by TBM involved driving through variable ground and in heavy groundwater flow below two runways at the airport at a depth of approximately 70m.

Significant ground treatment and tunnel protection works were called for in the variable strata, which also saw groundwater seepage increase to approximately 25,000m³ per day during the monsoon season.

Progress reached up to 40m in a day and the average daily rate of excavation was 20m. Final concrete lining works are underway.

The Maroshi-Vakola tunnel is part of a larger, 12.2km long water tunnel being built in three sections to Ruparel College. The

second drive is 4.5km long from Vakola to Mahim, and the final short drive is to Ruparel College.

Three shafts of 12m diameter and 70m-80m deep will be used for the works – at Maroshi, Vakola and Mahim. The tunnel is to be commissioned by August 2012.

The contractor's most recent water tunnel works in the city, on the almost 12km long Bhandup Complex to Charkop drive, also involved difficult geology but was completed early, it said.

Separately, HCC has won a contract that involves excavation of a 2.8km headrace tunnel with a 7.5m wide modified horseshoe-shaped cross section, plus diversion and tailrace bores, on the Pare hydro project.

The tunnels are part of a larger package of civil works on the project in the state of Arunachal Pradesh. The client is North Eastern Electric Power Co (Neepec).

Tingalpa formation was predicted.

Additional site investigation was done after the project had commenced, and the geology was found to be more variable and weaker, in general.

The consultant hired by the Government to review the JV's application to change plans said that normal levels of site

investigation for the size of project had been performed prior to the start of the job.

The Woolloowin shaft will also be used for access in the final concrete lining works, said the JV.

BrisConnections, the client and concessionaire for the new link, is a consortium of the JV partners with Arup, PB and Macquarie.

New route for Tideway

Thames Water has played down fears that it is to abandon a 12km length of the Thames Tideway tunnel in favour of diverting flows along an alternative route.

Reports from engineers close to the project said that the length of the 32.2km tunnel could be cut short and the flow diverted into the Lee Tunnel in a bid to save money.

"We have not yet had the public consultation so until then we are open minded on the route and we can't discount anything," said a Thames Water spokesman. A public consultation on the 32.2km project is expected to begin in Summer 2010 with the final scope of the scheme determined after this. "We can't rule it out but it doesn't mean it is likely to happen," said the spokesman.

The Thames Tideway project

consists of two tunnels. The first is a major 32.2km bore, with a 7.2m internal diameter, that follows the path of the Thames collecting spillages from 36 sewer overflows. It starts at Hammersmith in West London and terminates at Beckton Sewage Treatment Works in the east. The second is the 7km Lee Tunnel which begins at the Abbey Wells pumping station and also terminates at Beckton.

According to reports the water company is considering terminating the main Thames tunnel just east of the Tower of London and diverting the flows to the Abbey Wells station where it would then join the Lee tunnel. This would shave approximately 12km from the route.

Thames Water confirmed that construction of the Lee Tunnel is still on schedule to begin in April 2010 and appointment of the

contractor is planned for the end of the year. Two companies are competing for the £430M award, a joint venture of Morgan Est with Vinci Construction Grands Projets and Bachy Soletanche; and Murphy with Hochtief.

Construction of the main tideway is scheduled to begin in 2012 following public consultation and planning approvals. The project should be completed by 2020.

The cost of the scheme is still unconfirmed but is expected to be in the region of £2bn. However Thames Water is under pressure to cut its spending plans after industry regulator Ofwat determined that it should invest £4.6bn across its water and waste water network between 2010 and 2015. Thames Water wanted to spend £6.5bn. A final decision on its spending limits will be made by Ofwat this month.

Singapore KPE tunnel plaudit

Studies have ranked the Kallang-Paya Lebar Expressway (KPE) tunnel highly in both design and safety against European tubes, according to Singapore's Land Transport Authority (LTA).

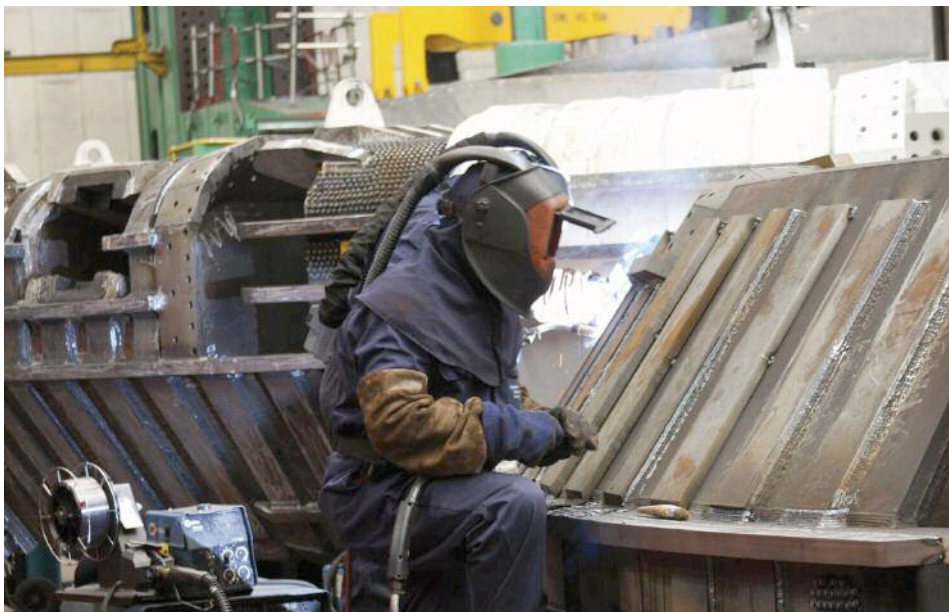
The plaudits come following studies sought by LTA from the European Tunnel Assessment Programme (EuroTap) and an earlier, independent benchmarking review by Allgemeiner Deutscher Automobil Club (ADAC).

Three quarters of the 12km road is in tunnel, the first phase being 3km long. The tunnel was built by cut and cover box construction in six contracts.

KPE is the longest underground expressway in southeast Asia, and links East Coast Parkway to Tampines Expressway.

The first phase of the KPE tunnel was opened in October 2007, and the second phase came into service a year later, in September 2008. The KPE road and tunnel cost approximately S\$1.7bn (US\$1.23bn), said LTA.

Markham cutterheads set for China



excavate a major rail project in Gansu province.

The cutterheads, each weighing 226 tonnes, are for two 10.2m TBMs to be used on the West Qinling project, which is to link the city of Longnan with the towns of Waina, Luotang and Fengxiang.

The machines will be used by contractor China Railways 18th Bureau (Group) Co to bore parallel, 16.6km long single-track rail tunnels for the project.

DavyMarkham doubled its welder workforce through contract hire to work three shifts, six days per week for faster fabrication of the cutterheads. The turnaround was about a third faster to meet Robbins accelerated programme, it said.

The cutterheads were despatched last month in modular components to Robbins' assembly facility in Chengdu, Sichuan province. The TBMs will then be dismantled for transport and reassembly on the West Qinling site.

A pair of cutterheads fabricated by DavyMarkham for Robbins have been despatched from the UK for assembly in China, where the main beam TBMs are to help

Progress builds at Thessaloniki

The first of two TBMs on the Thessaloniki metro project in Greece has holed through at a fully excavated station. Progress is accelerating significantly following earlier delays due to diaphragm wall complications at some part-opened stations and difficulties passing below old buildings.

The 6.12m diameter EPBM on the south tube holed through at Sintrivani station early this month, approximately 3km - almost half way into its 7km long drive. By the end of October the TBM on the north tube had excavated approximately 1,700m.

In September, the TBMs had advanced 412.5m and 148.5m, respectively. Maximum daily progress building the 5.3m i.d. tunnels was 25.5m and 21m, respectively.

The average daily production for the shields was 19.6m on the south and almost 18.6m, on the north tunnel - well ahead of the average rates of approximately 13.1 and 14.6m until the end of that month. The averages are based on excavation days only and exclude stoppages.

Tunnelling works are being done under a 60:40 subcontract by Seli and Aegek. Aegek is the lead partner in the overall metro JV with Seli, Impregillo, Ansaldo Trasporti and Ansaldo Breda. The

7.7km line includes 13 stations.

Two Herrenknecht EPBMs with Seli backups were launched for the eastward tunnel drives in January and April, respectively.

The lead TBM had advanced approximately 600m when the second machine got underway. The minimum distance between the shields is 150m and at the time of the station breakthrough this month they were approximately 500m apart.

The tunnels are at depths of up to 27m deep and are being lined with segmental concrete, five-piece bolted rings of 300mm thickness. There is also a custom-tailored two component grouting system.

Anticipated geology along the

alignment includes clay, sandy clay, and sand, with locally very weak ground. However, what was not expected was steel where there should have been fibres in some of the diaphragm walls at stations that had to be crossed by the shields.

Tool replacement and maintenance work involving hyperbaric intervention, which was also needed to cut into the problem walls, held back progress. In a single week there were eight hyperbaric interventions in 1.7 bar pressure.

There was also difficult tunnelling below a 15th Century mosque, which already has seismic damage.

The metro is being developed by Attiko Metro, which has also been building the metro in Athens.

Charity drive

The Strathspey Railway Charitable Trust is rallying for support from both the public and politicians for its "Rails to Grantown" project, which would see a railway line closed in 1965 reopened.

The Trust needs to raise nearly £5M to complete all aspects of the project including river bridge installation, track bed, track, new station buildings, car parks, platforms, land requirements and a new tunnel. The Scottish Government's Agency "Transport Scotland" requires a £1M contribution for the construction of a railway tunnel to pass under the re-aligned A95 road at Gaich near Grantown. The line extension to Grantown, once completed, will be maintained and operated by volunteers working on the trains, track and stations.

It is hoped the new line will bring further benefits to tourism, business and employment as well as complementing existing transport options in a very scenic part of the Cairngorms National Park.

G&V CC Member and Trust Vice Chairman Basil Dunlop said: "Grantown needs a good attraction to boost tourism and business, and this is the only achievable development on offer. It will also provide alternative transport within the Park, and re-establish a direct link with the national rail network".

Morgan Est set for Barry bore

An Iseki Unclemole was lowered into a shaft in Barry, Wales, early last month to construct part of a new flood

sewer. The TBM is being used in this section of the project by Morgan Est to install a 147m long stretch of 1.5m i.d. pipeline tunnel

for client Welsh Water, which is investing in flood alleviation infrastructure in a £130M (US\$218M), five-year programme.



MTR gets WIL underway

The first tunnel contract of the West Island Line (WIL) in Hong Kong's expanding metro network has been awarded by MTR Corp, which separately has seen milestones on a metro venture in Beijing and also a major rail scheme.

MTR signed a contract last month with a JV of Dragages, Maeda and Bachy Soletanche Group for Contract 703, which involves building the section of WIL between Sheung Wan and Sai Ying Pun stations.

The HK1.6bn (US\$206M) contract involves tunnel construction between the stations and sinking access shafts for works to be done at King George V Park and Sai Woo Lane Playground.

In total, the WIL extension will add 3km to the Island Line to take

it from the existing Sheung Wan station west to Kennedy Town. The project was approved for funding in July and is due for completion in 2014.

Two other tunnel contracts are under procurement: Sai Ying Pun and Hong Kong University stations, and the tunnels from Sai Ying Pun towards Kennedy Town (Contract 704); and, Kennedy Town station and associated tunnel (Contract 705). The former is due for award in the first quarter of 2010 and the latter before the end of this year.

Separately, the Hong Kong Government has approved construction of its section of the planned Express rail Link (XRL) to run across the mainland border to Guangzhou and Shenzhen. Its project representative on the link is Jacobs.

The project will tie Hong Kong into China's high-speed rail

Lovat TBM for Fairfax

Lovat is to supply a TBM cutterhead and main drive for a water tunnel project being undertaken by contractor Kassouf in Fairfax, Virginia.

The contractor placed the order to receive the hard rock cutterhead, forward shell and main drive in March next year, and will fit them to a Lovat gripper TBM it already owns.

The cutterhead will be fitted with 15.5" single tip discs with replaceable rings. Lovat said that steel for the rings will be manufactured using technology of its parent group, Caterpillar. The Canadian TBM manufacturer was acquired last year by Caterpillar (*T&T*, April 2008, p13).

Kassouf is to use the gripper to drive a 2,560m long tunnel through mostly diabase of low strength up to UCS 370 MPa, and with a Carchar Abrasivity Index (CAI) ranging 2.2-5.5.

The bore will also drive through a hornfels formation of mainly altered sandstone, shale and siltstone.

The UCS is 90MPa-145 MPa and the CAI range is 1.3-3.1.

network, and the full XRL link is due to be completed by 2015. The Hong Kong section of XRL will be 26km long and built in tunnels.

In mainland China, MTR's first investment has been in Line 4 of Beijing metro, which is 29km long and the mostly underground line has 24 stations (23 below ground). It is being developed as a public-

private partnership (PPP) scheme, and trial operations began in late September, on schedule (*T&T*, May, p8).

MTR is operating in the Beijing MTR Corp along with two partners - Beijing Infrastructure Investment Co and Beijing Capital Group. Their 30-year concession runs from the start of operations.

MTA awards ESA job

A JV of Granite Construction Northeast, Traylor Bros and Frontier-Kemper Constructors is to build the Queens bored tunnels and associated structures for the East Side Access (ESA) project underway in New York.

The US\$659.2M contract for Contract CQ031 was awarded to the JV by the Capital Construction Dept of the city's Metropolitan Transportation Authority (MTA).

Tunnelling works involve using a pair of TBMs to drive four tubes with a combined length of just over 3km below a rail storage yard in Queens. The package, including excavation of three emergency exit structures and other works, is expected to take 42 months.

Approximately 44%, or US\$291.5M, of the contract value is being funded by the Federal Transit Administration (FTA). The funds include US\$132.2M from the American Recovery and Reinvestment Act.

ESA will link the Main and Port Washington lines of Long Island Rail Road (LIRR), in Queens, to its new terminal being excavated below Grand Central station, in Manhattan.

Strabag JV wins Rohtang job

A JV of Strabag and Indian firm Afcons has won a contract to build a road tunnel at Rohtang Pass in Himachal Pradesh state.

The Euro250M (US\$370M) contract for the 8.8km long tunnel was awarded by a national agency, the Border Roads Organisation (BRO). Strabag's affiliate Dywidag International is to undertake the tunnelling work.

The tunnel cross-section is designed to be horseshoe-shaped with a finished width of 10m, including 1m wide walkways at each side. Within the

cross-section of the single bore and below the finished roadway, is to be a 2.25m high by 3.6m wide escape tunnel.

Drill and blast excavation of the tunnel is scheduled to start in the second quarter of 2010 and be completed by the end of 2015. Lining support is to be fibre-reinforced shotcrete and bolts with ribs in weakest zones.

Geology along the alignment comprises uniformly dipping alternate sequences of quartzites, quartzitic schists and thin bands of quart diolite schists.

There are also three anticipated fault zones and expectation of squeezing ground.

While tunnelling work will proceed from both portals the majority will be done from the south due to accessibility problems caused by snow during winter at the north end.

Rohtang is one of the world's highest mountain passes, and the tunnel is to be built at an elevation of 3,100m. The new tunnel will be a link that improves year-round use of the Leh-Manali highway.

Suruc tunnel pact for Seli

Turkey's Ilci Construction has extended its partnership with Seli on water tunnel excavation with an agreement to construct a new project in the Suruc region.

The 17km long tunnel is to be excavated using a 7.83m diameter double shield TBM supplied by Seli. The Italian firm will also provide auxiliary equipment, maintenance services and technical assistance during the drive.

Excavation is expected to commence around

the second quarter of 2010 and be completed within three years. The bore is to be lined with 300mm thick hexagonal concrete segments.

The Suruc project is a water transfer tunnel to support irrigation improvements in the region.

Seli and Ilci have been working together on another water tunnel project in Turkey - the 17km long Mavi ("Blue") bore, for which Seli has supplied a 4.88m diameter double-shield plus back-up and equipment (*T&T*, December 2008, p10).

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Bid docs out for Cityringen

Tender documents were issued last month to the four prequalified civils JVs in the running for two tunnelling and box station packages on the Cityringen project in Copenhagen – the latest major expansion of the Danish capital's metro network.

Cityringen will loop the city centre in 15.5km long twin-bore tunnels connecting 17 stations and five shafts, three of which are for excavating the tubes. The tunnels will also have four crossovers.

The works have been split into two packages, North and South. Client Metroselskabet plans to award the works in the middle of next year.

One or two JVs may be awarded the packages with responsibility for detailed design as well as construction work. The four JVs prequalified to bid are:

- Alpine Bau with FCC Construction;
- Bilfinger Berger with Vinci Construction Grands Projets and Per Aarsleff;
- MT Høgaard with Hochtief, Ed Zublin and E Pihl & Son; and,

- Salini Costruttori with Tecnimont and Seli.

Geology along the tube ring comprises glacial moraine over limestone, the main formation for TBM drives, with more sand in the northwest of the project. The groundwater level is high and the city has strict environmental controls.

It is expected that either EPBM or slurry shields will be used on the majority of tunnels, totalling approx 14.9km in each tube, and bored at depths of approx 15m-35m. Crossovers and bifurcations are to be excavated by sprayed concrete lining (SCL).

The city's recently built metro lines have 4.9m i.d. tunnels, which are nominally 20m between centrelines and a similar arrangement is anticipated.

The boundaries between the North and South civils packages are at Aksel Møllers Have station in the west of the tunnel loop, and in the east at the Øster Søgade lake, between Triangeln and Østerport stations.

