

JUNE 2009

# tunnels & tunnelling INTERNATIONAL



## FOCUS ON DRILL & BLAST

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and a look at the history of drills

## TRENCHLESS TECHNOLOGY

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# Contents

**FRONT COVER:**  
A rare glimpse of the stunning Northern Lights hovering above the tunnel site for the Ólafsfjörður Siglufjörður Tunnels in remote far northern Iceland (p16).

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## 30 HARDING PRIZE RUNNER UP A3 Hindhead Road Tunnels

The design and construction of the UK's longest road tunnel is described in detail in this Harding Prize runner up paper

## 37 SETTLEMENT CONTROL Australia's largest busway tunnel

*T&T* describes how constructing a shallow bus tunnel under a historic jail building in Brisbane proved an intricate operation

## 40 BRITISH TUNNELLING SOCIETY Disputes in construction and tunnelling - pt 1

In the first of a two part article *T&T* looks at project risk issues and the common causes of contractual disagreements

## TRENCHLESS TECHNOLOGY

## 44 BURIED UTILITY MAPS Trenchless key to success

Buried service and utility maps can be vague, leading to serious problems with asset damage during later construction

## 47 CLASSIFIED ADVERTISEMENTS

## 49 DATES & EVENTS



- 6 TBM Breakthrough on London's Ring Main water tunnel project
- 5 COMMENT
- 6 WORLD NEWS
- 13 BUSINESS & FINANCE

## FOCUS ON DRILL & BLAST

- 16 CHEMICAL GROUT IN D&B  
**An Icelandic struggle**  
Water inflows proved a serious headache to the project team on the Siglufjörður and Ólafsfjörður Tunnels in Iceland
- 21 CONFINED SPACES  
**Blasting through a tight spot**  
Drill & blast of the Spillvatten water tunnel in Sweden had it's challenges, not least working within the 12m<sup>2</sup> tunnel section
- 25 TRUE WORKHORSE  
**Horses for courses**  
*T&T* looks into the history of one of tunnelling's un-sung heroes - the simple drill - and its impact on drill & blast
- 28 PRODUCTS & SERVICES

# 21

The access tunnel halfway along the Spillvatten tunnel



## TURKEY: A FIRST BENEATH THE BOSPORUS.

April 13, 2009 marked an important event in tunnel construction. The breakthrough of the EBP Shield S-391 (Ø 6.11m) from Herrenknecht saw the construction of the first ever tunnel between two continents excavated using a tunnel boring machine. The "Melen 7" tunnel connects Europe and Asia crossing beneath the Bosphorus. It is the key element in a large-scale project designed to improve Istanbul's water supply on a sustainable basis. For this purpose, the river Melen, 170 kilometers away from Istanbul, is dammed in the Asian part of Turkey and its water is then guided into the European part of the metropolis with its 10 million inhabitants.

The tunnel follows an extremely complex route. With a gradient of up to 7.5%, it leads down to a depth of 135 meters below sea level. A huge challenge which has been successfully mastered by the construction site crew and the machine. The 3.4 kilometer long stretch was completed safely and on schedule in 13.5 months. A masterly performance, also thanks to the perfectly adapted "Full Service Tunnelling" concept in cooperation with our subsidiaries. Herrenknecht Formwork delivered 4 sets of segment moulds and the appropriate handling equipment, H+E Logistik delivered the conveyor belt installation for the removal of the excavated material.

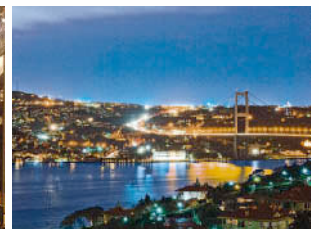
### ISTANBUL | TURKEY

#### PROJECT DATA

**S-391, EPB Shield**  
 Diameter: 6,110mm  
 Driving power: 2,000kW  
 Tunnel length: 3,400m  
 Geology: slate, limestone, sandstone

#### CONTRACTOR

OAO Mosmetrostroy



# ITA success

Just back from the 35th International Tunneling Association Annual General Assembly, this year held in beautiful Budapest, Hungary, and am pleased to report it was a pretty pleasing affair for the most part, both professionally and socially (although in tunnelling these do go hand in hand for the most part!).

Initial fears of a low attendance were unfounded and delegate numbers reached an impressive 1100, with 40 of the association's 55 member nations represented. Welcomed on-board were newcomers, Lao, to the ITA. There was also great news for Thailand who beat China to the post and will host the 2012 event in Bangkok, following on from Vancouver next year, and Helsinki in 2011.

Talking to many of the actual committee members and delegates, the feeling is that the ITA is really getting its act together, and seem more of an active body in actually trying to get information out there, rather than the slightly behind closed doors feeling that has been somewhat evident in the previous decade. The test will be to see how all of this technical information gleaned during the working groups actually finds its way onto job sites, how the promotion of tunnelling changes clients opinions, and how the training and education workshops help produce tomorrow's engineers. It

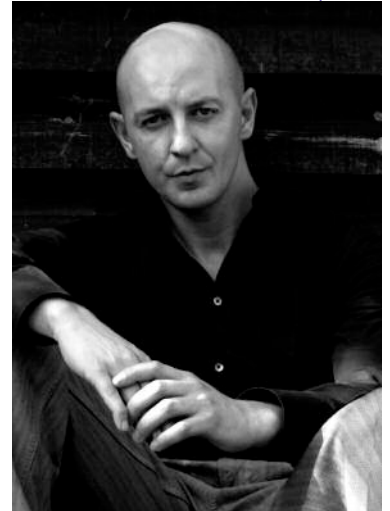
feels as though a significant corner had been turned though, and I'm confident that we'll soon see greater benefits from what goes on inside the ITA, to those outside of the ITA.