Stations are typically deep structures, platforms on the

approx 62m long boxes being at depths of approx 19m. There will also be semi-shallow boxes with platforms approx 13m deep.

The client is being helped on the civils design by a JV of Cowi, Arup and Systra.

A number of shafts were

eliminated from the early design as improved technology, such as sprinklers on trains, is to be used to help safety. The reduction also helps minimise traffic disruption from construction work (*T&T*, November 2008, p6).

Atlas Copco feels Q3 squeeze

Orders of drilling rigs for tunnelling projects remained very low in the three months to 30 September, reported Sweden's Atlas Copco in its Q3 results.

The construction segment also reported weak demand in the third quarter for most activities, falling sharply for rigs used on surface works. Few countries saw clear effects on investments from government stimulus funds in Q3, said the firm.

However, there was some improved activity in the mining sector compared to prior months, it added.

Overall, the Construction and Mining division reported operating profits were down 43% to SKr823M (US\$116M) compared to the same period last year. Sales revenues were 23%

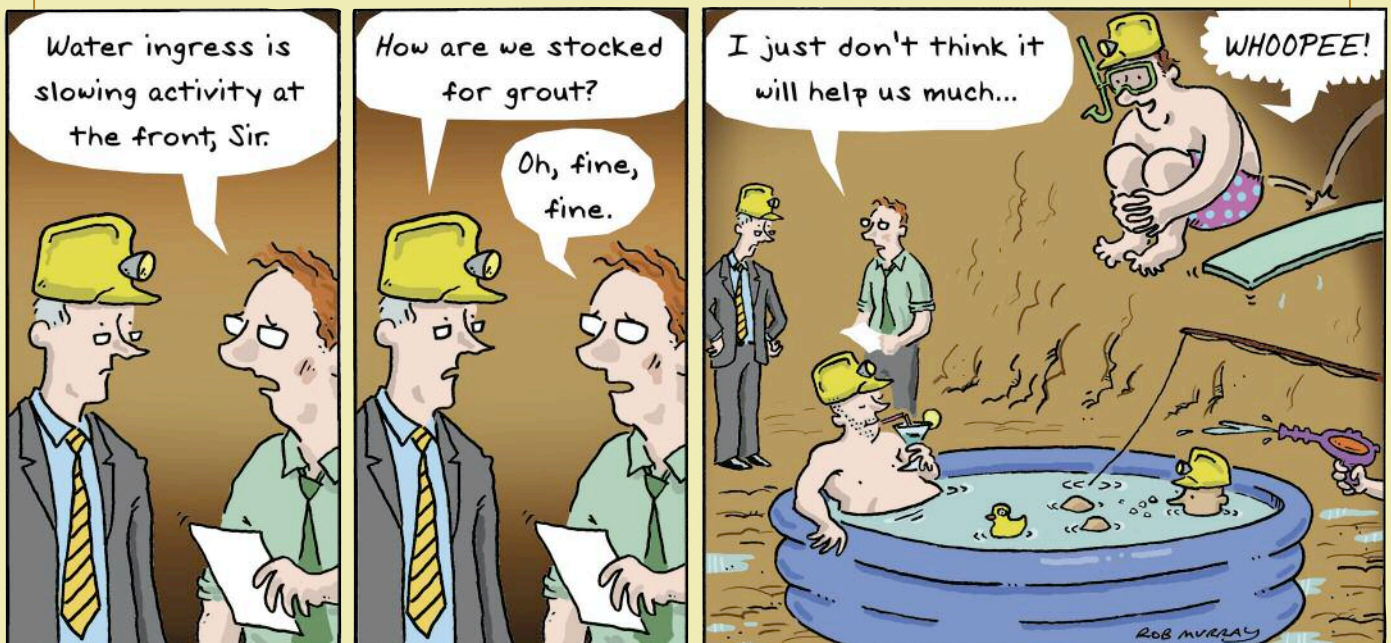
lower to nearly SKr6bn (US\$844M), and orders received fell 28% to SKr5.65bn (US\$795M).

For the nine months January-September, the division's operating profits dropped 41% to almost SKr2.6bn (US\$365M), and revenues were down 17% to SKr19.5bn (US\$2.74bn). Orders received fell by almost a third to less than SKr17bn (US\$2.4bn).

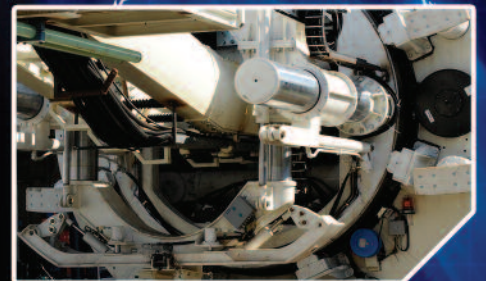
Future overall demand for the entire group is expected to stay the same although the firm expects some improvements in China and India.

Group operating profit in Q3 was down by a third to SKr2.4bn (US\$338M) on revenues 18% lower at almost SKr15.1bn (US\$2.1bn). Orders received fell by almost a quarter to SKr14.3bn (US\$2bn).

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Cutting through Austria's Inn Valley

State of the art jet grouting, advanced slurry TBMs and high tech compressed air use have been among a slew of techniques used for the complex Inn Valley railway in Austria reports Adrian Greeman



Above: The complex road, rail, stream and tunnel crossing at Stans

For two years, serious construction work has been underway on the exploratory tunnels for the Brenner Pass high speed rail project in Austria. Like the world record length 57km Gotthard Base Tunnel, now finishing excavation work in Switzerland, this will eventually be a very long deep-level base tunnel, in this case 55km, and up to 2000m under the high Alpine peaks.

To service this future link, a major programme of works is underway in Germany, Italy and Austria to build or upgrade a new European high-speed freight and passenger corridor, passing from Berlin and Leipzig through Munich and on into Italy to Naples and Palermo in Sicily.

A key early project is upgrading lines in the River Inn Valley, the centre of Austria's picturesque mountain Tirol. There are few choices for the route except to pass along the valley floor, just as the existing rail line does and the A12 motorway across the Brenner Pass.

But fitting new lines into the narrow valley is not easy. The flat lowland in the glacial U-shaped basin is at a premium for agriculture and dwellings, and there is also the river meandering through. Widening the existing twin track corridor to four lines is not

possible, as it would involve major realignment to accommodate gradients and curves for a 250km maximum speed track, and would increase noise and disruption in a popular tourist destination.

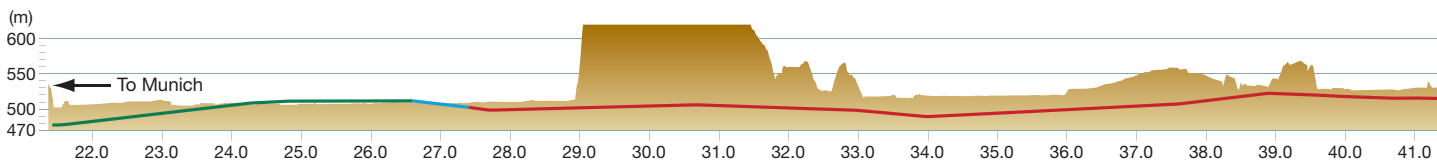
Shallow tunnels are the solution selected by Austrian Railways and the special Brenner Eisenbahn company (BEG) it set up to carry through the roughly €2.5bn (£2.3bn) project. Setting the new line just underground does not consume surface land, or impact the environment too much and bypasses valley bends by cutting through mountain outcrops. Some 32km of the 40km project, is bored or in cutting.

But that has meant complex challenges for the tunnellers, now largely completing the civil excavation work after six years of construction (T&T September 2004) not least from geology. The valley floor comprises a deep layer of alluvial and mountain erosion debris fans, mixed up into

300m of heterogeneous sands, silts, loose gravels and sometimes cobble blocks. Its open structure is saturated by the river water with a table hovering 2-3m down and just 1m in the summer meltwater season. It means high water pressures at many points on the tunnel, up to 3 bar.

Settlement and disturbance is also a critical issue as the line criss-crosses under the motorway, old bridges, buildings and villages, and the existing railway.

Various techniques have been used to cope, in eight major construction contracts. Two long valley floor sections used Herrenknecht Hydroshields, and there is underwater excavation for cut and cover and assorted compressed air drives. There are also complex jet grouted ground arches and improvements. Most complex of all is a jet grouted tunnel "tube" in the ground at Stans excavated inside. There are also two major but conventional bored tunnels.



First section of the route begins in the lower part of the Inn Valley near the German border. For 5km the existing corridor is simply widened to four tracks, and then central high speed lines diverge and drop down a slope in an open cut before swinging out into a long tunnel section of over 13km split into a number of contracts.

First tunnel work tackles the 790m long cutting and a short entry section of cut and cover tunnel of just over 1600m. Though relatively straightforward, this €57M (£51M) contract, one of the last to start in April 2008, had its challenges, not least because of safety issues working close to the busy main line which carries over 350 trains daily. The contractor Strabag has constant communications with the operational teams.

The section was made within excavated steel pile trenches, the tunnel section, starting at 15m depth, being completed with a backfilled concrete arch made using a travelling formwork. Strabag used Doka formwork for the 12.5m lengths. The concrete is a watertight B300 specification sealed with resin injection at the joints and there is an additional PVC membrane around the outside "to be sure" says Martin Pellizzari, project spokesman from the BEG client.

In the alluvial ground the cut and cover excavations between sheet pile walls were inevitably water filled, and divers from local specialist firm Nautilus were a significant part of the operation. They guided the crane-mounted clamshell grabbing out of the usually 70m long compartments to ensure a smooth base in murky and often freezing water, and were crucial for work on a 1.6m thick underwater concrete slab which plugs the trench base before dewatering. Most all they were important for installing 15m long heavy ground anchors which help resist uplift, guiding the crane mounted drills over the water and fitting steel plate anchor connections.

Deepest dives were for a shaft on one of the safety rescue tunnels which are provided every 500m on the shallower sections of the tunnel. Shafts provide

Right: Fig 1 - Jet grouting was required underneath the abutment at Wiesing bridge ahead of the TBM drive
Below: The tunnel in section

stairwells and access for small escape tunnels which link to the main tunnel.

Inside two long mountain drives on the project these shafts are replaced by cross passages driven from a second safety tunnel running alongside the main bore.

Just such a mountain drive takes the tunnel on for its next 4.2km on a curving route through a mountain bluff on the south side of the valley underneath the town of Brixlegg. Porr Tunnelbau and Germany's Bilfinger & Berger tackled the job with conventional drill and blast methods using Atlas Copco jumbo rigs and diesel trucks to muck out.

"We had an initial contract earlier for a 4.8m width service and investigation pilot tunnel which the main contractor could use as additional access, allowing him to open a total of five faces" says Pellizzari. "Blast rounds were typically 3.5m and support according to rock convergence." As with all the alignment, the initial lining, in this case shotcrete, is finished with an inner cast in situ concrete lining.

Two main issues confronted the tunnellers. First, although much of the rock is sound granite and limestone, there were sections of anhydrite, which expands on contact with moisture and required overcutting and then the use of a squeezable aggregate in the concrete lining to prevent cracking. The mix contained polystyrene balls to achieve the required compressibility.

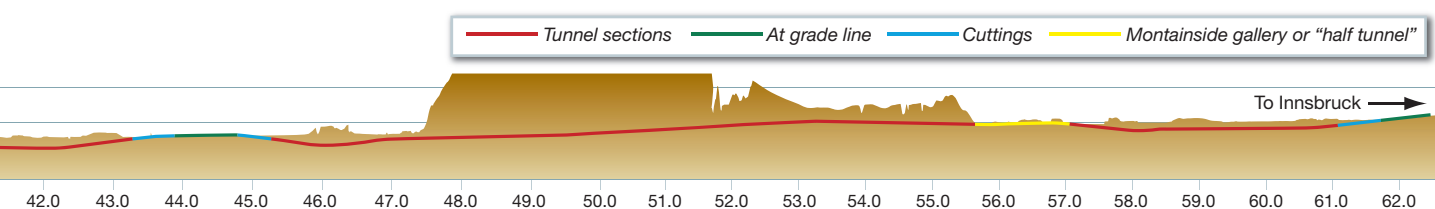
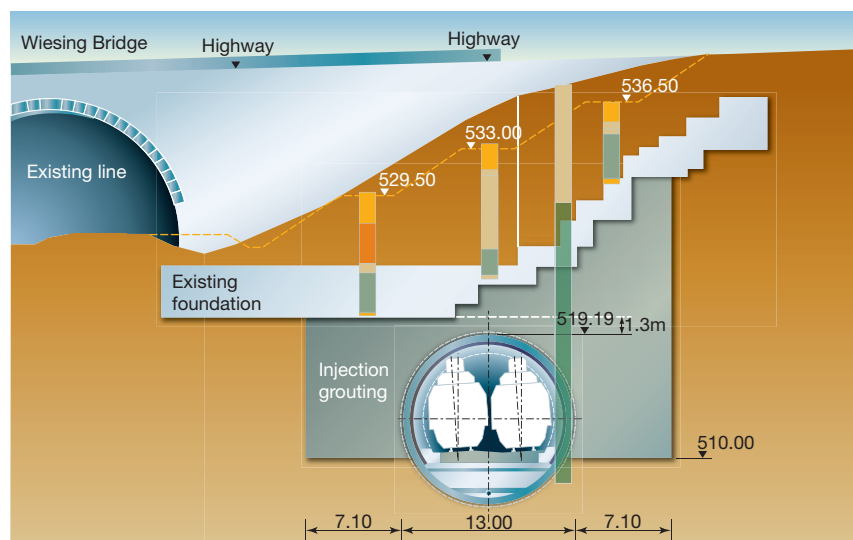
A more important issue was the presence of a mountain water table on around 1km of the drive, sitting up to 60m above the tunnel. To deal with this the section was drilled and dewatered before excavation, which was an issue because it feeds local springwater used for the community.

When the drive was complete and a watertight tunnel lining was in place capable of resisting up to 6 bar pressure, the dewatering stopped. But the springs did not return as expected. A trial and error detective task was needed to grout various drainage points in the tunnel before levels eventually began rising again.

On other sections of the drive where the rock cover is much higher, and therefore potential water pressures higher, a drained tunnel design was used.

This rock tunnel leads into the one of the most potentially difficult sections, taking the tunnel alongside the river in the valley, and criss-crossing the river, the motorway and the rail line. For this work, in water column depths of up to 36m, pressures of up to 3.6bar were expected and it was decided to use sealed TBMs, the choice being slurry Hydrosields from Herrenknecht. Each was 13.03m in diameter, the largest used in Austria and close to the biggest anywhere in the world. Final internal tunnel diameter is 12.16m for the double high speed track.

The section divides naturally into two parts because a small mountain bluff

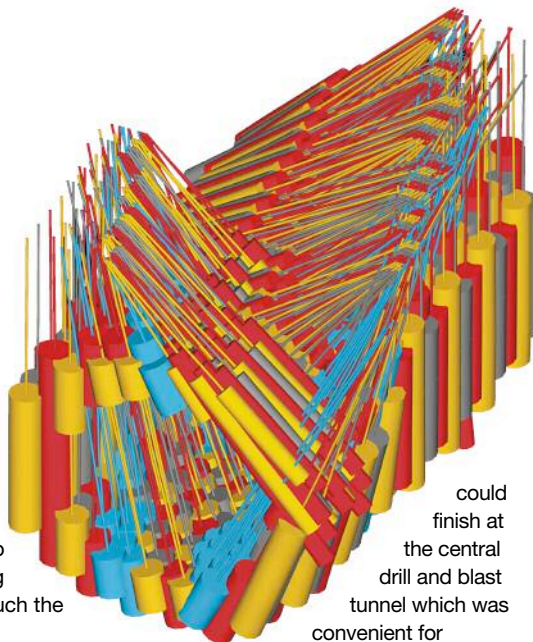


intrudes on the alignment just over halfway along, where a short drill and blast section has been carried out. Its 663m length left a drive of 5.8km to be made from the end of the Brixegg tunnel on to the town of Wiesing and a second 3.5km drive onwards past Jenbach. The second contract also includes a section of cutting and grade level line where the rail emerges briefly to make a connection with the existing railway, but otherwise has pretty much the same challenges as the first.

There were minor difference in the machines. For the longer Wiesing section contracting team Porr and Max Bögl used a brand new machine with a 2-chamber system where the rear working chamber contains a compressed air bubble for fine regulation of the tunnel face pressure particularly at difficult spots, where as little as 13m of overburden was present. It started work in June 2007.

A contracting group of Strabag, Züblin and Hochtief used a rebuilt machine originally from Kuala Lumpur for the shorter drive which began in November 2007. This machine had hydraulic rather than electrical drive and used a partitioned base element which divides the face chamber in two as a defence against clogging by excessively silty clay ground. This machine faced a maximum 3 bar pressure but came within half a machine diameter of the surface at one point.

Both machines had to handle a heterogeneous mixture of ground types including the capacity to cut and crush larger rock pieces and boulders. Both finished in good time, the first longer drive in February this year, six month early and the second drive in April. The machines drove in opposite directions, so that each



Left: The complex jet grouting "tube" at Stans to stabilise the ground

could finish at the central drill and blast tunnel which was convenient for reception chambers. Outer shields from the machines will remain in the tunnel walls as the internal components are stripped down and removed.

Apart from the machine technology itself, both drives involved significant use of jet grouted ground stabilisation, forming grouted "umbrella" arch shapes over the tunnel line at significant points underneath bridges and motorway embankments. One of the most important was under the abutment of a century old bridge crossing the river at Wiesing (see figure 1) and of major local tourist importance.

A large number of shafts – eleven on the Wiesing contract and five more on the Jenbach section were also needed for emergency tunnels. Each was made as polygon of diaphragm wall panels, excavated underwater and sealed with base plug slab at up to 35m deep. Short pipejacked connections to the main tunnel, using Herrenknecht slurry machines ran anything from 20m to 137m and were connected at the end by "NATM" excavation within a block of solidified ground produced by piling, diaphragm wall methods, or jet grouting. Twice these did not fully seal the ground and ground freezing had to be used to

finish the connections.

Jet grouting really came into its own on the next section of the route, with perhaps the most complicated geometry on the alignment as old and new rail came together. For this part the now at-grade line dips back into a cutting and then into tunnel, the first 780m long section carrying the new line beneath the town of Stans, close to the river.

Above the new tunnel sits a realigned and now parallel section of the old railway in a tunnel box, with upper and lower railways both passing on a skew underneath the A12 motorway bridge and part of its embankment. To further complicate matters, two small tributaries of the Inn enter the river at this point requiring landscaped culverts at right angles slotted through the two tunnels (see aerial photograph).

Herdina says that a TBM was contemplated for the section but for such a short drive would have been very expensive, though in the end perhaps not much more than the complex grouting selected. The idea for this was to improve the ground beneath the motorway and town by jet grouting.

This did not produce simply a block in the ground. Instead precision control was used to make a "tube" of solidified ground, through which the tunnel could then be bored or rather excavated.

"The idea was to mix the ground with cement grout through jet grouting to produce a 2m thick annulus" says Marco Ziller the project engineer for Italian specialist ground engineering company Trevi which did the two year long project.

"The mixed ground hardens to a lean concrete strength of perhaps 5N/mm² which was the client's minimum, though we averaged more like 10N/mm². But because it is a ring it will be very strong and resist the movement of the ground around it when excavating inside."

It also needed to be watertight, or close to it, with no gaps. To do that meant several things had to come together. Firstly the grout drilling would have to be very precise, which meant tight control of the drill strings and of the pressures for the grouting injection. Trevi has developed techniques to allow this with millimetre accuracy says Ziller, using electronic position detectors within the drill string, combined with

Left: Drill and blast on the longer tunnel section from Stans to Terfens village



accurate measurement of the drill position at the surface.

Second, a precise model of the pattern of hardened ground had to track the build up of the ring. For this Trevi developed a 3D modelling software specifically for the job, using the drill measures to calculate the shape. A copy of the program was passed to the client so that BEG's engineers could make their own checks.

But all that would be useless if the grout did not stay put. Unpredictable mixtures of gravels, silts, sands and boulders in the ground made it difficult to assess the dispersion. So too did the groundwater saturation. "And you must remember it is moving; not as fast as the river but significantly, which means the grout can wash out before it has set" explains Ziller.

Trevi's team devised a six point grouting system. Instead of a single drilling, each grout column is made up from a ring of six drillings. "You do three alternate positions first and then the positions between," he says. The second three act as infills to compensate for any washout.

A final drilling is made in the centre of the hexagon. "By now you have a ring of grouted ground which acts as some protection from the groundwater. By pumping a higher pressure in this central injection you can fill the void completely, 'repairing' the outer six at the same time."

The drill sequence then uses these clusters to build up the shape of the tube in the ground.

All this was tested beforehand on a full scale site mock-up, with excavations to inspect and diamond core drilling to assess the results. Trevi used multicoloured grouts to see just what the interaction was in the ground.

For the actual job Trevi worked from the surface for the drilling, a substantial amount from the side of the motorway, which is one of Europe's busiest, which required nearly 30 different traffic patterns.

The result was good. The tube was made in short lengths with jet grouted partitions across the tunnel line to separate them. Each was tested by pumping out the groundwater to assess inflow and leakage which was minimal. "The client wanted 5lt/sec and we mainly achieved 2lt/sec" says Ziller.

Excavation was carried out within the ground "tube" using compressed air and conventional means. The existing line was then added using cut and cover methods to position it above and the remaining concrete structure completed.

The five year project was the longest tunnelling contract on the scheme says Pellizzari.



Above: Grouted tube stabilisation was used substantially in loose ground

From this complex section the line runs on into a second major rock tunnel, 8,380m long. "Just over 3340m was in hard rock, mostly Dolomite, and the rest in loose ground" says Pellizzari "a complex mixture. The geologist was amazed."

Straightforward drill and blast with Atlas Copco jumbos did the rock tunnel section which contained a 2km long extra wide profile where the tunnel is 17.4m across and 12m high to contain three tracks. "It means we can have a passing place without using space in the valley" says Pellizzari.

The soft ground, comprising alluvial and glacial deposits in terraces was excavated with extensive use of forward grouted tube roof support in a single layer and for some low overburden sections in double layer. A 500m section of forward dewatering was needed and a short 127m length of compressed air excavation underneath a concrete slab where the line passed a shallow valley. Contractor for the €139M (US\$208M) project was a grouping of Strabag, Hochtief and Züblin, working from August 2003 until a November 2007 breakthrough with another year to finish the tunnel. A small length of mountainside gallery was next before the last full tunnel section of just over 4km which was also done by compressed air. Excavation was within heavy sheet piled walls, with a concrete slab above and a concrete box built inside. The top down method was used because it was the least disruptive on the village of Fritzens and other dwellings.

The contract, also with a joint venture of Strabag, Hochtief and Züblin, included

complex work underneath the station at Fritzens. "It was not possible to put a slab on the lines there so a forward jet grouted umbrella arch had to be made from the compressed air excavation approaching the station" says Pellizzari. He thinks it is the first time the techniques have been used together.

"There was some trepidation since disrupting the lines above would have blocked much of central Europe's freight transit" he says. A computerised real time monitoring system was used with liquid relative movement gauges and laser absolute level measurement on multiple points above. Engineers from the Strabag group doing the work could constantly check the impact of the grout injection pressures, as could BEG.

The section is being completed with a cutting ramp and a short surface run before connection back into the existing rail. Work started in March 2005 and finishes at the end of this year.

Tunnelling across the whole project has gone well, both on schedule and within budget once inflationary factors such as the steep steel price rises are taken into account, says Pellizzari.

Currently the focus is on completing the inner linings and some cut and cover work, and track installation, which will use a mass spring anti-vibration system from Austrian company Getzner with concrete track slab supported on point bearing pads. Signalling and electrical work is underway too with a completion for high speed testing in early 2012, followed - all being well - by opening later the same year.

T&T



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Dishing the dirt

Supply and removal work on section three of the Weinberg tunnel was made challenging by crowded conditions, tight emissions controls and stringent limits on transport of materials. Project manager for Rowa Tunnelling Logistics AG, Heinz Jenni explains

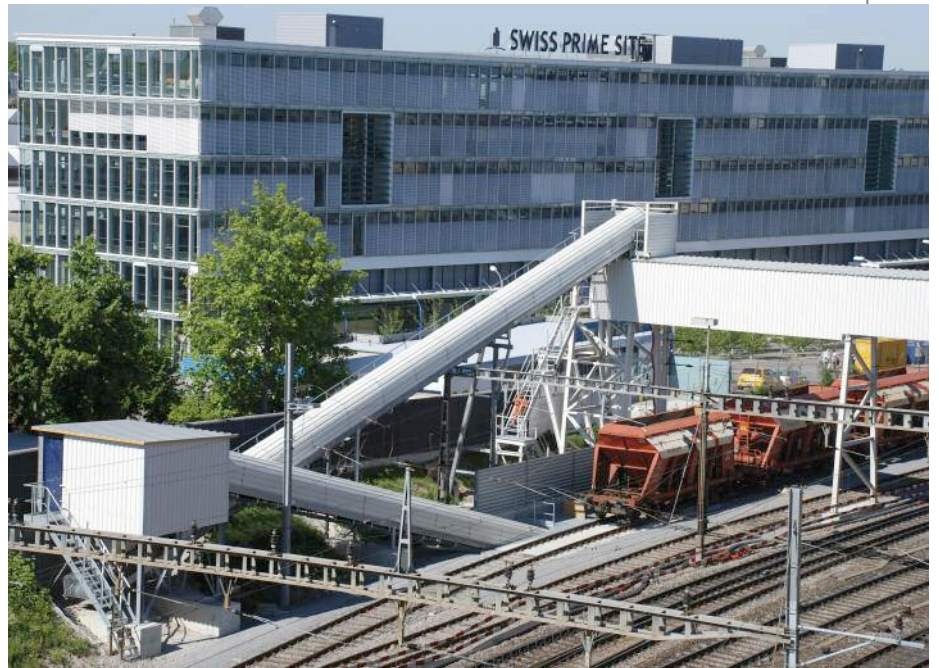
Swiss Railways is increasing the capacity of Zurich's main train station by building a new railway line underneath the city, running between Alstetten and Oerlikon. Opening in 2013, the double track railway, called the connection line, is being partially constructed by the consortium Weinberg Tunnel (ATW). ATW was contracted to construct lot 3 of this major project, and it has contracted the design of supply and removal installations to Rowa Tunnelling Logistics AG under a turn-key arrangement.

Rowa were appointed in February 2008 to develop, produce, supply, assemble and start up the muck removal installation. Completion was scheduled for October 14th 2008 so the team had less than 8 months to complete the contract.

The tunnel has an excavation diameter of 11.3m and a heading capacity of 20m per day. Designing the muck removal system required close cooperation with the client thanks to a range of challenging parameters.

Space was very limited, especially on site in Oerlikon and the requirements of the heading dictated a step by step construction of the facility. At times, assembly work was only possible during night because necessary track blockings were unavoidable. Transit traffic at the installation site Oerlikon had to be guaranteed at all times. A particular challenge was presented by the very cramped local conditions as well as the need for a smooth integration of the different interfaces between installation site and Brunnenhof shaft.

Furthermore stringent requirements were imposed with regard to handling and



transporting rubble material and gravel inside urban areas. Restrictions also demanded that the project met admissible emission limits during the planning phase. To minimize noise and dust pollution, the complete installation was encased throughout.

However despite the challenges Rowa was able to complete the project within the limited timeframe. The solution employed uses a continuous conveyor belt on a short transverse conveyor to remove the rubble from the entry tunnel, and from there with the transport conveyor alongside the support wall for approximately 800 m to the bunker facility. This bunker facility serves as buffer storage for rubble from the main tunnel and from the escape and rescue galleries. Filling capacity roughly matches a daily performance of approximately 6500 t.

Rubble removal takes place in trains with 16 wagons each with 60 t load capacity making a total capacity of approximately 960 t per train. The train is completely loaded within 30 minutes by an automatic train loading installation.

Due to the very busy flow of train traffic at the Oerlikon station, only seven free entry and exit time slots are available.

Above: Trains loading installation
Right: Gravel supply installation





Gravel transport to Oerlikon is facilitated by train. From the discharge gutter, the gravel is then transported across the train crossing via conveyors to the bottom of the Brunnenhof shaft. From there, the gravel is unloaded either into silos for the supply of the TBM heading, or directly arrives via elevator at the concrete installation aboveground.

The conveyor bridge consists of a steel construction with supports and housings for all the conveyor belts, i.e. including the bridge alongside the supporting wall, the connections to and from the bunker installation, the gravel conveyor bridge and the track crossing.



Above: Supply and removal installation place Oerlikon
Above left: Conveyor bridge across Regensberg bridge

The conveyor belts are housed in canvas. A maintenance walk way is built on one side. On the conveyor bridge alongside the supporting wall, the two conveyor belts are stacked one on top of the other (bottom for rubble, top for gravel). Below the conveyor bridge throughout the entire length, a metal sheet is installed for safety reasons.

The supply- and removal installation at Oerlikon is already in use and has proven its usefulness. With the realization of this very challenging installation, Rowa has

been able to prove its ability to deliver difficult projects within tight deadlines. It has also enabled the company to gain valuable experience in regard to the construction of turn-key supply and removal installation in urban areas. These include ensuring smooth integration of interfaces with Swiss Railways, managing road traffic and neighbouring lots, working in crowded conditions, meeting special emission-guide values and special assembly planning and its execution.

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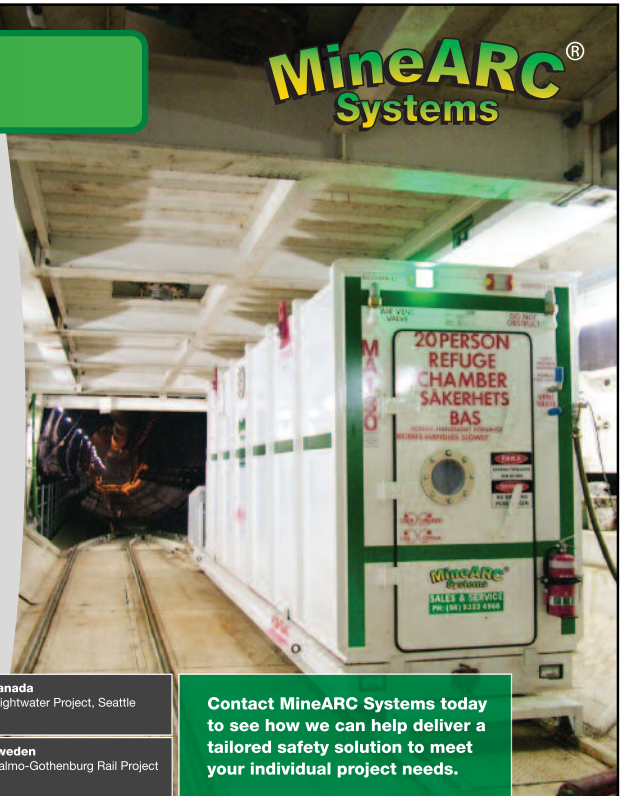
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Fast track to Jo'burg



Working on Gautrain, Africa's first high speed rail link, has been a unique experience. The project is the largest underground railway presently under construction in the southern hemisphere. Its unusual challenges set it apart from infrastructure projects elsewhere in the world.

On Gautrain, more than other projects, the design and construction techniques have been powerfully shaped by a range of factors including the availability of local materials, employment laws, ground conditions and budget restraints.

In addition Atkins has been designing tunnels in ground whose engineering properties for tunnelling had not been previously established. And all of this was required to fit an extremely tight schedule.

The project

Constructed and managed by the Bombela Consortium, Gautrain is an 80km rapid rail connection between Pretoria and Johannesburg, with a separate shuttle link between Sandton and OR Tambo International Airport (which was renamed in 2006 after the former anti apartheid politician Oliver Reginald Tambo) (see box 2).

After three years of intense construction activity, South Africa's Gautrain project reached a major milestone in September with the final breakthrough of the last tunnel drive. Rob McCrae, technical director of Atkins tunnelling division, looks back on the unique challenges of this landmark project

The majority of the route runs above ground, but the most southerly section, a 15 km stretch to the centre of Johannesburg, is below the surface.

Atkins has been involved with the project since carrying out preliminary design work in 2005. As well as designing the permanent way and alignment for the entire route, the company is responsible for two detailed design packages for the underground civils work.

The scope of work includes providing detailed designs for 15km of underground tunnels, three underground stations, two crossover caverns and an interface portal adjacent to Marlboro station. There have also been a number of emergency shafts and associated safety havens to design.

The challenge

A key target date in the Gautrain calendar is next year's FIFA World Cup, with the

aspiration that the airport shuttle link will be completed in time for the event.

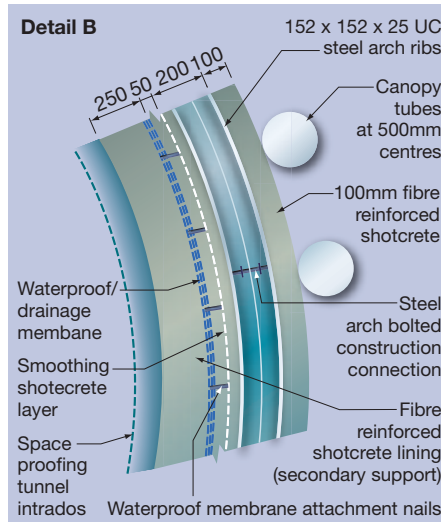
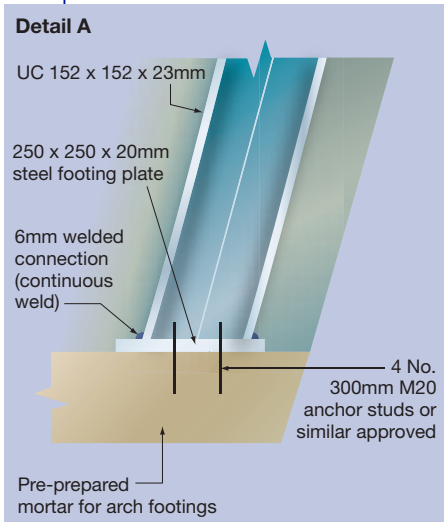
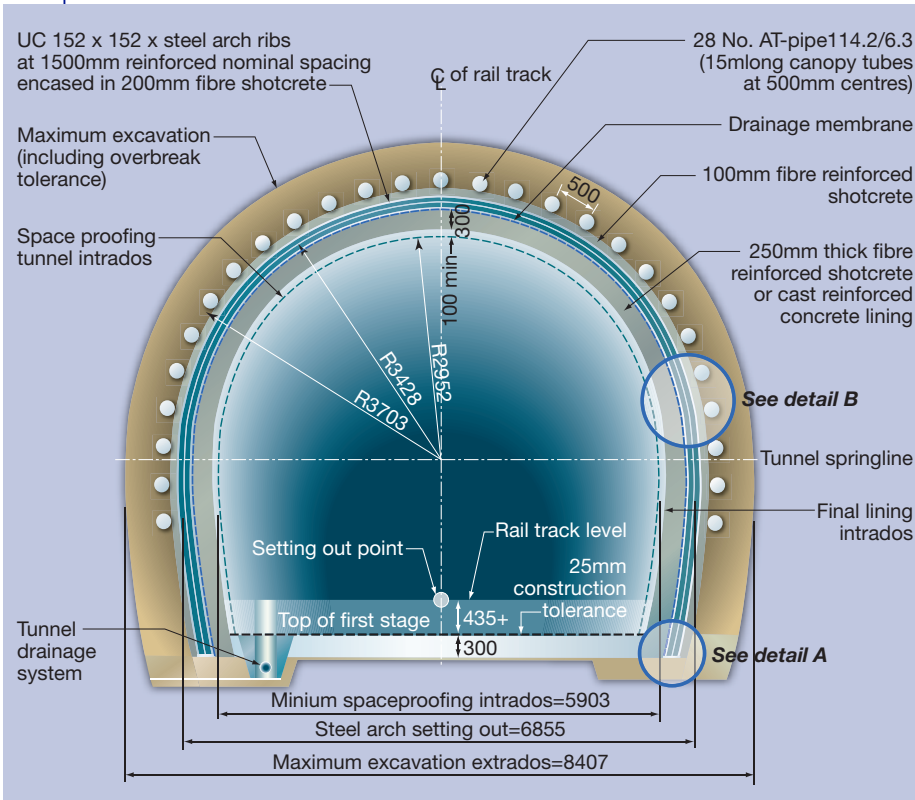
This has meant a very tight programme.