My one gripe remains though – too many papers that are way too specific and overly technical. Maybe I was unlucky, but many of the presentations I saw fell into the “I know more equations than you” bracket. I suppose this is to be expected from such a consultant heavy delegation, but it would be great to see a few more contractor based papers, with more emphasis on actual construction challenges. Up to four tracks running simultaneously also leads to the inevitable room confusion, although for the British contingent, the fact the rooms were named after composers produced an unexpected laugh when asked for directions to the Brahms and Liszt area.

All in all though, a really good effort, so congratulations are in order to the Hungarian Tunneling Association for all its hard work.

One final thing I learned in Budapest, it's virtually impossible to say goodnight to the Scandinavian contingent, you just go to the bathroom, slip off home, and worry about your headache in the morning....

Tris Thomas



## COMPANIES IN THIS ISSUE

365 Environmental Services	46	CH2M Hill	7, 14	KPMG	7	Perard Torque Tension Ltd	27
AD Group	28	Corderoy	7	Laing O'Rourke	14	Porr	14
Aecom	7, 14	CVA	8	LCR	14	Poyry	11
Alcatel-Lucent Schweiz	11	Ditch Witch	46	Leighton Contractors	8	Robbins	13
Alpine-Bau	11, 13	Doka	28	Liebherr	33	Samsung C&T	13
Arup	7	Douglas and Partners	39	Lovat	6, 8, 10	Seli	8
Atel Installationstechnik	11	D-Tec	28	Maunsell	8	Sembawang Engineers and Constructors	13
Atkins	7, 33, 34, 35	Euroform	14	Maz BogL	14	Shanghai Tunnel Eng	13
Atlas Copco	22, 23, 25, 26	Geotek	16	McConnell Dowell	13	SIG Swiss Industrial Company	27
Balfour Beatty Rail	11	Golder Associates	8	Metrostav	16	Sinclair Knight Mertz	37, 39
Balfour Beatty	33, 34, 35	Gryaab AB	21	Metrotrace	14	SKEC	13
Bamtonnelstroy	8	Háfell	16	Meyco	33	Standard & Poor's	41
Banverket	13	Halcrow	7, 35	Minova	18	Strabag	13
Boulderstone Hornbrook	8	Hawkins Brown Architects	7	Morgan Est	6, 10	Systra	7
Beca Carter Hollings & Ferner	13	Herrenknecht Formwork	7	Mosmetrostroy	7	Tamrock	17, 18
Bechtel	7, 14	Herrenknecht	7, 8, 11, 14	Mott MacDonald	7, 30, 33, 34, 35,	The Engineers Collaborative	13
Berwin Leighton Paisner	41	Highways Agency	33, 35	Najder Engineering	18	Theiss	28, 37, 39
Beton- und Monierbau	14, 21, 22, 23	Infotec	44, 45	Navigant Consulting	41	TRSS Thales Rail Signalling Solutions	11
Bickhardt Bau	14	Interegger	14	NFM Technologies	7, 10	Tubelines	14
Bilfinger Berger	8, 13, 14	Jacobs Engineering	7, 14	Nichols Group	7, 14	Volvo	18
Bouygues	6	Jeager Bau	14	Obayashi	13	Wayss & Freytag	6, 14
Broyt	18	John Holland	28	Odebrecht	8		
Canary Wharf Group	14	Kenny	13	Orica Mining Services	18		
Capita Symonds	7	Komatsu	18	Ostu/Stettin	14		
Ceresola TLS AG	28	KPMG	14	Parsons Brinckerhoff	8		

# New River Head finish

**E**xcauation was completed last month on the water supply tunnel that will extend the London Ring Main in the north of the capital.

Morgan Est holed through with a Lovat shield at the 7.5m diameter New River Head reception shaft after driving the 4.5km long tunnel that links the

Coppermills treatment plant with the main Ring Main.

The TBM was launched a year ago from a 10.67m diameter shaft at Stoke Newington Reservoir. The work was done in shifts operated over 24-hour days, five days/wk.

Geology along the alignment comprised London Clay and Thanet Sands, and the route for

the shield – “Cleo” – passed below tube lines, sewers, rail and canal tunnels. The shafts were sunk to approximately 50m depth.

The 2.85m i.d. bolted, segmental concrete lining is to have a secondary, insitu reinforced concrete layer to give a finished diameter of 2.6m. The contract remains set for a

completion in 2010.

Initially a contract with Amec, awarded in early 2007, the work was undertaken as Morgan Est following the acquisition of the former firm which saw the transfer of its tunnelling business and other assets. The contract value is US\$44.6M.

**Above:** Morgan Est holes through with a Lovat TBM in London to complete a 4.5km long water tunnel drive



## Kick-off for Koralm

**W**ork has formally started on the main construction of the Koralm twin tube rail tunnel, in Austria, with formal groundbreaking at the east portal.

The Wayss & Freytag-led JV was awarded the contract late last year and work involves construction of two single track tunnels as well as road crossings.

Tunnel works will extend over 2.3km as part of the package, which covers a total of 5.5km of the route, including surface and earthworks. Excavation is by drill and blast and the tunnel lining will be constructed using NATM, cross passages are to link the tubes every 500m and main excavation work is to start later this year.

W&F's share of the JV's package on the four and half year long contract – itself only part of the almost 33km long main tunnel scheme – is approximately US\$140M.

Exploratory tunnel work for the project commenced in the late 1990s and the site investigation effort has been active for design development over much of the past decade.

The Austrian rail infrastructure company, OBB Infrastruktur Bau, is developing the Koralm tunnel between Grand St Florian and Unterbergla and the east portal in the region of Frauental. The section is on the line between Graz and Klagenfurt in the south of the country.

As part of a wider range of infrastructure investment in the high-speed rail network, and part of the strategic trans-European rail improvement, the Koralm tunnel is expected to help significantly cut rail travel within Austria as well as across the Continent.

## Miami Port Tunnel back on

**N**ew funding arrangements have been agreed to help resume development of the Port of Miami Tunnel, which was awarded last year to a winning bidder but then hit financing difficulties at the end of the year.

The Florida Department of Transport (FDoT) said at the beginning of this month that agreement has been reached on commercial issues for the project, paving the way to financial close.

The milestone means that all parties have agreed to the terms for the winning bidder, Miami Access Tunnel (MAT), to proceed

towards financial close on its plans for the project, which FDoT said would continue on a Public-Private Partnership (PPP) basis. The target date for financial close is 1 October.

MAT, which is led by Bouygues with investment bank Babcock & Brown, won the PPP contract in February 2008. The concession contract has a 35-year term. On the public sector side of the scheme, MAT's partners are FDoT, Miami-Dade County and the City of Miami.

However, late last year as the global financial crisis worsened it

became more difficult for the bank to maintain its plans for significant equity involvement. As a consequence, FDoT announced last December that it could not close the deal on the PPP project (*T&TNA*, December 2008, p7).

The parties have been working for months to save the twin tube subsea link. Bids for the concession were opened in early 2007 with MAT tendering a 47 month construction period and a Maximum Availability Payment (MAP) of US\$33.3M to be received annually.

# Design jobs for Crossrail

The first four design contracts on the Crossrail project have been awarded for a total cost of approximately US\$63.4M to Mott MacDonald, Arup and Atkins, and Capita Symonds.

Design work was pushed ahead at the end of last month shortly after construction formally started, and project developer Crossrail Ltd has appointed its permanent Programme Director (see p14).

Crossrail said Motts had been awarded the approximately US\$14.6M design contract for sprayed concrete lining (C121).

Working together, Arup and Atkins won two design contracts: the east-west running bored tunnels (C122), worth approximately US\$27.6M; and, Tottenham Court Road station (C134), in central London, for approximately US\$16.2M.

Capital Symonds was awarded

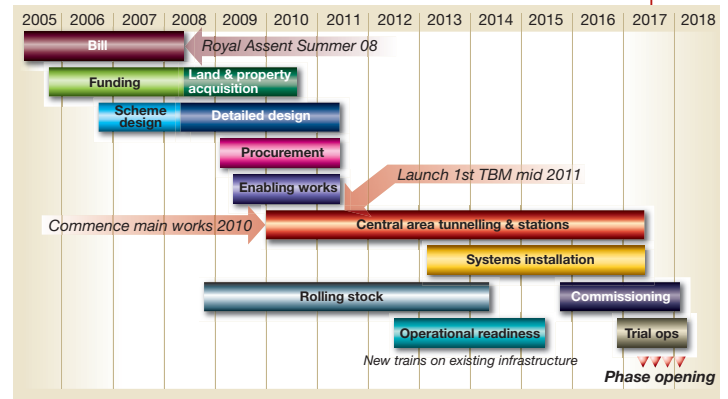
the design contract for Royal Oak Portal (C150), in west London, which is worth approximately US\$4.9M.

Main construction work for the US\$25.3bn scheme is set to start next year. Tunnelling work by TBM for the 6m i.d. in twin tubes is to get underway in 2011, and rail services are to start in 2017.

At the end of last year a dozen firms were awarded framework agreements for the right to bid for design packages, with Arup and Atkins listed separately. Crossrail expects to be awarding further design contracts over the next few months.

The Arup/Atkins partnership said the firms have collaborated on various international projects and also on earlier Crossrail design works.

For the contracts just awarded they are to work with up to 150 staff in a single office



operation at the client's offices in Canary Wharf.

For the 18 month package just awarded to design the bored tunnels, the team is to undertake construction planning, detailed design of the segmental concrete lining and track systems, and co-ordinating assessments of ground movements for all excavations – tunnels, stations and shafts along the route.

The team said that Tottenham Court Road station is due for completion by April 2011. Arup is leading the work, and the team also includes cost consultant Corderoy and Hawkins Brown Architects.