BOX 1: Dr Robert McCrae

Dr Robert McCrae has worked for Atkins since 1996 and is now a technical director of Atkins tunnelling division. He has extensive UK and International experience in tunnelling, rock mechanics, geotechnical studies and site investigation.

Recent roles include Atkins senior positions on the Belfast Storm water sewer project and West Rail in Hong Kong.

Until recently Robert was the project manager for the underground section of the Gautrain project in South Africa. He is currently working for an Arup/Atkins joint venture as deputy package manager for the central bored section of Crossrail.



Caption: Typical section through a class 6 rock support structure

Station in Johannesburg, crossing through some dramatically changing ground conditions along the way.

The land between Marlboro and Johannesburg rises by 225m. As a result the tunnel climbs towards Johannesburg at a gradient of around 4 per cent, at a depth of between 20 and 80m below ground level. A major challenge has been adjusting the alignment of the route to create the best conditions for tunnelling.

For around 80 per cent of the underground section – a 12km stretch from Marlboro to Houghton – the ground is formed of very hard, tightly jointed granitic rock. This is overlaid by weathered granite which can be up to 30m deep and which made up much of the tunnelling horizon between Rosebank and Houghton.

However, in the final section of the tunnel, from Houghton to Park Station in central Johannesburg (a distance of nearly 3km), the route encounters the very different conditions of the Witwatersrand formation, with heavily metamorphosed shales and volcanic rock.

From the beginning it was clear that two tunnelling approaches would be necessary to cope with the contrasting stretches of ground.

As is well known, South Africa has a long tradition of mineral and metal extraction. With this in mind, the project team decided to drill and blast through the granitic rock. This approach had two benefits. As well as utilising local expertise in mining and explosives, it also created jobs for many local residents, giving a boost to the local economy.

Meanwhile an EPBM tunnel boring machine was procured to excavate the difficult soft ground conditions in the weathered granite between Rosebank Station to the Wilds in Houghton.

Drilling and blasting

With large numbers of workers employed on the drilling and blasting sites, the tunnel had to be designed in a way that would use sophisticated modern blasting techniques that could be supported by modern plant. The size and height of the tunnel was also constrained so that the full face could be removed in a single blast.

Over the course of the project, the team was averaging two blasts a day. In good conditions this gave a daily advance rate of more than seven metres on the twin track tunnel, with roughly 500 tonnes of rock being displaced with every blast.

Construction was underway in November 2006, just two months after detailed design work had started. This has meant a very tight programme as construction for the first Operation Commencement Date (OCD1) should be completed at the end of June 2010.

To help meet the timetable more than 300 Atkins staff have been involved in supporting Gautrain over the past three years. In a highly coordinated programme, offices in the UK, Hong Kong, Sweden, U.A.E. and India have been feeding in detailed designs to the 80-strong design

team based in Johannesburg.

Throughout the project Atkins has worked very closely with client the Bombela Civils JV (see box 2) to ensure that the development of the design was tightly aligned with the construction methods.

It is an accolade to the entire project team that the first phase of the project, the airport link to Johannesburg, is on track to open in time for the 2010 World Cup.

The ground conditions

Gautrain's 15km underground section stretches from Marlboro Portal to Park

The blasted tunnel was then sprayed with shotcrete, rock bolted, and coated with a final layer of shotcrete.

Atkins designed the shotcrete as a permanent rather than temporary support, eliminating the need for a later cast in situ permanent lining and thus saving considerable time.

Fast and flexible assessments

After every blast geological engineers assessed the quality of the rock and specified the support required, using a classification system to define the thickness of shotcrete and rockbolt patterns needed. This strategy provided a fast and flexible response to the changing ground conditions. Throughout the project, the shotcrete had a strength of 40 MPa, and varied in thickness from 50 to 200mm.

Where necessary a localised drainage layer was embedded within the shotcrete to collect and channel any groundwater from the tunnel.

On one (300m) stretch of the drilling and blasting route, immediately to the north of Rosebank, poor ground conditions required the use of pre-support of the ground ahead of the tunnel face utilising 12m spiles – about 100mm in diameter.

All in all, drilling and blasting proved a successful strategy. As would be expected with tunnelling through hard granitic rock, there were few settlement issues and the only major challenge was minimising vibration from blasting when tunnelling through residential areas.

Imbokodo: The hard rock that grinds

Due to the much softer alluvial loose material in the 2.5 km section from Rosebank station to the Wilds in Houghton, it was necessary to use a tunnel boring machine. This EBPM was named Imbokodo, which literally means 'the hard rock that grinds.' It was this rock that inspired female activists in the 1950s anti apartheid movement to sing the phrase "Strike a woman, strike a rock – IMBOKODO!"

The 145m long 885 tonne Herrenknecht machine was designed and custom built in Germany to cope with the difficult ground conditions.

On the whole the TBM section worked extremely well, with the amount of ground settlement well within expectations. As is customary the drive followed roads as much as possible.

The only problem the contractor encountered on this stretch was when an already fragile water main burst above the

BOX 2: Gautrain: The Background

Gautrain, in the province of Gauteng, is one of the biggest infrastructure projects in South Africa, bringing world class technology to relieve a heavily congested road system.

The NM1 Ben Schoeman Highway running between Pretoria and Johannesburg is the busiest in the southern hemisphere, struggling to accommodate 300,000 passengers on week days. On this road commuting times are often measured in hours rather than minutes.

Travelling at speeds of 160km an hour, Gautrain will link ten stations over an 80km route. Commuting times between Johannesburg and Pretoria will be reduced to 40 minutes, while the airport shuttle to Sandton Station should take between 10 and 20 minutes.

Once opened in 2011, it is estimated that Gautrain will reduce congestion by 20 per cent on local roads and boost tourism and business in the region. The construction phase is estimated to have created 93,000 direct and indirect jobs alone.

The project is being constructed by the Bombela Consortium, a partnership between Bouygues Travaux Publics, Bombardier Transportation, Murray & Roberts, the Strategic Partners Group and RATP Developement. It is currently Africa's largest ever public private partnership.

Atkins has a long history of working with the consortium's partners, most recently with Bouygues on West Rail in Hong Kong and with Murray & Roberts on the Bahrain World Trade Centre.

tunnel. But this was swiftly repaired and did not affect the overall boring programme which was running 24 hours a day.

Boring The machine completed borinwas completedg at the end of January 2009, and the shell has been left embedded in the ground at Houghton where it meets the drill and blast section driven from Park Station.

Cavern Challenges: Reducing costs

One of Atkins' biggest technical achievements on the Gautrain project has been in the value engineering of the three underground stations and two crossover points for the track.

To keep costs down, the size of both Rosebank and Park stations was reduced as much as possible. Rosebank is a cut and cover box, supported by temporary contiguous piles and ground anchors. Park Station is also a cut and cover box, but uses diaphragm walls as the permanent structure.

The largest underground cavern on the project is the 20m wide crossover at Mushroom Farm Park to the North of Sandton. Here the designers used various finite element models and a specialist modelling package for assessing the fractured rock.

But Sandton station is possibly Atkins' greatest technical achievement on the underground section. The final designs have led to dramatic time and cost savings, clawing back around 11 months from the programme.

Sandton is the meeting point of the two rail routes. It must accommodate three platforms: the two tracks running between Johannesburg and Pretoria, and a single track for the shuttle train from Sandton station to the airport.

The original plan was to excavate a 38m deep box, creating a deep cut and cover station. This would have required the displacement of 160,000 cu m of rock.

BOX 3: Single track safety solutions

For the 4.5km stretch between Sandton and Marlboro, where passenger usage is heaviest, Gautrain is twin track with a tunnel width of 10.5m.

On the less busy sections the route is reduced to single track, with a tunnel width of 5.9m. This includes the underground section from Sandton to Park Station. A single tunnel design is highly unusual in an underground urban railway. Normally a second tunnel acts as an escape route in emergencies.

To meet safety requirements in the single

track tunnel, Atkins designed a series of evacuation shafts along the route at approximately 1km intervals. The shallower shafts in the TBM section are designed to allow egress to surface by lifts and stairs. In the deeper areas of the alignment at shafts E1, E2 and E5 all over 60m deep, this was not considered feasible. Therefore underground safe havens where provided which can accommodate a maximum of 800 people for up to eight hours. The havens are fire proofed and have their own air and water supplies.



Left: Safe haven inside the tunnel towards emergency shaft 1

Atkins put forward an alternative solution. Instead of one large box, two smaller caverns were proposed. Because of the restrictions on track gradient and the existing ground levels, they had to be 50m below ground, and were linked by cross passages and accessed by much smaller box shafts.

The form of these caverns has been dictated by tunnelling conditions. As a result, the south/north and airport lines are in one cavern, with the north/south line housed in a separate cavern.

To make best use of space the tracks are staggered in height. The spur line to the airport lies between the two other tracks at a lower level.

With this approach, only 75,000 cu m of rock has been excavated, less than half the original quantity, and eight months have been saved from the programme. There has also been less disruption to the key financial district above.

Before starting work at Sandton a number

of detailed ground surveys had to be taken. The ground on the site is principally granitic rocks cut by diabase dykes.

Unfortunately, as no major underground civils work had been carried out in the area before, it was difficult to get a detailed understanding of the general quality of the ground and orientation of the dykes.

Through the sinking of many boreholes and probe holes, it became clear that the rock quality was much poorer in the north-east corner of the station. Unfortunately, as this lay below a major road junction it was difficult to develop a consistent picture of the problem.

So the Atkins team developed a bespoke methodology for measuring the quality of the ground. It produced a 3D model of every borehole and probe hole in the area, plotting in three dimensions the different classifications of the rockhead. Points were manually connected between the boreholes to create the best estimate of the rockhead and diabase distribution.

Complex solutions

The results of the 3D model showed that Atkins needed to design a complex rock support solution that coped with both the fair granite and diabase, as well as low rockhead and very poor quality rock at the northern end of the station. As elsewhere on the project, rock bolts and shotcrete now provide most of the support.

An in situ concrete arch is normally required in underground structures such as Sandton, both for waterproofing purposes and to create a high quality finish.

But as the station is only 100m long, using an internal shutter to cast the arch, along with the temporary framework support, would have proved costly in the 17m high cavern.

As an alternative approach, Atkins has dealt with the waterproofing problem by designing a patchwork of interceptor drains that sit inside the shotcrete rock support.

The drainage layer is then covered by a second layer of shotcrete, which also provides an anchorage for the drill and fix bolts. Weepholes have been installed to drain the rock directly into the drainage layer.

As a result the concrete arch is no longer necessary. A sympathetic lighting system has been installed into Sandton station to enhance the appearance of the shotcrete finish.

Designing out the cast in situ concrete arch has saved the programme a further three months.

Progress report

Tunnelling is now completed at Gautrain. In mid-September breakthrough occurred on the last tunnel drive between Park and Rosebank stations. Track is being laid in the northern tunnels, to complete at the end of 2009. Track will be laid in the southern tunnels next year.

At Sandton station, all excavation and support was successfully completed earlier this year and the fit out of the cavern has started. Mechanical and electrical work is well underway.

The project is on track to open the airport link next May 2010, in time for the FIFA World Cup.

In total design construction and operational approvals for this high capacity rail system will have been achieved in 45 months - a truly phenomenal achievement, especially since nothing like this has ever been done in this part of the world before. An achievement of which the entire project team is justifiably proud.

T&T

BOX 4: Working culture: The people

Owing to cultural norms and superstitions in many parts of the world, women are rarely seen working on underground tunnelling projects.

This is not the case in South Africa where strong equality laws post apartheid have given women unprecedented opportunities to work in this traditionally male dominated sector.

On the Gautrain project it has not been unusual to see large numbers of women labouring and operating plant below ground.

Atkins has committed to taking on and providing training for disadvantaged local labour wherever possible. The company is providing funding for local employees to retrain for meaningful careers once they leave the Gautrain project.

Atkins has also adopted an orphanage for AIDS victims in the township of Alexandra, northeast of Johannesburg. This is a long term commitment that will link us to the Gauteng province long after the Gautrain has opened.

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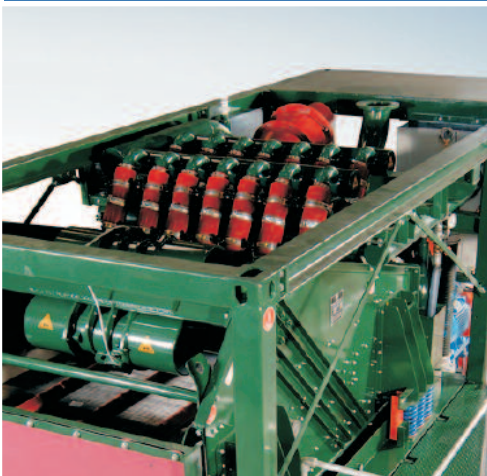


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One of India's most ambitious urban infrastructure projects since gaining independence in 1947, the Delhi Metro is fast approaching completion. TBMs are making their final breakthrough, the NATM sections are mucked out and cut-and-cover stretches are cut-and-covered.

The rapid transit system redefined travel in India's capital. The first phase of the project is already fully operational and construction of the second phase is in full swing. Constructing Phase II is very ambitious as the entire project has to be completed ahead of the Commonwealth Games to be held in New Delhi in October 2010. This means that while Phase I comprising 65.1km was completed in seven years and three months, Phase II comprising about 125km is being constructed in just four-and-half years, a very challenging task.

Despite the challenges that remain on the project, the Delhi Metro Rail Corporation (DMRC), the organization executing the project, is confident of completing the second phase on time as it has consistently beaten deadlines. While Phase-I was completed ahead of schedule, three lines of Phase-II have already been added to the Metro network up to nine months before the deadline extending the operational network to 77.67km.

Milestone

Some 35km, or 28%, of the 125km Phase II extension is underground, marking a significant increase on the 13km of tunnelled sections on the Phase I, which is just 20% of the 65km network.

Fourteen TBMs were employed on the extension to ensure a speedy excavation of the tunnel network – the largest number of TBMs in any south Asian city at one time. The TBMs undertook 30 tunnel drives working on three corridors: Central Secretariat – Qutub Minar, the Airport Express Line and Central Secretariat – Badarpur.

The twin bore TBM tunnels have an internal diameter of 5.78m and the thickness of the lining is 275mm. TBM tunnelling on Phase II was completed on 12 October 2009 when the last machine achieved breakthrough.

TBMs, however, weren't suitable for the whole network. Where it was difficult to lower a TBM, NATM was chosen, and where it tunnel was shallow enough and free of surface obstructions, cut-and-cover is being used.

Only small cut-and-cover portions remain



Breakthrough of one of 14 TBMs used on Phase II



Some 35km of the Phase II runs through tunnels

Rush hour on Delhi Metro

Dr E. Sreedharan of the Delhi Metro Rail Corporation looks at how a 125km extension to the Delhi Metro is being completed in just four and a half years

under construction on the project but should be completed before the year's end.

Central Secretariat – Qutub Minar

The 12.53km line from Central Secretariat – Qutub Minar is almost entirely underground. TBMs were used for the majority of the stretch to build 7.15km of tunnels. The contracting JV of Continental Engineering Corporation and SOMA Enterprises drove four EPBMs operated on this stretch, two manufactured by Herrenknecht and two by Robbins. The first TBM on this corridor was launched at

India National Army Market in February 2008 and the last TBM was taken out in August 2009 from Green Park.

The soil showed a predominance of clay over silt and sand. It also had high moisture content, as the water table in the area is comparatively high. The machines achieved a similar performance rate with the Herrenknecht TBMs excavating 24m on average per day and the Robbins TBMs excavating 25.6m of tunnel per day on average.

TBM tunnelling hit a major challenge on this stretch. The drive between INA and

Jor Bagh struck unforeseen hard rock that resulted in severe damage to some of the cutting tools and caused the cutter wheel to stall in September 2008. Investigations revealed that the rock appeared to be in the form of a ridge of strong quartzite running north-south, roughly following the tunnel alignment.

After exploring various options, the team decided that replacing the soft ground cutting wheel of the TBM with a suitable rock cutting wheel was the best option.