Capita Symonds noted that the Royal Oak Portal was one of four on the project, and the construction area is particularly important as the launch site for TBMs to drive the Central West Tunnel sections. The design

contract involves the tunnel portal structure, local surface structures and utility services, and providing space for the pit head and TBM assembly.

Recently, Crossrail picked Bechtel, with Halcrow and Systra, to be Project Delivery Partner. Its Programme Partner is Transcend, a JV of Aecom, CH2M Hill and Nichols Group.

In addition to those appointments and the first design package awards, 17 contractors were also recently awarded Enabling Works Framework Agreements.

Jacobs Engineering UK with KPMG to be the Project Representative for Department for Transport (DfT).

Chief Executive of Crossrail is Rob Holden, and non-executive chairman is Terry Morgan. The early development of the scheme was led by Doug Oakervee.

# Breakthrough on Bosphorus bore

The EPBM driving the 3.4km long "Melen 7" water tunnel below the Bosphorus in Istanbul has holed through.

The 6.11m diameter shield was launched in March 2008 by Russian contractor Mosmetrostroy and bored at depths up to 135m below water level, achieving progress rates up to 20m per day.

The large water depth required the Herrenknecht machine (S-391) to be designed to take pressures up to 13.5 bar, and seals for the segmental concrete lining have been designed to withstand pressures up to 20 bar. Segments moulds were supplied by Herrenknecht Formwork GmbH.

Launched from the area of Sariyer on the European side of the capital, the TBM bored at a slope of 7.45% for 2.3km to then run almost horizontally for the remainder of the drive. Cover below the seabed reduced to approximately 35m in parts.

Breakthrough was in April, at the 140m deep reception shaft in the Beykoz area. The TBM was designed with small shield segments to enable dismantling and removal from the 8m wide shaft.

Works on the project will next focus on fitting steel pipes into the tunnel for completion by about the second quarter of 2010. The major



**Celebrations following TBM breakthrough on a water tunnel below the Bosphorus**

water resources project is taking supplies from the Melen river basin, about 170km from Istanbul on the Asia side.





# All change at Republica

**T**he TBM drive on Line 4 of the Sao Paulo Metro is to resume this month after the shield had been left waiting outside Republica station from late last year. Only in May was it pulled through as part of a revised tunnelling and fit-out plan.

Restricted space within the station had led to an original plan to dismantle and extract the 9.46m diameter EPBM, then rebuild it from within the relaunch shaft on the other side. The

backup train would have been pulled through.

In discussions with Odebrecht-led JV contractor, Consorcio Via Amarela (CVA), the tunnelling subcontractor Seli examined alternatives to dismantling, including driving the Herrenknecht shield around the station.

In the end, CVA concluded it was worthwhile cutting open parts of the station and constructing pre-stressed concrete slide beams to pull the TBM through intact and

over a live metro line.

Advantageously, Seli used the time to relocate the support services from the start of the tunnel to the re-launch chamber, thereby freeing up the built tunnel plus five stations, including Republica, for early fit-out.

Launched just over two years

ago near Faria Lima station to bore east, the TBM will next drive to Luz station and then terminate near the ventilation shaft at Joao Teodoro by November. The shield is building 1.5m long rings (7+1) for the 8.43m i.d. tube that will hold twin tracks (T&T, November 2008, p11).

# Gathering for Sochi

**T**he first of five Lovat shields is on site in Sochi to shortly begin excavation for a total of 16.4km of tunnels in preparation for the Russian city hosting the 2014 Winter Olympics.

Contractor Bamtonnelstroy will use the shields to drive three service tunnels and two rail tubes for the scheme.

The initial machine supplied is a 5.9m TBM (RME232SE) previous used on Novosibirsk metro and fitted with a new rock cutterhead. It will shortly start a 2.4km long drive.

The 4.3m diameter TBM (RMP167S) built last year for the contractor was earmarked for the Krolsky water drainage tunnel but is being relocated to Sochi. The machine will be used to bore a 2.8km long tunnel.

Following refurbishment, a 6.2m diameter double shield TBM is to be brought to Novorossiysk port this month for transport to Sochi. The machine will be used to bore a 4.2km long tunnel.

Lovat is also providing a 10m diameter double shield by the third quarter. It will be used to bore a 4.2 km long tunnel.

By the beginning of next year there will also be a 10.6m diameter (RMP419SE) machine manufactured for Sochi. It is expected that the TBM will start on a 2.8km long drive in the middle of 2010.

Seli recently noted that along with Lovat the firms were supplying equipment as part of a wider co-operation agreement in Russia they have with Bamtonnelstroy (T&T, April, p6).

# Clem7 bores completed

**T**he second of the pair of shields driving the Clem Jones ("Clem7") tunnels in Brisbane has holed through to complete major excavation on the road project.

Late last month the 12.34m diameter Herrenknecht TBM reached Woolloongabba after driving 4.3km with an intermediate breakthrough at Kangaroo Point after 2.5km.

The double shield gripper – S-375, or "Matilda" – was the first of the twin TBMs to be launched, at Bowen Hills in December 2007, by contractor LBB JV.