A rock cutting wheel was shipped in and installed after an intricate operation including digging a shaft very close to a residential area. After three interventions to inspect the new cutter tools, excavation through the mixed face of rock and soil proceeded without major incident and the rock ridge was finally cleared in February 2009. The ridge set work back by some six months but the original tunnel alignment was maintained and the tunnel completed as designed, within tolerance and within the overall target date for completion of work for that section.

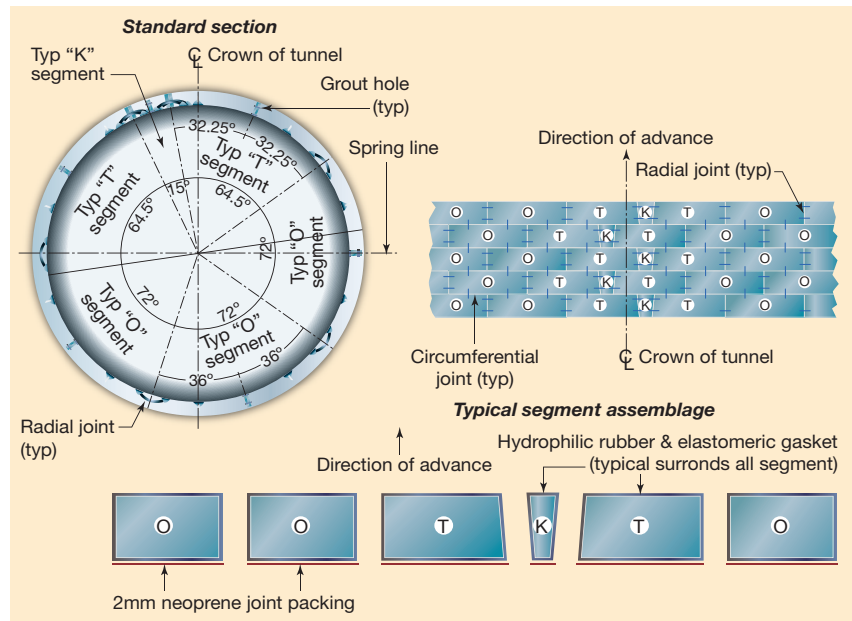
For the final TBM drive on the Central Secretariat to Qutub Minar corridor Metro Tunneling Group (a consortium of DYWIDAG, Larsen & Toubro, Samsung, Shimizu and IRCON) drove two Herrenknecht EPBMs to complete the 3.14km Green Park to Saket stretch. The first TBM was lowered in December 2008 in this stretch and the last TBM broke through in April 2009. The average daily rate of tunneling was 14.4m.

To complete the line a 185m section had to be tunnelled using NATM. It was the first time DMRC had attempted to excavate in soft ground using NATM. The section is the final part of the 1.85km stretch linking Qutab Minar station with Saket station. For the first 645m the line runs above ground and then enters a cut-and-cover tunnel for 1020m before reaching the NATM section.

The 185m tunnel south of Saket station was too short to warrant a TBM and the proximity of the Qutab Minar, a world heritage site, was a further deterrent to excavating an access shaft. NATM tunnelling in the soft ground proved difficult as the soil needed to be immediately shotcreted and strengthened to prevent collapse.

Throughout the excavation contractor Larsen and Tourbo had to observe all the precautions of the Archeological Survey of India guidelines as construction was close the Petheora Rai Ka Kila historical monument.

Only one shaft was sunk and the daily average rate of excavation was 1m.



Airport Express Line

Some 15.7km of the 22.7km Airport Express Line is underground. The underground section was built using cut and cover tunnels, TBM bored tunnels and a NATM stretch.

Three Herrenknecht TBMs were used to build 2.2km of tunnel from New Delhi to RML Hospital Circle. One of these TBMs was earlier used on the Green Park – Saket stretch. It was dismantled and relaunched. Two were EPBMs equipped with disc cutters, one was a regular EPBM. The TBMs launched into mixed ground, including rock strata in November 2008 and achieved final breakthrough in September 2009. Contracting joint venture Alpine; HCC and Samsung achieved an average daily excavation rate of 14m.

Two more TBMs were used on the Airport Express Line to build 1.6km of tunnel from Dwarka Sec. 21 to Indira Gandhi International Airport. Both the machines were EPBMs and manufactured by Okumura, Japan. They encountered Delhi silt conditions and worked from January to June 2009 with an average daily progress of 10.2m. The contractor was a JV of Shanghai Urban Construction Group (SUCG) and Larsen & Toubro JV.

During Phase-II, DMRC constructed its deepest tunnel so far which passed below the existing tunnel of Central Secretariat to Vishwavidyalaya line at Rajiv Chowk. The depth of the new tunnel, which is part of the Airport Express Line, is 45m and it passes 20 to 25m below the old tunnel.

NATM tunneling was used to build a 2.85km-long tunnel between Talkotara Garden and Buddha Jayanti Park on the

Above: Cross section of a TBM driven bore and details

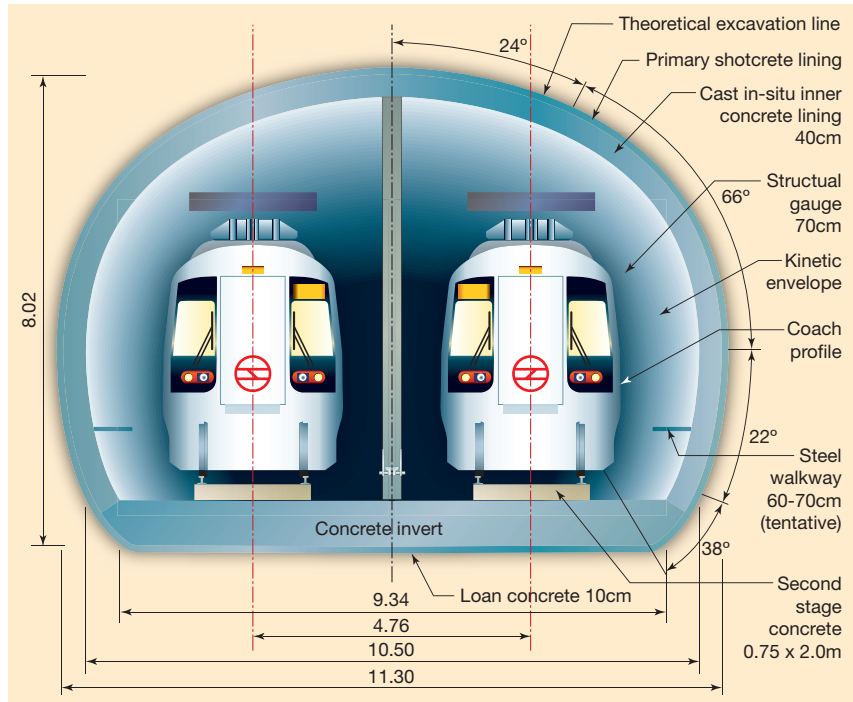
Below: NATM was used for a 185m section south of Saket Station

Airport Express Line, which is India's longest tunnel in an urban area built by NATM. The ground profile comprised of weathered quartzite and schists. Three shafts were sunk for the construction work and the average tunnel excavation achieved was 6.8m per day by the



FUNDING PATTERN

The total cost of the second phase is expected to be over Rs 19,000 crore (approx. US\$4.7bn). Of this, 29% will be financed through equity contributions subscribed equally by the Central Government and the State Government of Delhi, 8% by subordinate debt by the two Governments, 3% each from property development earnings and internal accrual, 1% as grant and 56% as soft loan from the Japan International Cooperation Agency.



Above left: A view down the NATM section of tunnel south of Saket Station
Above right: A typical cross section in a NATM tunnel section
Left: This was the first NATM excavation in soft ground ever attempted by DMRC

contracting JV Alpine & HCC.

The stretch will host a high-speed line from the city center to the Indira Gandhi International Airport. The distance will be covered in some 18 minutes and three of the six stations on the route will have check-in facilities.

Central Secretariat – Badarpur

On the 20km long Central Secretariat to Badarpur line. TBM tunneling was used for 4.2km. Four Herrenknecht EPBMs were employed in different stretches of

the corridor from September 2008. This section witnessed the last TBM breakthrough of Delhi Metro’s Phase-II at Lajpat Nagar on 12th October 2009. The soil in this corridor was found to be a mixture of sand and silt. Contracting joint venture Italian-Thai Development Public Company and ITD Cementation India achieved average daily progress of 12m.

Opening times

Over the next year, another 113km of Phase-II will be added to the Delhi Metro

which will then cover over 190kms and have 144 stations, becoming one of the largest Metro networks in the world. The new sections will be added in a phased manner from December 2009 to September 2010. The target schedule for these sections is:

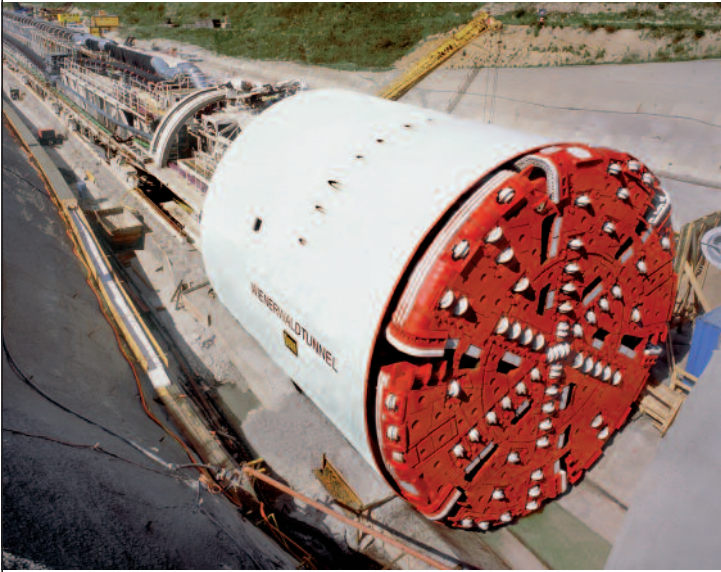
- December 2009 - Yamuna Bank – Noida Sector 32
- December 2009/January 2010 - Yamuna Bank-Anand Vihar ISBT
- January 2010/ February 2010 - Inderlok/Kirti Nagar – Mundka
- March 2010 - Qutub Minar – Gurgaon
- July 2010 - Central Secretariat -Qutub Minar
- August 2010 - Central Secretariat – Badarpur
- September 2010 - Dwarka Sector 9 to 21; Anand Vihar ISBT- Vaishali, Ghaziabad ; Airport Express Line

Meeting strict deadlines while working in one of the most congested cities in the world, DMRC has successfully completed tunnel construction without major incident and without disrupting the lives of the people of the city. That, perhaps, is the biggest achievement of the organization during Phase-II.

T&T

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Pointing in the right direction

Scandinavian tunnellers are trying out a new underground navigation system for drill rigs that promises to be quicker, easier to use and more accurate. *T&T* takes a look

Any time that can be saved in the drilling, charging, blasting and mucking out cycle saves money. And no where is this more true of construction projects than down a tunnel.

At the Northern Link bypass project in Stockholm, Sweden, the Norwegian contractor Veidekke is the first to use a new technology that is promising to radically improve in-tunnel rig positioning and accuracy. Veidekke is currently advancing some 11 faces at the Northern Link. Three, three-boom Atlas Copco Boomer XE3 C face drilling rigs and one, two-boom Boomer E2 C rig are at work at the site, as well as an Atlas Copco Boltec bolting rigs and two mobile Unigrout grouting plants.

The Boomer XE3 C rigs benefit from the RHS E rod handling system, but a less tried and tested technology is trying its footing on this complex construction site, Atlas Copco's Total Station Navigation system. Veidekke is currently testing the system on two of its rigs, one of its XE3 C face drilling rigs and its Boltec bolting rig.

Total Station Navigation automates the navigation process, allowing the operator to position and navigate a rig without the presence of a surveyor. Atlas Copco Rock Drills and Leica Geosystems teamed up to develop the navigation system. The firms reached an agreement in 2008 defining Atlas Copco as an OEM partner for Leica Red Line products integrated with

underground and surface equipment. The agreement enables Atlas Copco to integrate the latest Leica development of positioning and navigation sensors with the new, computerized underground and surface drilling equipment. Total Station Navigation for Boomer and Boltec is the first of a series of options expected for rig deployment.

Setup

The tripod mounted Total Station is placed behind the rig and at the push of a button on the rig's control panel, the station locates two fixed reference points via prisms on the back of the rig. Total Station then automatically locates navigation

Below, left: Fig1 – To establish its correct positioning, the tripod mounted Total Station Navigation system first gets a fix on the drill rig

Below, right: Fig 2 – The system establishes two reference points by locating the two prisms mounted on the back of the rig



prisms on the tunnel walls and the exact location of the rig in the tunnel is calculated. Visual confirmation of the rig's location is provided on the screen of the rig's control panel that simultaneously displays the drill/bolting plan.

Olle Sundmalm, Veidekke's surveyor at the Northern Link site argues the system is a major step forward in navigation and will prove to be of great benefit for operators and surveyors.

"We normally navigate using a measuring instrument and two flags positioned on one of the boom arms to determine the rig's location relative to the tunnel and the drill plan," explains Sundmalm. This means that a surveyor must be present each time the rig needs positioning.

"Total Station allows the operator to perform the entire process on his own and much more quickly, normally in around five minutes. It also means that they do not have to wait for a surveyor to arrive before they can get on with the drilling and the rig's location relative to the tunnel is displayed in real-time on the rig's monitor.

"The benefit for the surveyor is also clear – we now have more time for planning and for checking that the drilling data that is transferred to the rig is correct."

The new system has been used for about three months at the Northern Link. Veidekke reports that the complex nature of the underground road tunnel system, with curving tunnels, inclines and declines, has sometimes made clear sight of tunnels' laser prisms difficult. It has though been possible to use the new system for around 75% of the tunnelling.

Anders Östberg, plant and machine manager at Veidekke says that the system has already delivered increased accuracy. "We measured the accuracy achieved on the first day we used Total Station and the accuracy was very good," says Östberg.

The navigation system is part of the Atlas Copco concept High Precision Tunnelling. The concept aims at helping drill rig users to reach even higher levels of quality and productivity in tunnelling by using add on equipment. There are five options in the range for drilling equipment, based on the latest technology and tunnelling know-how: Tunnel Manager software, Measurement While Drilling, Total Station Navigation, Tunnel Profiler, Rig Remote Access and Rig Remote Access Server.

Strength in numbers

Östberg argues that Total Station would save the contractor money by speeding the



Below, left: Fig 3 – The system then finds the position of the rig in the tunnel by locating reference prisms mounted on the tunnel walls

Below, right: Fig 4 – The co-ordinates are calculated instantly by the rig's on-board computer where the operator brings the information up on the display screen



setup but the real benefits are found in combining technologies. "The set up time is also minimal compared to the more usual method we use with a surveyor," says Östberg. "Ultimately though, I think the biggest benefit for us will be avoiding underbreak when combining Total Station with Tunnel Profiler. To correct underbreak is expensive so this system should save us a lot of time and money."

Excavating the right tunnel profile from start saves a considerable amount of time and money. The Tunnel Profiler is an intelligent 3D-scanning system for rapid and high-precision tunnel profiling. A section can be scanned immediately prior to drilling the next round, requiring very little extra time.

Data is processed and the rig operator is informed of any over or underbreak in a matter of minutes. This means drill plans can be corrected very quickly. The system aims to reduce costly finishing to an absolute minimum. Rapid adjustment of drill plans can save up to 5cm in overbreak. According to Atlas Copco, in a tunnel with a

40m² profile, this can yield savings in overbreak-costs of about €125,000 (US\$185,000) per kilometer, in terms of concrete and man-hours.

Östberg says, "Given our experience so far with Total Station, I think it will be quickly adopted by Scandinavian contractors." T&T



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Breathing easy

The maintenance of adequate air quality is recognised as a key issue for occupational health and safety within tunnel construction sites. Because of its importance, the issue of air quality is influencing the choice of construction methods, tunnelling sequencing and the equipment selected to undertake excavations.

For example, Donald Lamont of the UK Health and Safety Executive has reported that at the A3 Hindhead Tunnel construction site, the bench excavator has been changed to an electrically powered machine; new diesel-powered face excavators have been purchased that conform to EU Stage III emission standards, and low sulphur diesel fuel is used for all plant working in the tunnel. The tunnel is being built from both ends, which reduces the maximum length of tunnel to be ventilated. A conveyor cassette system has been introduced that allows the conveyor loading point to be closer to the face, reducing the travel for the diesel loading shovel, while two ventilation ducts per bore provide a strong ventilating flow along the tunnels.

The subject of air quality within tunnelling sites was given added impetus by the European Commission's Directive 2006/15/EC on Indicative Occupational Exposure Limit Values. This directive set a new IOELV of 1 part per million (ppm) for short-term exposures to nitric acid (HNO₃). It is known that long-term inhalation of nitric acid may lead to the development of lung diseases such as bronchitis. The main route through which nitric acid is generated in tunnel construction sites is through a chemical reaction of water vapour with nitrogen dioxide (NO₂), which is an extremely toxic gas generated by diesel engines, blasting and welding processes.

Even at low concentrations, nitrogen dioxide can affect the human respiratory response, especially for asthmatic individuals, whose response to allergens can be negatively enhanced. At higher concentrations, nitrogen dioxide can attack lung tissues insidiously without major symptoms, but can cause collapse shortly afterwards, with symptoms of acute broncho-pneumonia.

The World Road Association (PIARC) published a report on "Pollution by Nitrogen Dioxide in Road Tunnels" in 2000, which proposed a threshold limit of 1ppm for

Fathi Tarada, Co-Chairman of the World Road Association (PIARC) Working Group on Air Quality, Fire and Ventilation reviews the methods for meeting tougher air quality requirements



Above: Fathi Tarada

nitrogen dioxide for healthy people. At the time of writing that report, there was a lack of suitable sensors that could reliably detect nitrogen dioxide in tunnels. Therefore, the report proposed that nitrogen dioxide levels could be assessed as 10% of the total nitrogen oxide concentration (by volume). However, recent measurements by the French Centre d'Etudes des Tunnels in a busy city centre tunnel indicated no such relationship. Instead of inferring NO₂ levels from measured NO levels, the active monitoring of nitrogen dioxide through measurement devices based on Single Wavelength Optical Transmissometers and Chemiluminescent Analysers is now a feasible option. The PIARC Working Group on Air Quality, Fires and Ventilation is currently working on updating the requirements for tunnel ventilation, in consideration of new critical pollutants such as nitrogen dioxide.

The British Tunnelling Society has recently published a best-practice guide on the occupational exposure to nitrogen monoxide (NO) in a tunnel environment. Similar to nitrogen dioxide, nitrogen monoxide affects the respiratory function, and repeated exposure to high levels of NO in the workplace may give rise to an increased risk of emphysema. A key recommendation given by the BTS is that nitrogen monoxide levels should not exceed 5ppm, based on an 8-hour time-weighted average. This is significantly more onerous than the 25ppm

level proposed by the European Union's Scientific Committee on Occupational Exposure Limits in Directive 91/322/CEE.

Due to the much more stringent standards being proposed for nitrogen oxides, the control of these oxides has become the key air quality issue for many tunnelling sites. Other airborne pollutants are mentioned in tunnelling standards such as BS 6164:2001, Code of Practice for Safety in Tunnelling in the Construction Industry, including dust (which may contain crystalline silica) and methane, and the control of these pollutants is still very relevant. The airborne pollutants and their method of control, including the choice of ventilation flowrate and monitoring regime, should be decided using a risk assessment, as required by the Control of Substances Hazardous to Health Regulations 2002 in the United Kingdom.

The simple expedient of blowing more air into a tunnel under construction to dilute airborne pollutants down to acceptable levels may not be possible or appropriate. The external air may be quite contaminated itself, reducing the benefits of external air supply. In addition, high air velocities can lead to the generation of dust, which is generally unacceptable in a construction site. Because of this, the selection of electric machinery such as tunnel boring machines will become increasingly favoured, at sites where air quality issues are likely to be critical.

Another solution to improving air quality in tunnelling sites is to use mobile filtration devices. For example, trailer-mounted electro-static precipitators are available that can be driven into tunnels under construction, and good experience has been obtained with this technology in Japan, with significant reductions in airborne dust concentrations. Panasonic previously manufactured mobile electro-static precipitators with 33m³/s flowrate and a 90% dust collection efficiency, and reported reductions in tunnel dust concentrations from 6 mg/m³ down to 1.5 mg/m³, compared to an Occupational Exposure Limit Value of 3 mg/m³. In addition, discharges of dust from the construction portal were visibly reduced, improving the local environment.

T&T

Segmental linings in earthquakes

At the first BTS meeting of the 2009/10 season in September, Gary Kramer of Hatch Mott MacDonald delivered a presentation on the Seismic Response of Segmental Tunnel Linings.

Kramer began by describing how research into seismic response came out of design work for the Silicon Valley Rapid Transit Project (SVRT) an extension of the Bay Area Rapid Transit (BART) from San Francisco in California, to San Jose. The extension is being designed by the Valley Transit Authority and will ultimately be operated by BART. Though the project is in final design, it is suffering from a lack of political will, along with many major projects in the USA, as the recession impacts on construction industry finances.

The tunnelled section of the extension will be an 8.2km long twin bore, with three

cut and cover stations, two portals and two ventilation structures. The TBMs and linings will be owner procured.

Typical cover will be 12m with 25m in some sections to avoid obstructions. The geology is deltaic alluvial deposits lightly over-consolidated with stiff silty clays and interbedded sand layers. The groundwater table varies from three to five metres below grade.

The project is located in one of the most famous seismic regions in the world (see Figure 1). The San Andreas fault runs roughly north-south to the west of San Jose and has a potential for a magnitude 8.0 seismic event. The Hayward fault to the

north has a potential for a magnitude 7.3 and the Calaveras has a potential for a magnitude 7.0. The Lower Silver Creek fault has negligible offset potential so no special provisions were required.

Lining

The tunnel lining will be owner designed with an internal diameter of 5.44m, a length of 1.5m, a thickness of 254mm with a double taper. The ring will have a universal trapezoidal arrangement.

All the joints will have packers with traditional reinforcement. The use of a hybrid fibre reinforcement design had been looked at although it is likely that it will stay as normally reinforced. Dowels will be used on the circumferential joint with bolts on the radial joints and a single EPDM gasket.

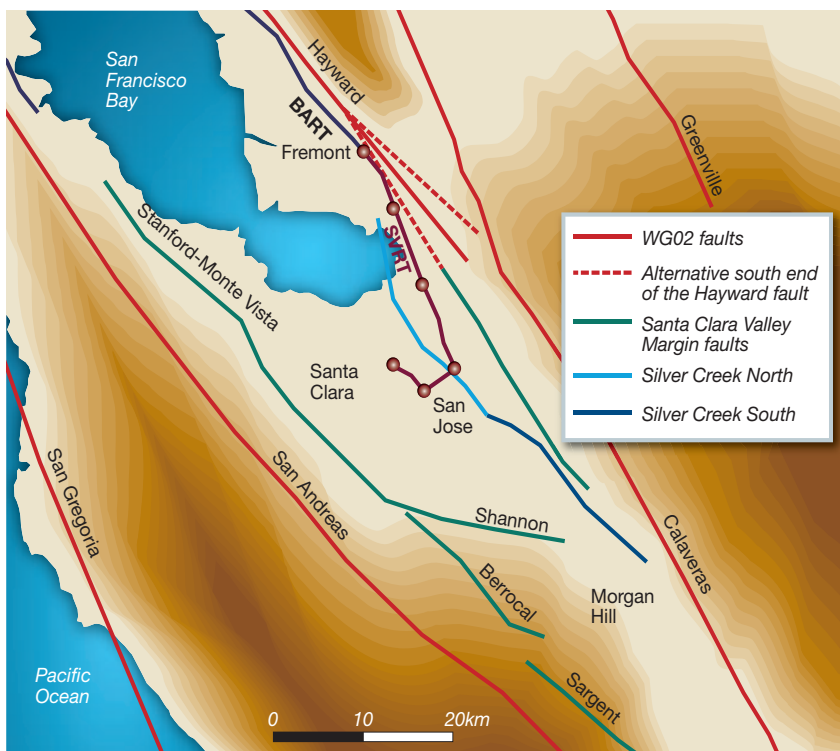
The project was to be designed to the BART Facilities Standard (BFS). The existing tunnels for BART have used steel linings which are rigidly connected and performed very well during the 1989 Loma Prieta earthquake. However the cost of using such a lining for the SVRT project would be prohibitively expensive.

The BFS had a number of provisos for segmental linings that tended to be appropriate for steel linings only. Though BART staff were receptive to the use of segmental concrete linings they had little experience of these and had a concern over stability during seismic events. Their concerns included:

- Where they had been used before in seismic zones.
- How do they behave in a seismic event?

It was explained to BART staff that concrete linings were now used virtually everywhere but being surface seismic engineers, they were not familiar with underground projects. Research was carried out on schemes where the use of pre-cast tunnel linings of a similar size to those envisaged to SVRT coincided with known seismic events.

The thousands of systems with concrete



Left: Fig 1 - Locations of Major Faults in Northern California

Table 1: List of tunnels where the effect of seismic events has been documented

Tunnel	Earthquake	Earthquake date	Surface horizontal acceleration near tunnel (g)	Post event tunnel condition	Source(s)
LA Metro	Northridge	1/17/94	0.4	No damage	Monsees and Eloff, 1999 and EERI, 1995
Isobe Dori shield tunnel	Kobe	1/17/95	0.5*	Some spalling at segment joints	JSCE, 1995
Athens Metro	Athens	9/7/99	0.25†	No damage	EERI, 1999
Taipei Metro	Hualien	3/31/02	0.20	No damage	Tapei Times, 2002

linings were cross-referenced with those in seismic locations which reduced the list down to the hundreds with most of those in Japan. This was compared against seismic events and this produced a list of 12 schemes.

However, with inspections of structures after significant seismic events generally only covering damaged sections, facilities where no damage occurred generally go unreported. The most significant was Michoacan in Mexico, which underwent an 8.1 quake and the Loma Prieta quake in 1989.

The list of tunnels with little or no damage after a seismic event but with a documented performance was only four projects long (see Table 1).

Structural analysis

A high level structural analysis was therefore required to justify the use of concrete linings to BART. The concern of BART in particular was whether the segment joints would pull apart causing a collapse of the lining system.

Acknowledging the help and expertise of SC Solutions Ltd in Sunnyvale, California, Kramer explained that a paper produced for RETC in 2007 documented the detailed analysis undertaken by them to show that a segmental lining would not separate.

Explaining P (compression/extension), S (shear) and L (love/Rayleigh) waves in seismic events, Kramer described how it is the L waves which are those affecting shallow tunnels in seismic zones

Three types of seismic events occur that can affect tunnels:

- The potential for fault rupture if the tunnel crosses the fault – This was not part of the research presented here – though the solution where this occurs is generally to construct an oversized tunnel allowing for quick repair in the event of a rupture.
- The potential for liquefaction. The potential on the SVRT project for this was low. This occurs in saturated loose soil, a seismic event increases the porewater

pressure, resulting in a complete loss of shear strength.

- Ground shaking which can cause compression/extension of the lining and longitudinal bending of the tunnel. Of most concern is the shear wave propagation from the bedrock below causing an effect called ovaling or racking.

To analyse this, a programme called SHAKE is often used to model a vertically propagating wave from the underlying rock formation. For each soil the shear modulus is inputted, with a strain and damping factor added for each soil layer. Also added would be the outcrop acceleration of the rock (assuming it was exposed at surface). The shear strain and displacement versus depth/time are obtained for the entire soil column. The model does not take into account the presence of the tunnel or any surface structures.

Shear force

A Type C soil was used for SVRT, which is dense enough that it is effectively bedrock. The departure from square is the shearing strain (see Figure 2). There are very small strains at depth but these increase towards the surface as the rayleigh and love waves become more prevalent.

Fundamental to understanding underground seismic design are the ground mass deformations and their interaction with the tunnel excavation and structure itself. The tunnel must accommodate the ground movements without excessive damage itself. The tunnel will never stop the ground movement.

The modelling was to look at overall shear strains of 0.2% to 0.4%. The shear strain being the 'out of square' that the hypothetical ground mass would go through in a seismic event. There are various methods for dealing with the seismic response of tunnels. Common behaviour assumptions to virtually all of them assume linear elasticity of the ground mass and lining:

- Idealized ground/lining interaction considers full slip or no slip

Left: Table 1 - List of Tunnels where the effect of seismic events has been documented

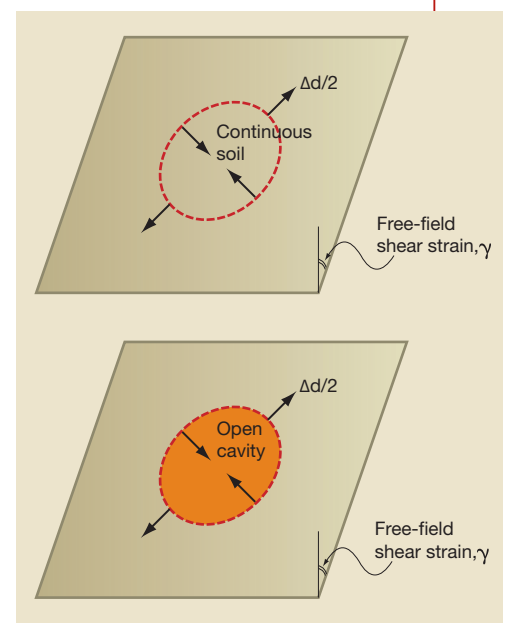
- Separate analysis of the static and seismic effects
- Continuity of the tunnel lining is generally assumed i.e. no joints

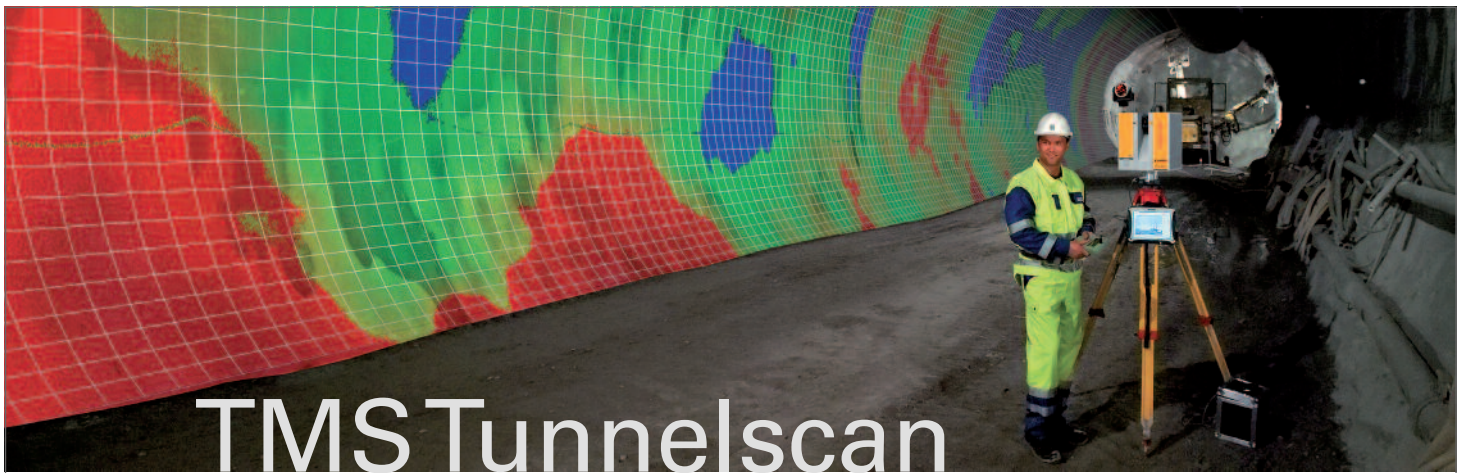
A segmental lining system does have joints however, allowing flexibility and can thus respond better in a seismic event.

The various methods over-estimate the internal lining loads but do underestimate displacements. Both of these need to be as accurate as possible because seemingly conservative on strength is actually non-conservative in a seismic event as it is a displacement controlled event, not a strength controlled event. Making the lining material stronger doesn't necessarily mean that you have a stronger lining.

The linear elastic closed form solutions developed by a number of researchers predict under seismic loading that tensile stresses will develop in the lining system what would be problematic in a jointed tunnel. The stability of a lining system depends on maintaining the continuous joint contact between the segments and between the rings so the methods that have to be used have to predict the forces and displacements as accurately as possible so that there are two demands on the tunnel lining system itself. A displacement demand and a more traditional strength demand. The lining system must deal with both.

Below: Fig 2 - Free field shear distortion of ground (after Wang 1993)





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The length of a Monarch caterpillar „Danaus plexippus“ after 10 days and the vertical offset of the laser from the line of site of the theodolite used in VMT’s tunnel guidance systems.

3D Modelling

SC Solutions brought their expertise in dealing with seismic connections and structural analysis so were able to 3D model the effects on the lining using ADINA software to look at the stability of the lining and modelled the joints as a no-tension, friction-only connection with compression. They did soil structure interaction, and finite element modelling to predict ovaling response so shear strains of 0.2% and 0.5% were used to envelope the conditions to a maximum credible earthquake to assess if any instability occurs with excessive birdsmouthing, slipping or separation by joint rotation between segments. The need for inter segment connecting devices such as dowels and bolts was evaluated, as the dowels and bolts were just alignment devices, not intended as structural devices. Internal loads also needed to be provided for the structural design of the segments.

Construction loading was put into the 3D model as well as seismic ovaling. It was important to follow the stress path history in the ground during construction as well as subsequent to construction and the dissipation of pore pressures as well as the seismic event itself. To do this, a non-linear soil behaviour would be required. The Mohr Coulomb (M-C) approach was adopted here. Other systems such as Duncan-Chang have since been used to compare. Partial slip was allowed for rather than no-slip between the lining and ground. No tension frictional behaviour was allowed between the radial and circumferential joints. Circumferential dowels were modelled as non-linear springs. The radial joints (bolts) were deliberately not modelled so the joints would not be restrained from opening and then see what the opening demand on the bolts would be.

The 3D model was placed inside a soil medium with a trapezoidal lining. A rectangular lining was also tried as, at the time of the analysis, a decision on lining types had not been reached. There was a concern about additional torque and shear angles of a rectangular lining but these turned out not to be an issue. The soil conditions modelled are listed in Table 2.

The sand and clay-1 were generally stiffer materials but the clay 2 was an extreme case of very soft clay to check the sensitivity. Cracked and uncracked properties were used. The concrete strength was 41 mpa (6000 psi). Modulus of elasticity was 38,500 Mpa, poisson ratio of 0.15.

It is important in seismic design to use what are termed expected properties, not necessarily the specified properties (e.g. 46 Mpa actual for concrete strength).