Geology was mainly tuff with some arenites, phyllite with quartz veins, and faulted rock, and the TBM had cover of 6m-30m. Below the river, the JV didn't encounter as much water as expected.

The first shield – S-376, or "Florence" – completed its drive in mid-April although it was

launched after Matilda (T&T, May, p6). The machines holed through at Kangaroo Point in December 2008 and January, respectively, leaving the last drive of 1.5km to be done.

LBB JV is a JV of Leighton Contractors, Boulderstone Hornibrook and Biffinger Berger. It is building the 6.8km long North-South Bypass twin tube toll link on a fixed time and cost design and construct (D&C) contract for concessionaire RiverCity Motorway.

The tunnels were renamed as Clem7 during construction of the North-South Bypass. Much of the additional excavation on the project has been by roadheader. The main tunnels are linked by 60 cross passages.

Tunnel design was by Biffinger, and geotechnical work was done by Golder Associates. Principal project design was by a JV of Maunsell and Parsons Brinckerhoff.

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# Barcelona switchover

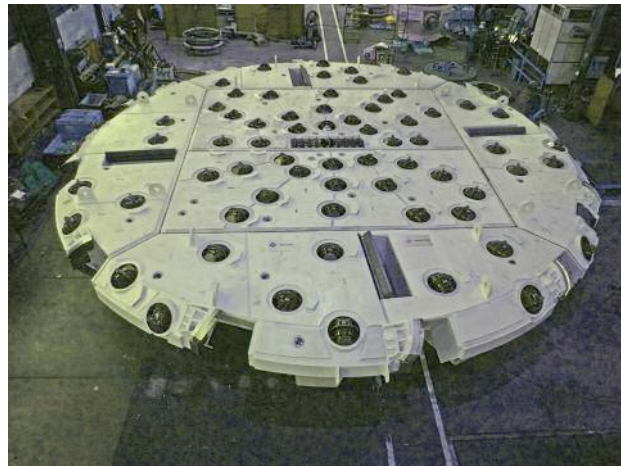
**F**urther excavation of the partly-built Line 9 of Barcelona metro will see switchover of TBM cutterheads to match alternating hard rock and softer ground.

The switchover system was developed after contractor UTE Linia 9's specified TBM – a 11.95m diameter NFM Technologies shield – met rock much harder than expected on the second section of its work on Line 9.

After the TBM had bored the first, 4.3km long section of 10.9m i.d. tunnel it was brought to the second, 8.5km long section between University Zone and Sagrera station.

However, soon the excessively hard rock was met.

In July 2008, after advancing 1.8km, the TBM was stopped as a new plan was developed. Instead of trying to continuously adapt the cutter tools to match the strata it was decided to order a hard rock cutterhead to change



**Above:** New hard rock cutterhead for Barcelona metro, Line 9 bore

with when required.

To reach the machine, a 22m diameter shaft was sunk to a depth of 44m deep and then a semi-circular pit was excavated a further 14m. At the base, an 18m long access gallery (18m high by 7.5m wide) provides access to

the face to changeover the NFM cutterheads.

The original dual-mode cutterhead is on standby for further soft ground work, and any future changeover is expected to be done either in the tunnel or at a station.

# Tube tussle in Calgary

**A** renewed bid is underway to have a tunnel built below the new runway in Calgary after the Airport Authority failed to include the structure to help mitigate road network changes.

A box tunnel costing US\$68M-US\$91M has been proposed by community and business lobby groups to help keep traditional access to the airport open. The owner plans to close the Barlow Trail route as a new runway is built.

The tunnel proponents argue that the route would be an economic lifeline for their area. However, they report that the Airport Authority's expansion plan is pushing ahead with the route closure, by 2011, without the tunnel.

The backers of the tunnel have limited time to get the plan changed to ensure the cut and cover works get underway before the runway is built.

The tunnel would pass below the runway and taxiways in a 180m long and two 60m long sections. While it would be sized to eventually take dual, three-lane roads plus a twin-track light rail to keep initial costs down it would not be fitted out fully at the outset.

Planners at the City of Calgary are to hold a public hearing on the project on 10 June.

While not opposing the expansion, the Community Association of NE Calgary and some Business Associations in the provincial capital are lobbying for a re-think.

averaging 10 rings per shift, and wear and tear increased but water ingress by then made it too difficult to change tools at the face. Tailseal brush degradation also meant ingress at times disrupted the build area. The TBM successfully holed through at Beddington in April.

# Completion at Croydon runs

**E**xcauation of the 9.8km long Croydon Cable Tunnel has been completed by Morgan Est using a Lovat mixed face EPBM that met wetter, more difficult geology in the latter stages.

The 3.6m diameter TBM was launched in April 2007 and holed through at Rowdown after 2305 rings later that year to complete

the first section (T&T, December 2007, p11).

Retuning to the first shaft, at Kent Gate Way, the shield was re-launched in January 2008 and by then it was envisaged, with the expectation of consistent geology, to finish that drive and then the fine bore before the fourth quarter last year.

Geology along the alignment was anticipated to comprise moderately weak to fractured chalk with flints for the 400kV power tunnel being built for National Grid.

The lining consists of 1.2m long rings (6 plate bolted trapezoidal, fitted EPDM single gasket) that are 3m i.d. with 180mm thick, steel fibre reinforced plates made by the contractor. Grout was inert, non-setting with limestone aggregate.

With the first drive in dry conditions and enabling advance rates averaging mid-20s rings per 10 hour shift, reaching up to low 30s, progress slowed in the later bores as increasing amounts of free flowing water was met. There were sub-vertical fissures and during wet caisson shaft sinking at Beddington the flows were approximately 500 l/s.

The second drive completed in June 2008, at Lloyd Park, after 2718 rings. The TBM was re-launched in July and progress rates reduced further as EPB mode continued to deal with water pressures ranging from 2.5 bar-3 bar.

Towards the end of the last, 3168 ring drive the rates were



**Above:** Final breakthrough at Croydon Cable Tunnel, London

# Gotthard TBM bores, fit out pushes ahead

**W**ith further breakthroughs approaching on the Gotthard Base Tunnel, almost 87% of the 57km long twin tubes have been excavated and trackwork and equipment installation started last month.

By early this month the excavation work was 86.8% complete, almost 2.1km having been driven to advance the remaining faces to take the total length of tunnel, galleries and passages built to 133km.

Breakthroughs are due shortly to complete the Erstfeld section and less than two years of TBM tunnelling remains until the final breakthrough, expected around the second quarter of 2011. The 7.7km long tubes are being built by twin 9.58m Herrenknecht TBMs.

Just over 400m of tunnel was left to drive by the east TBM on the Erstfeld section by the beginning of last month. The machine boring the west tunnel had advanced 5,148m, or 72%.

On the Faido section just over half of the east tunnel has been bored by the beginning of May, and the TBM stopped for

maintenance to late April. By the start of last month the west tunnel was half built.

The 9.43m diameter Herrenknecht Grippers had recently successfully passed through the anticipated difficult syncline geology of the Piora Basin stretch of the Faido section.

Following a year of planning on the trackwork and equipment contract, work is getting underway on the first, surface stretch of the line to begin 7.5 years of site work. The rail link through the Swiss Alps is due to open by late 2017 (*T&T*, December 2008, p10)

The contractor is Transtec Gotthard Consortium, which includes Atel Installationstechnik, Alcatel-Lucent Schweiz, TRSS Thales Rail Signalling Solutions, Alpine-Bau, and Balfour Beatty Rail.

The JV has Poyry supplying engineering services.

Almost 87% of the twin tubes at Gotthard Base Tunnel, in Switzerland, have been excavated



## Sweden picks Fosmark to bury waste

**S**weden is to excavate an underground storage complex at Fosmark, near Osthrammar, north east of Uppsala, after the site was chosen between the two favourable locations studied in detail over the last few years.

The Swedish Nuclear Fuel and Waste Management Co (SKB) said Fosmark had clear advantages with bedrock being dry with few fractures, and that the tunnel complex could be smaller than at the rival site of Laxemar, near Oskarshamn.

Both locations were picked following almost 20 years of analysis of geology across the country.

Detailed site investigation with bedrock drilling was undertaken over 2002-7.

By the third quarter of last year the analyses of data from both sites had not delivered a clear winner, both bedrocks exhibiting favourable conditions.

It was noted then, though, that at Fosmark the rock stresses did not increase as rapidly as previously assumed.

Of the two locations, the proposal for a waste vault complex at Fosmark would require slightly deeper excavation, at depths of approximately 450m-500m.

Early concepts had considered a possible depth of 400m but when it was found that rock stresses were not increasing so much with depth as expected then the advantage of going a bit deeper to further reduce fracture zones was studied.

The increase in depth brought Fosmark to about the same depth as proposed for Laxemar, based on preliminary site investigation data.

However, in identifying Fosmark as having a geological advantage the fewer fractures at the site will help SKB deal with key construction challenges: developing grouts and equipment to manage inflows; and, learning to durably seal fractures at depth.

These tasks were described by SKB in the September 2007 interim research report.

Research into the excavation method and challenges has been underway at the Hard Rock Laboratory on Aspo, near Oskarshamn.

While the choice has finally been made the next step for the

Swedish Nuclear Fuel and Waste Management Co (SKB) is to submit applications for permits to the Swedish Radiation Safety Authority and the Environmental Court.

Waste is to be placed in welded copper canisters that are embedded in bentonite clay inside dedicated deposit holes through the tunnel complex.

The submissions for permits are expected to be made by mid-2010, and SKB has previously said it hoped to have decisions by 2012-13.

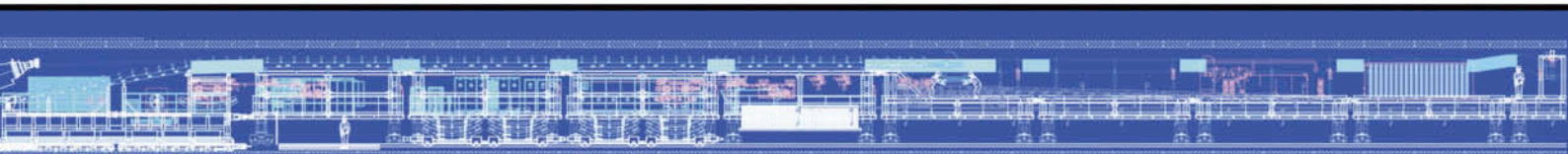
It had also said excavation and completion of the spent waste repository could take five years, to about 2018, and no further information has been made available following the election of the site (*T&T*, Aug 08, p8).