Table 2: Ground parameters used for modelling

Soil behaviour parameter	Mohr Coulomb sand	Mohr Coulomb clay-1	Mohr Coulomb clay-2
Total unit weight, γ	19.7kn/m ³	19.7kn/m ³	19.7kn/m ³
In-situ horizontal pressure coefficient (K0)	0.65	0.65	0.60
Effective friction angle (ϕ')	37.5 degrees	Not used	Not used
Effective cohesion, (c')	0	Not used	Not used
Undrained shear strength (Su)	0	100kPa (at tunnel depth)	100kPa
Effective tensile strength, T'	0.5 kPa	Not used	Not used
Poisson's ratio, ν	0.35	0.49	0.49
Elastic modulus, ES	335MPa	270MPa	40MPa

Above: Table 2 - Ground Parameters used for modelling; Right: Fig 3 - 3D model used for seismic modelling

Kramer then presented the lining analysis results:

- The diametric displacements
- The internal force
- Rotational gapping
- Demand on connecting devices

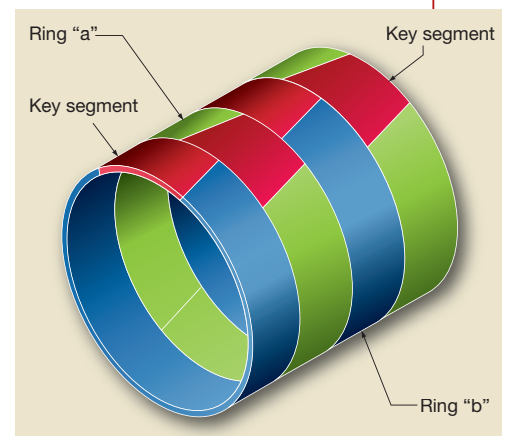
There was a very good comparison between the free field perforated ground and the linear elastic predicted for full slip. So full slip linear elastic analysis does provide a good comparison.

Interestingly as the model went to the higher strains for the 0.5% strain, the non-linear finite element modelling showed less displacement occurring than the free field perforated ground or the elastic full slip solution. This is significant because a flexible system was being modelled and also allowing the soil to develop plasticity around it which also acts as a structural fuse reducing the displacements and hence the demand on the lining system.

At 0.2% strain the model deformations were very close to the elastic continuous lining solution. At the higher strains the model deformations were significantly less. This was due to the relatively uniform compressive thrust that stiffened the lining and tended to prevent the tensile strains that would occur using a linear elastic model.

The axial forces were generally compressive throughout a uniform thrust for the full range of strains that occur.

Two rings were modelled beside each other with two exterior rings to act as a buffer for boundary conditions. The uniform distribution of the axial forces is very similar to the elastic model for a full slip case and higher thrusts do occur in stiffer soils and lower thrusts in softer soils (see Figure 3).



QUESTIONS AND ANSWERS

Question 1 - Sigmund Lopkavski; Arup
What performance criteria was BART hoping to achieve in a seismic event?

BART required all systems operational within three working days. For the station tunnel interface the analysis showed a movement of about 25mm. Their criteria was to allow for 100mm of movement.

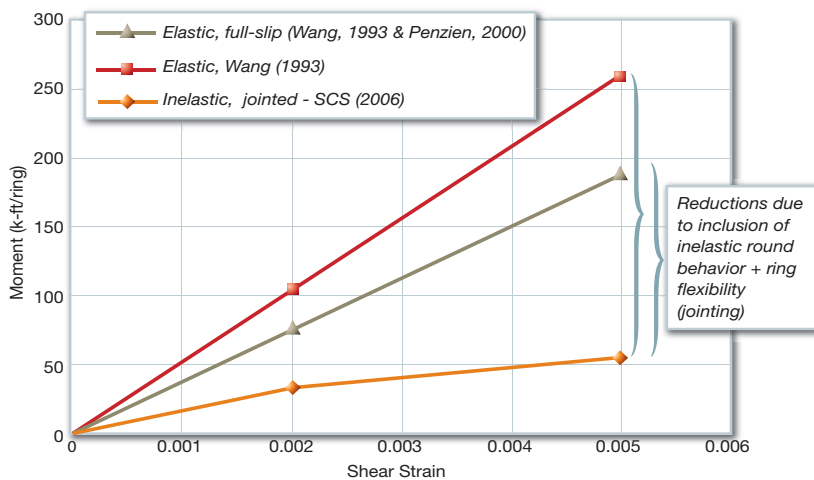
Question 2 - Milutin Srbulov; Mott MacDonald
How much did the analysis cost?

This was about US\$200,000 and took 8 months

Question 3 - David Court; BAM-Nuttall
Could more lining plates per ring be considered in larger tunnels to allow more movement?

More segments had been considered but these would have required fibre reinforcement. These could not be used for these conditions. In Japan hybrid designs with fibre reinforcing and normal reinforcement at critical locations were being developed.

Rapporteur: Andrew Hindmarch



Above: Fig 4 - Comparison of analysis results using different solutions

The graph in Figure 4 gives a comparison between the bending movements using the linear elastic solution developed by Joe Wang in 1993. A full slip was then used with a modified version of Joe Wang in 1993 and Joe Penzien's paper in 2000 at 0.2% and 0.5%. The solution modelled by SC Solutions significantly reduced bending moments in the segmental lining by taking into account the inelastic behaviour of the ground.

Of key importance to the study was the segment rotation and gapping. The model had to be tested for its ability to predict the joint separation at high strains. It is pointless to model an effect if the model can't predict it. By taking the model to extreme strains of 1.2%, this did develop a gapping and rotation that could lead to instability of the segments.

The maximum predicted rotation angles and joint widths at the modelled strains showed that birdsmouthing did not occur over the range of expected credible earthquakes. The 1.2% referred to above is about double what would ever be expected in any seismic analysis. There was no total

loss of contact with joint separation when the non-linear soil M-C effect was used. The linear thrust was always compressive even at 0.5% shear soil strain.

The key conclusion is that the joints themselves collect strain without generating load which is one of the inherent benefits of a flexible segmental lining system. That is their inherent advantage. The circumferential joint friction is not overcome when the connecting devices were looked at and the dowels did not contribute to joint sliding resistance. The presence of dowels in reality would cause damage to the concrete. The connecting devices were modelled as flexible elements but the joints remained in contact. Owalling did not impose a significant force or displacement demand on the devices. The connecting devices are therefore not required for stability which is typical for static conditions. Small keys (< 20 degrees) could be problematic at high strain levels from a joint separation perspective.

Some additional analysis was done outside of SC Solutions work which looked at longitudinal bending where the strains could be quite high. The concern was whether the joints would open up in the lining and uncompress the gasket. The results of that analysis obtained using the linear elastic analysis was to avoid the use of axially stiff connecting devices e.g. curved steel bolts. Kramer stated that any bolts across the circumferential joint in high seismic zones are to be avoided to prevent damage from the bolt being pulled. This occurred in a tunnel at Kobe in Japan along some of the bolts. The Kobe structure performed well but there was some cracking around some of the bolt pockets and minor spalling from this effect. Therefore a maximum force for the expected displacement should be specified for those devices.

Conclusion

In conclusion, the analyses were undertaken successfully. They evaluated the state of stresses in the ground around the lining and in the lining itself during construction and seismic ovaling. Due to joint friction, construction loads and the inclusion of a non-linear behaviour no gapping occurred demonstrating the stability of the segmental lining system for the range of ovaling strains. BART's consultants looked at the results, accepted them and approved the lining system. Bending moment comparisons were undertaken showing that the benefit of including the inelastic effects versus using the more simplified methods, were that the bending moments were significantly less. That resulted in little, if any, changes in reinforcing for the SVRT conditions although there have been other lining designs undertaken where a modest adjustment in the reinforcement was needed, generally going one wire size higher. Seismic ovaling places negligible demand on the connecting devices which are not required for seismic stability. The devices themselves should be detailed to have compatible force displacement characteristics and flexibility.

A 2D analysis using FLAC was undertaken using a pseudo-static analysis where the ground is subjected to a maximum shear strain similar to a pushover analysis. A full, dynamic analysis was also undertaken giving similar results. For static loads the bending moments generally increase to around 50-100% for high seismic event like a 0.4% strain.

A 3D pseudo-static analysis was one with and without the invert concrete to see whether or not the presence of this would act as stiffening to the tunnel lining but again, no significant effect was found to occur.

A 3D pseudo-static analysis was also carried out of single and twin tunnels to see whether the pillar between may be at risk. There was a 25% increase in loading which warranted a change to the strength design.

A pseudo-static analysis of tunnels with a cross passage to see whether a risky event may make the cross passage lining punch holes in the segmental lining was carried out. Again there was no impact except possibly minor repairs.

A full 3D dynamic was done on the station tunnel interface which would pull the station away from the tunnel. A gap of about 25mm would occur so the connection between the tunnel and the station had a gap to allow movement to occur but retain watertightness using an omega ring concept.

T&T

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At the sharp end – progress in reliability

Following rapid progress with disc cutters in the 1980-90s, cutter technology is approaching maturity, with development efforts concentrating on improved reliability and more peripheral applications. Maurice Jones checks out the current technologies and manufacturers.

There are many variables that can ensure a successful TBM drive, but the correct selection of cutters is a vital factor. Having confidence that a drive can be completed without downtime due to cutter changes removes a major worry from the project manager. TBM equipment specialist Herrenknecht refers to it as “a question of trust in lifetime, efficiency and reliability” which is important in consideration of the variable and sometimes extreme conditions to which they can be subjected and the effect of these on mechanised tunnelling project profitability. According to Herrenknecht these can include conditions such as ground temperatures of up to 50°C, rock strengths of up to 400 MPa, high water pressures, dust and abrasive sand.

When cutter changes do become necessary, they need to be completed quickly, safely, within available logistics and to the recognised machine design. An important factor in overall costs is the ease of replacement of worn or failed components on used cutters, and at what stage of the drive this needs to be carried out. The activity can be part of the supplier's service or carried out by the contractor's own trained personnel in a surface or underground workshop.

Ground conditions

The selection of cutters, and their arrangement on the cutterhead, is chiefly dictated by the expected ground conditions including not only the ground's hardness (or softness), measured as Uniaxial Compressive Strength – UCS. However it is also affected by the expected orientation of planes of weakness and their spacing, tensile strength, brittleness and abrasivity and other mineral content. The possible data on the ground conditions has to be matched by the available thrust at the TBM's cutterhead and the design of muck

removal arrangements to prevent clogging and/or unnecessary energy consumption through grinding of the cut material.

Another factor greatly affecting the choice of cutters is the diameter of the tunnel and TBM, since the gauge and other outer cutters have to travel comparably great distances whilst those nearer the centre will travel less but may be subject to higher axial loading and bearing forces.

The Excavation Engineering & Rock Mechanics Institute at the Colorado School of Mines, US, under Prof. Levent Ozdemir, has carried out studies over several years into TBM performance with particular reference to ring cutters and relevant rock properties. UCS tests include an analysis of how the sample fails i.e. structurally along lines of weakness or non-structurally in an 'intact' manner. Rock tensile strength is assessed according to the Brazilian Tensile Strength (BTS) test, again with observation of the mode of failure. This gives a measure of brittleness and thus the rock cutting efficiency possible.

The more familiar Cerchar Test is used to assess abrasivity and thus to estimate cutter wear during TBM excavation with extrapolation to estimate cutter costs given the tunnel dimensions.

The effects of rock mineral content, especially how it affects abrasivity, can be limited by use of larger diameter cutters since they carry more material to wear before needing to be changed. The allowable ring wear volume before the cutter must be changed is increased by over a third in 19-in. (483-mm) cutters. Larger diameters also facilitate the use of higher capacity bearings for greater TBM thrust (and hence penetration) and torque. According to hard-rock TBM innovator The Robbins Company, 19-in. disc cutters can be operated at 311 kN load compared to the 267 kN load limit of a 17-in (432-mm) cutter, still with increased bearing life. When operated at maximum

load the 19-in. cutter's bearing is only at 84% of its roller bearing load rating whereas the 17-in. cutter at maximum load is at 93% of its roller bearing load rating.

Robbins recently developed 20-in. ring cutters to give a wear volume 58% greater than that of 19-in. cutters with consequent improvements in cutter life and reduced cutter changes. Such 20-in. cutter rings are currently being used on two Robbins 10m-diameter double-shield machines on the Alimineti Madhava Reddy (AMR) project in India. This is to be the world's longest tunnel without intermediate access – at 43.5 km long.

These 20-in. cutters are also installed on the world's largest hard rock TBM, the 14.4m-diameter Robbins machine for the 10.4km-long new Niagara Tunnel in Canada.

The importance of overall TBM design to the selection of cutters leads TBM manufacturers to emphasise the importance of integrated technology. Herrenknecht states that innovations in TBM technology and cutter tools go hand-in-hand. They see the cutter tools in the context of cutterhead design and changing procedures for the cutters. “If the cutter tools are effectively aligned, this not only simplifies the necessary maintenance work,” they say, “but also positively influences profitability.”

Disc cutters

Both disc cutters and roller cutters penetrate the rock face by crushing the rock in front of the cutting element as it is thrust forward. Rotation of the cutterhead with corresponding rotation of the cutter on its heavy-duty bearing ensures that the crushing action finds a different part of the face. The desired action is for the rock between these 'crush zones' to break off the face for mucking out.

Disc cutters tend to be more efficient in breaking off the rock at the face, depending on the ground conditions. According to the

Robbins disc cutters are made to bore through any type of material that can be fractured with no set maximum rock hardness other than the economic limit of slower progress.

Of course it is not a simple matter of being able to expect greater progress in softer rock, even when the structure is taken into consideration. Robbins warns that since cutters will penetrate deeper into soft rock a potential situation may result that the TBM may not have enough power to turn the cutterhead. In harder rock the cutter capacity may limit progress rather than the machine power.

Increasing demands

Although the pace of technical development in cutters has not been so rapid of late, the increasing demands placed on TBM systems have, in turn, placed more demands on the cutters employed. One such demand is the higher pressures experienced at the face in some projects. Herrenknecht says that tools can be expected to work under ambient pressures up to 20 bar. The company's answer in current development is pressure-compensated disc cutters. Disc cutter bearings work in a chamber sealed from ambient conditions. The seal sets can usually accomplish a differential pressure of 3-4 bar so, consequently, under ambient pressure greater than 4 bar pressure compensation of the bearing chamber of the disc cutters is necessary. This can be done by a membrane construction that allows for a pressure transfer from the ambient medium to the oil in the cutter bearing chamber.

Below left: Assembling a larger diameter (19-20-in.) disc cutter for higher capacity loading and wear; **Below right:** Robbins 20-in. diameter disc cutters and backloading holders installed on the 14.4m-diameter hard-rock TBM cutterhead used for the current Niagara Tunnel project



Another Herrenknecht development is the narrow single-disc cutter, which allows narrower spacing between cutters on the cutterhead. The company says that many current and future projects require cutterheads with cutter spacing of only 70-80 mm, thus allowing a much higher face opening ratio of 30-35% for better muck flow, especially for mixed face conditions. Such faces can include soft soils as well as very hard rock at the same time, such as in residual soils overlying fresh bedrock. This type of ground needs a large number of disc cutters (and their holders) with small spacing, but this contradicts a high opening ratio. The new development allows for a cutterhead design with disc cutters arranged in rows on the arms, allowing for comparatively large apertures between them.

As demonstrated by the Palmieri range, disc cutters are available in single, double and triple-disc designs with single housing or as a twin-disc centre cutter with double housing. Palmieri cutters are now manufactured and supplied by a separate company within the Palmieri group in Gaggio Montano (Bologna), with other tunnelling equipment, including cutterheads, being supplied by Palmieri Tunnelling-Drilling of Venturina (Livorno). Palmieri claims the widest range of sizes from 6 to 20 in. (150-500 mm) diameter to cover microtunnelling systems as well as large-diameter TBMs. The cutters are equipped with high-temperature-resistant seals to minimise bearing contamination at water or air pressures up to eight bar.

Cost balance

In costing the use of a TBM any saving in the purchase of cutters needs to be balanced against the cost of TBM standstill (lack of availability) and the costs of unplanned tool changing.

Quality of manufacture and control directly affects the strength or weakness of cutters, especially in the metallurgical process. Cheap cutters are available which may differ little from more expensive versions in superficial terms but which could tend to wear out quicker or fail when put to use, especially under harsh conditions.

Robbins says that one of the problems in incorrect cutter choice is lack of experience amongst some contractors, causing them to base cutter decisions purely on purchase price. "Rings made of 'less developed' materials are often used on project with the intent to cut costs, but with the consequence that cutter life and penetration can be compromised. Using cutter rings that optimise cutter life and penetration will ultimately benefit the contractor in the long run," says Robbins.

Although known mainly for hard-rock work, Robbins confirms that disc cutters are being manufactured for more varied conditions, and longer and larger diameter tunnels.

Red Horn Engineering of Singapore has been manufacturing Black Diamond cutters at its factory in Shanghai since early this year following its acquisition of the range from Pacific Tunnelling of Australia. Albert Per of Red Horn points out that, whilst basic ring cutter design has changed little, there are more demands on performance of the cutter ring itself for the same cost. However, "the necessary material available at reasonable cost is very much limited," he says.

This cost pressure from customers has led some suppliers to offer lower price cutters



with different material, claims Per. "Most of the time," he continues, "the cutter cost skyrocketed because everyone is rushing and pushing the limit resulting in unpredicted wear and faulty cutters." This includes such things as cracked rings and failed bearings.