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# Detroit axes Upper Rouge tunnels

**D**etroit has stopped the Upper Rouge Combined Sewer Outfall scheme over concerns about the affordability of major capital spend in a weakening economic climate.

The City of Detroit's Water and Sewerage Dept (DWSD) confirmed to T&T that it has issued a termination order on the South contract (PC-764), which was awarded last year to a JV of Kenny and Obayashi. The job involved excavation of a 5.75km long sewer.

The North contract (PC-763), which was still in procurement, has been cancelled.

In total, the Upper Rouge CSO sewer tunnel was to be just over 11km long. The CSO is to be

excavated at a depth of 46m and will have a finished diameter of approximately 9.25m (T&T, October 2008, p12).

DWSD said that the termination letter for the South tunnel contract was issued on 29 May and was expected to take effect from 13 June. The move to axe the scheme takes effect immediately on the North contract.

The City authority has blamed the weakening economy for the move, which it said was made to avoid placing a higher tax burden on people at a bad time with unemployment rising.

No information was immediately available on the cost

# S'pore Downtown awards push

**S**KEC Singapore Branch and McConnell Dowell have won a contract to design and build sections of the underground Downtown Line Stage 2 in Singapore.

The South Korean contractor was awarded a US\$156M contract for tunnels between Beauty World and Hillview stations. Construction work on the civil package on contract C915 is set to start in the third quarter for completion by 2015.

McConnell Dowell has been awarded a US\$236M contract to design and build Beauty World station, near Jurong Kechil.

The Australian firm's package on contract C916 also includes designing and constructing the adjacent tunnels - two 1.1km long tubes of 5.8m i.d. plus two cross passages and 135m of cut and cover tunnels. All works have a deadline to finish of mid 2015.

Downtown Line will be 16.6km long upon completion and have 12 stations. It will link with three

other lines - North East, North South and Circle Line. The client is Singapore's Land Transport Authority (LTA).

LTA appointed The Engineers Collaborative as checker on C916. Supervising services are being provided by Beca Carter Hollings & Ferner (S.E. Asia).

Rival bidders for the main civil works on C915 were McConnell Dowell, Alpine Bau and Shanghai Tunnel Eng. On C916, the other tenders were submitted by Sembawang Engineers and Constructors and Samsung C&T.

Procurement is underway for the main civils works on contract C918 - the design and construction of Duchess station and adjacent tunnels. The submission deadline is late June.

Bids are now being assessed for contract C920 - design and build of Newton station and adjacent tunnels. Four bids were submitted, by: Ed Zublin; Penta-Ocean Construction; Samsung C&T; and, Shanghai Tunnel Eng.

# Stockholm rail job bagged by Bilfinger

Bilfinger Berger has been awarded a contract to build tunnels and an underground station as part of the Citybanan project in Stockholm.

The German contractor is to build a 1.9km long stretch of the rail project below the heart of the Swedish capital. The value of the contract is approximately US\$142M.

Two tunnels are to be built in the contract - the main, dual-track tube and also a smaller service bore which will run alongside. The pair of tunnels are to be excavated by drill and blast.

In addition, the contractor is to build a 700m long station below the existing subway station. All tunnelling works are to be completed by 2015 for the entire new rail line to be operational by 2017.

The 6km long link is being developed by Banverket, the Swedish Rail Authority, to overcome a bottleneck in capacity in the centre of the city. In addition to drill and blast excavation the project also calls for construction of an immersed tube tunnel.

consequences of cancelling the US\$316M contract with the Kenny/Obayashi JV. Construction work started in October 2008 with a planned duration of four and a half years.

Bids for the South tunnel contract were received a year ago. However, by the third quarter, when award had yet to be made and so the risk of losing contributory funding was right up to the wire, relations over the procurement progress became more strained between the State of Michigan and the City council.

The JV contractor was appointed in September 2008.

The procurement push on the North tunnel contract began shortly afterward with advertising notices, and it was then planned that tenders would be called for by late November. However, the procurement was delayed and by last month the contract had progressed no further.

DWSD added, it is negotiating with the state authorities to revise permitting requirement for the project facilities.

# Niagara cost jump

**T**he cost of the Niagara power project has jumped by almost two-thirds due to difficult tunnelling conditions and the new construction schedule has put back completion three and a half years, said Ontario Power Generation (OPG).

In announcing its first quarter results, the client said the renegotiated design-build tunnel contract with contractor Strabag has resulted in the target cost of the overall project jumping to an estimated US\$1.46bn from the original estimate of US\$900M.

The design-build contract for the tunnel was about two-thirds of the initial sum, on a fixed price basis (T&TNA, September 2008, p9).

The revised schedule for the project envisages completion

being delayed from the original plan of mid-2010 to the end of 2013. OPG added that the renegotiated contract was being finalised in Q2.

Strabag is driving the tunnel on a revised alignment in Queenston shale, a mudstone, for the Niagara hydro project. By the end of Q1, on 31 March, the TBM had bored 3794m, or 37% of the tunnel.