With mixed ground additional possible performance failures include increased torque (possible cutterhead stall), cracked rings and bearing failure such as from a bent shaft. On hard, homogeneous tunnel faces the loading is shared more equally amongst the cutters but in mixed ground penetration can tend to be different between cutters, resulting in increased impact from hard inclusions. Per also cites the case of a mixed faced with a band of very soft ground that can stop a disc cutter from turning, creating uneven wear. Uneven wear of the discs will deter the normal rolling action, even when returning to hard ground, resulting in more uneven wear to the disc and perhaps the holder body too.

The correct material is also important in such conditions. "Just remember," points out Per, "that a really hard cutter can reduce wear, but only for hard rock. It will crack easily when in mixed ground as it will be more brittle. For hard ground a thinner tip and standard rolling torque is recommended, and for mixed ground a wider tip (cutting edge) and lower rolling torque."

According to Per bearing seal failure is not a common fault and is usually due to incorrect set up. "Most of the time a seal failure is due to improper installation or an unclean (assembly) environment. The seal face is machined almost perfectly flat, thus any foreign particles can result in leaking. One cutter failed the pressure test and a strand of hair was found on the seal face. The cutter passed the test once the hair was removed."

A recent Black Diamond development is a patented single-bearing cutter with a 2-cup bearing in a single cone designed by NTN for Red Horn. It eliminates the need

for torque adjustment. There is an even pressure on the bearing to create the rolling torque over a longer bearing life. "Our seals sit perfectly on the bearing and when the cup is tightened a resistance is created from the seal and bearing to create the rolling torque." For lower torque a shim plate is added between the bearing to push out the cup and release the contact pressure between the cup and cone.

All Black Diamond cutters have the torque set after assembly, but if a lower torque is required a shim plate can be added. Per says, "These improve the speed for maintenance and repair, and also eliminate the possibility of over or under torque, which can result in unforeseen failure of the cutter."

Roller cutters

Prior to the development of ring cutters, the hardest ground was tackled by cone- or frustum-shaped cutters set with rows of carbide inserts that could penetrate the rock face under the required pressure and grind it for removal. Whilst ring cutters are more efficient for most sizes of TBM, roller cutters, originally developed for large-diameter rotary drilling, are still found in tunnelling applications of smaller diameter such as raiseborers and microtunnellers, and also for shaft drilling.

Well known for its long expertise in carbide element design, manufacture and applications, Sandvik produces tricone bits and roller cutters for raiseboring in the Sandvik Mining & Construction range.

Meanwhile the development of small ring cutters for smaller diameter tunnel and microtunnelling drives continues amongst specialist manufacturers.

Picks and scrapers

Tunneltec, which makes a wide range of ripper and scraper tools for use in medium-to-soft ground, emphasises the importance of the cutting material that comes into contact with the ground. Managing director

Friedhelm Allwicher and marketing manager Stefan Jansen report that there has been a trend to using more tungsten carbide (often known central Europe as 'widia') in the composition of the tool, with corresponding less use of hard facing. The Tunneltec product range does not use hard facing in any case, replacing it with carbide buttons.

In mixed ground picks and related tools tend to be subjected to shock loading more often than in homogeneous ground, or that experienced by rolling cutters. Therefore the static cutters have to be designed to cope with this type of loading. Jansen mentions that in a recent tunnelling project TunnelTec employed different compositions of tungsten carbide and different types of brazing to handle shock loading.

As mentioned earlier, the outer cutters, especially gauge cutters, have a comparatively hard life throughout a drive but their durability must be assured. Jansen comments, "One important issue (with cost) is to cut the gauge area to avoid big problems with melting over-cut." Efficient gauge cutters are needed to provide the space for forward movement and steering, but since they are set at an angle to the TBM axis, they need to be constructed to withstand high forces across their own axes.

Part of the Seli group, InnoTek of Rome offers three types of tools using carbide (widia) inserts. These are rippers for digging into the face and removing boulders, cutters housed on TBM blades to remove spoil dug out by rippers, and scrapers for loading out the spoil. Scrapers also guarantee correct operation of the cutter tools (gauge cutters) in the peripheral areas of the cutterhead.

Bewarder of Germany offers a very wide range of cutters including static and ring cutter types for all standard BM types. Types include various shapes of pick and scraper cutters, reamers, centre cutters, copy cutters and the aforementioned discs. Bewarder claims that careful selection of carbide insert quality and the use of heat-treated steel optimises wear protection, and helps to produce a very good cost-performance ratio. Inductive brazing with temperature-resistant solder is used for bonding between the carbide and tool body material.

Changing

Even though backloading of cutters is now commonplace, it can still be a tricky and time-consuming procedure. This is especially so in soft ground in consideration of the medium used to support the open ground (compressed air, pressurised slurry, etc.). If mid-drive cutter changes can be avoided it improves both

Right: Part of a dual-function 2,26m-diameter TunnelTec rock cutterhead delivered last year to contractor Dibco of Toronto. It features both fixed and disc cutters and can be converted to soft-ground use. Its first project was for a siphon sewer in Calgary.





Above left: Breakthrough of an 8.16-m Wirth EPB TBM equipped with TunnelTec tools on the Castellanza metro project, Italy. The cutterhead is equipped with both static rippers and scrapers and disc cutters with carbide bullet inserts. **Right:** Disc cutters shown on the cutterhead of a 9.90m-diameter NFM Technologies TBM on completion of 1140m in a single month for the Madrid-Gijón high-speed railway route

safety and scheduling.

The desirability of completing a tunnel drive without tool changing is more important with metro construction, especially in urban areas. This avoids any increased tendency to subsidence in a particular but unplanned location. According to Jansen one solution is to have more tools per track, thus sharing the load. Another is to work with different heights of tools so that well-working, virtually fresh, tools are available over the complete drive.

Changing ground conditions present an extra challenge especially when trying to avoid cutter changes mid-drive. Jansen says that to meet both these requirements, "Geological analysis is essential in order to realise (or modify) the cutterhead layout and to arrange the tools including types, placement, height and quantity. At one job-site in the north of Italy using an earth-pressure balance (EPB) machine, the cutterhead has been assembled with Tunneltec cutters and tools to manage sand and gravel at the beginning of the drive followed by limestone, and then sand and gravel again at the end."

Customisation & compatibility

It might be thought that there was little scope for customisation in supplying a 'consumable' product ranges such as cutters but Stefan Jansen of Tunneltec has identified a trend for customisation of cutterheads and tool layouts as a factor in the increase of TBM supply with a 'buy back' option for use in later projects. The cutterhead invariably needs customised cutter arrangements to meet the expected new excavation conditions when they become known, as this is unlikely to be known at the time of TBM design. Repeat customisation may be necessary from job to job to suit the aim of the project and complete it successfully.

"We see that customers want more and more standard TBMs in order to have less different spare parts," comments Jansen, "but on the other side, they want a cutterhead (as the important part to dig out the material) that is optimised for the related project. Thus we will have more and more different cutterhead layouts around the world."

Durability development

Even with previous experience of similar tunnelling conditions, it can be difficult to predict the life of cutters, although, whether through better products or better planning, this is increasing. In a recent 11.38m-diameter NFM EPB TBM application in Wuhan under the Yangtze River, China, for rail tunnels Tunneltec tools (face scrapers, face rippers and bucket (mucking port) scraper all lasted for 2700m without changing, and were still not worn out. The cutterhead was equipped with 250 face picks and 16 bucket scrapers. Geology comprised sand layers, gravel and shale with face pressures up to 7 bar, which would have made any tool changes risky and expensive.

In the more difficult geology of a 9.18m-diameter Metrobus Brescia (Italy) project that included abrasive material, cobbles and limestone layers, TunnelTec tools lasted for 1467m without changing compared to 80m for the tools previously used. A Herrenknecht TBM was fitted with scrapers, welded-on rippers, replaceable rippers and a nose cone ripper.

Stefan Jansen emphasises the importance of comparing the circumstances of each project in comparing tool life, since simple longevity figures can be misleading.

According to Robbins improved materials have surfaced to meet the demands for increased cutter life and loading. For example, cutters that are made for high-load situations consist of a material that keeps its properties at

a higher temperature, and is therefore tougher and more resistant to chipping than standard cutters. Both variations of cutter, says Robbins, are equally resistant to abrasive wear. Robbins cutters using purer and tougher materials have been available since 1998. These cutters, of generally longer life, have been used successfully on project such as the Manapouri Hydroelectric Project in New Zealand and La Malata Land Outfall in Ferrol, Spain.

Service

In addition to the support of customers with product advice, manufacturers usually need to provide job-site support such as in the form of cutter stocks and refurbishment facilities in a workshop such as the mobile unit Red Horn provides. At the end of tunnelling the cutter consignment balance will be returned to Red Horn within an agreed time frame and the contractor charged for whatever is used.

Tunneltec relies on staff site visits whenever required due to contractor problems, advising whatever the tools that are used.

Herrenknecht's range of practical customer services includes a cutter database as a management tool. The data relates to experience of wear rates and cutter exchange strategies gathered during a number of projects. Database users can develop economic project strategies for cutter disc exchange and refurbishment. The database also records the cutter type as well as the time, place and reason for the exchange or refurbishment. The database can, therefore, deliver a complete history of each cutter disc, reports on the respective costs incurred during the last excavation and permits the forecasting of favourable maintenance intervals including cutter exchanges. The database software is available in multiple languages. T&T

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Dates & Events

26-27 NOVEMBER

Austrian Southern Railway Link Conference 2009 Leoben, Austria

This event focusses on Austria's Southern Railway Link, specifically, the design and construction of the 32.8km long Koralm Tunnel and the 27km long Semmering Base Tunnel along the route. November 27 involves a site trip to the currently under construction Koralm Tunnel Lot KAT 1. Contact: Marion Kainrath: email: technologieakademie@unileoben.ac.at; web: technologieakademie.unileoben.ac.at

01-03 DECEMBER

STUVA TAGUNG'09 Hamburg, Germany

Every two years the STUVA conference takes place with various topics from the fields of underground construction. The conferences draws some 1,500 tunnelling experts from more than 30 different countries. An exhibition accompanies the event. Contact: STUVA: email: info@stuva.de web: www.stuva.de

27-29 DECEMBER

13th International Conference on Structural & Geotechnical Engineering 2009, Cairo, Egypt

This two day event will cover all aspects in the field of structural and geotechnical engineering, organised by the conference secretariat, Ain Shams University Faculty of Engineering, Structural Engineering Department. Contact: Prof. Dr Eman Soliman; tel: +2 02 26839318; email: Info@ICSGE2009.com; web: www.ICSGE2009.com

17-19 MARCH 2010

ISTSS 2010 Frankfurt, Germany

The 4th International Symposium on Tunnel Safety and Security. Manuscript abstracts should be submitted to the Secretariat by 01 June 2009, poster abstracts by the 01 October 2009. Contact: Anders Lönnermark, SP Technical Research Institute of Sweden; tel: +46 10 516 56 91; email: anders.lonnermark@sp.se; web: www.sp.se

17-19 MARCH 2010

IINTERtunnel RUSSIA 2010 Expocentr, Moscow, Russia

IINTERtunnel Russia 2010 provides an opportunity for suppliers of products and services to the tunnelling sector to showcase their capabilities and exchange ideas and experiences. IINTERtunnel RUSSIA will be held at the Expocentr in Moscow, Russia Contact: email: intertunnelrussia@mackbrooks.com; Web: www.intertunnelrussia.com

19-25 APRIL 2010

Bauma 2010, Munich, Germany

The 29th International Trade Fair for Construction Machinery, Building Material Machines, Mining Machines, Construction Vehicles and Construction Equipment will be held in the Messe Muenchen Messegelaende 81823, Munich, Germany. Contact: email: info@bauma.de; phone: +49 89 949 11348; fax: +49 89 949 11349; Web: www.bauma.de

2-7 MAY 2010

North American Society for Trenchless Technology No-Dig 2010, Chicago, USA

The 2010 NASTT No-Dig show will be held at the Renaissance Schaumburg Hotel and Convention Center, Chicago. The conference theme is "Rebuilding North America's Underground Infrastructure Using Trenchless Technology" and will include infrastructure investment; social costs and impacts; industry trends, advancements and new concepts. Contact: NASTT; web: www.nodigshow.com

14-20 MAY 2010

2010 ITA World Tunnel Congress, Vancouver, Canada

Not long after the 2010 Winter Olympics, the International Tunnelling Association (ITA) visits the spectacular city of Vancouver, British Columbia, for its yearly conference and exhibition. The usual combination of working groups, open sessions and technical talks will all be included. Contact: web: www.wtc2010.org

8-10 JUNE 2010

InterTunnel 2010 Turin, Italy

Tunnelling exhibition aimed specifically at clients, contractors and consultants involved in the construction of and equipping and operation of tunnels. Contact: Mack Brooks Exhibitions; web: www.intertunnel.com

9-11 JUNE 2010

Swiss Tunnel Congress, Lucerne, Switzerland

Tunnelling developments in the Alps will doubtless be a talking point at the Swiss Tunnelling Society's STC. The event will be held at the KKL Lucerne. Contact: fgu@thomibraem.ch web: www.swisstunnel.ch

14-16 JUNE 2010

International Conference Underground Construction Prague 2010 Transport and City Tunnels

The Czech ITA-AITES Tunnelling Association will host its 11th International Conference at the Clarion Congress Hotel Prague. Lectures will be simultaneously interpreted into English, German and Czech. Contact: Czech ITA-AITES: tel: +420 266 793 479; email: ita-aites@metrostav.cz; web: www.ita-aites.cz

15-17 JUNE 2010

European Rock Mechanics Symposium (EUROCK 2010)

Eurock 2010 is an ISRM Regional Symposium of Europe. The Symposium covers all the aspects of rock mechanics and rock engineering, from theoretical research to engineering practice, with emphasis on applications to natural hazards prevention, infrastructural construction and sustainable development. Contact: Jean-Paul Dudt, Laboratory for Mechanics of Rock (LMR), EPFL-ENAC-LMR Station 18 CH-1015, Lausanne; tel: +41 21 693 23 25; fax: +41 21 693 41 53; email: lmr@epfl.ch; web: www.lmr.epfl.ch

19-23 JUNE 2010

North American Tunneling Conference, Portland USA

The 2010 NAT will be held at the Marriott

BRITISH TUNNELLING SOCIETY

10 DECEMBER: **Debate by BTS Young Members Group**

Chaired by Kate Cooksey, chair of the BTS YMG. 6pm start at the ICE.

21 JANUARY 2010: **Construction of Deep Shafts**

Speakers will discuss the challenges of constructing deep shafts. Presented by Alan Auld of Alan Auld Associates and Dave Setchell of Cementation. 6pm start at the ICE.

Downtown Waterfront Hotel in Portland, Oregon. Conference and exhibition information and registration is available on the SME web site. Contact: Society for Mining, Metallurgy and Exploration (SME); web: www.smenet.org.

23 - 27 OCTOBER, 2010
ISRM international Symposium 2010 and 6th Asian Rock Mechanics Symposium, New Delhi, India

Contact: Mr. V. K. Kanjlia, Member Secretary, Indian National Group of ISRM: tel: +91-11-2611 5984/2688 2866/2410 1591; fax: +91-11-2611 6347; email: uday@cbip.org/cbip@cbip.org; web: www.arms2010.org

12 - 16 SEPTEMBER 2011

6th International Symposium on Sprayed Concrete, Norway

Sixth International Symposium on the modern use of wet-mix sprayed concrete for underground support will be held in Tromsø, in the north of Norway. Contact: Siri Engen The Norwegian Society of Graduate Technical and Scientific Professionals - Tekna; fax: +47 22 94 75 01

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.

Fax: +44 20 7936 6826

Email: editor@tunnelsonline.info

Web: www.tunnelsonline.info

Contacts

HEAD OFFICE
Progressive Media Publishing
John Carpenter House
7 Carmelite Street
London
EC4Y 0BS
UK

WEB
www.tunnelsonline.info
EMAIL
editor@tunnelsonline.info
TEL
+44 20 7936 6826
FAX
+44 20 7936 6813

HOW TO CONTACT US

EDITORIAL

EDITOR

Jon Young
Tel: +44 20 7936 6826
Email: jyoung@tunnelsonline.info

TECHNICAL EDITOR

Maurice Jones
Tel: +44 20 7936 6827
Email: mjones@tunnelsonline.info

CONTRIBUTORS

**Amanda Foley, Adrian Greeman,
Bernadette Redfern, Patrick Reynolds**

STAFF WRITERS

Emma Gritt, Nicole Robinson

GROUP EDITORIAL DIRECTOR

John Band

PRODUCTION & DESIGN

DESIGNER

Natalie Kyne

TECHNICAL ILLUSTRATOR

Nick Stenning

EDITORIAL PRODUCTION MANAGER

Dan Gardiner

PRODUCTION CONTROLLER

Loraine Lee
Tel: +44 20 8269 7799 Fax: +44 20 8269 7840
Email: llee@progressivemediagroup.com

ADVERTISING

ADVERTISING MANAGER

Shelly Palmer
Tel: +44 20 7936 6848 Fax: +44 20 7936 6813
Email: spalmer@tunnelsonline.info

NORTH AMERICAN MANAGER

Steven Caming - Granite Media Services
Tel: +1 603 447 1187 Fax: +1 603 447 6166
Email: granitemediaservices@yahoo.com

EUROPEAN MANAGER

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

ITALIAN OFFICE

Ediconsult
Tel: +39 02 477 10036 Fax: +39 02 477 11360
Email: milano@ediconsult.com

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Jon Young



Maurice Jones



Shelly Palmer



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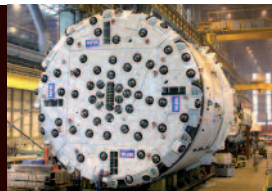
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