Difficult ground with early rockfalls and also rock with much sub-vertical fracturing has resulted in progress with the 14.4m diameter TBM - "Big Becky", a Robbins main beam - being slower than planned on the 10.4km tunnel. Excavation began in September 2006. A year ago, it had advanced 2km and discussions moved to a possible re-alignment.

# Crossrail starts work

Foundation work at Canary Wharf station plus contract award for preparations on the Isle of Dogs have joined the early utilities activities in central London to further gear up excavations on the Crossrail project, which last month saw the formal launch of construction and appointment of the permanent Programme Director. The British Prime Minister, Gordon Brown, and the Mayor of London, Boris Johnson, launched construction of the US\$25.3bn scheme when visiting piling work for the underground station at Canary Wharf, in east London.

The station will be one of the biggest on the east-west route through the capital and has a fixed budget of US\$797M, as agreed last year by Canary Wharf Group (CWG) with the Government and developer Crossrail Ltd. The funding deal will see CWG contribute US\$239M of the budget

but take the risk of additional costs, the Government stake being capped at US\$558M.

Last month CWG picked Laing O'Rourke as preferred bidder for the enabling and civil engineering works. The station box is to be finished in approximately three years. The contractor was among 17 firms recently awarded Enabling Works Framework Agreements to bid for various work.

Crossrail Ltd has appointed Andrew Mitchell as its Programme Director. He is currently with Network Rail as Senior Programme Director for the Thameslink Programme, and prior to that worked on its Southern Power Upgrade after joining in 2001. Mitchell worked previously in Hong Kong on the airport and West Rail, and other projects internationally.

Interim Programme Director, Graham Plant, will continue in the post until Mitchell joins later this

year. Plant joined the scheme in 2007 to help develop the delivery strategy and last year was appointed to the Board.

The scheme calls for a total of 41.5km of 6m i.d. in twin tube tunnels to be excavated by TBM, and seven shields are expected to be used. Main construction starts next year, tunnelling is to get underway in 2011 and rail services are due to begin in 2017.

Crossrail Ltd is a wholly-owned subsidiary of Transport for London though previously was a JV with the Department for Transport (DfT). With the Government contributing significant funds to the scheme, last month DfT appointed Jacobs Engineering UK with KPMG to be its Project Representative (*T&T*, May, p12).

Chief Executive of Crossrail Ltd is Rob Holden, and non-executive chairman from the start of this month is Terry Morgan. They were

formerly chief executives of London and Continental Railways (LCR) and Tube Lines, respectively. They take forward the leadership of the scheme from Doug Oakervee, who secured Royal Assent and brought into the procurement phase and early construction work.

Crossrail recently appointed Bechtel as the Project Delivery Partner, and the developer's Programme Partner is Transcend, a JV of Aecom, CH2M Hill and Nichols Group.

## Euroform bags metro job

Euroform is to supply the segment moulds to Turkish contractor Dogus Insaat ve Ticaret for construction of part of Sofia's second metro line.

The Italy-based subsidiary of Herrenknecht plans by August to provide Dogus two sets of segment moulds with a pneumatic vibration system plus associated equipment.

Dogus is in a JV with local firm Metrotrace that has been contracted to construct the new line, which includes a 3.8km long tunnel and four stations.

The Ministry of Transport awarded the US\$235M contract in the third quarter of 2008. Work began on the project in the fourth quarter, with a 45 month construction period. Dogus will use a 9.4m diameter Herrenknecht EPBM to drive the tunnel lined by 8.43m i.d. segmental concrete rings (6+1), 1.5m long and 320mm thick.

The 6.4km long metro extension is part of the country's strategic infrastructure development plan – the Operational Programme on Transport 2007-2013.

The job has been split with Metrotrace to build a 2.6km long section with three stations for US\$101M. EU funding is being given to the scheme – approximately US\$258M which is equivalent to three-quarters of the combined contract costs.

# Silberberg tunnel award

The contract to build the Silberberg rail tunnel in Germany has been awarded to a JV of Bilfinger Berger, Max Bogl Construction, Wayss & Freytag (W&F) and Bickhardt Bau.

Deutsche Bahn awarded a contract worth approximately US\$310M to the JV to build the 7.4km tunnel and the parallel, smaller rescue tube plus a series of shafts. Main excavation is planned to commence in about a year and the project is to be completed by 2013.

Cover to the drill and blast excavation is up to 120m. There will be eight emergency cross passages at a maximum of 1km intervals to connect to the rescue

tunnel. Geology along the alignment includes greywacke and volcanic strata, and the faces will be advanced from two intermediate adits.

In addition, the JV is also to build the Brandkopf and Lohmeberg tunnels on the section of the network. They have a combined length of 2.5km.

Silberberg tunnel will be the second longest tube on the 107km long new section of high-speed track being built on the Ebersfeld-Erfurt section of the rail network. Most tunnels are being built in that section, in the mountains in Thuringia. Silberberg is on the other side from the 1.3km long Baumeite

tunnel, the contract for which was awarded to Beton und Monierbau (*T&T*, May, p13).

Key projects in the lower mountains further north, between Erfurt and Leipzig/Halle, include the Finne and Osterberg twin tube tunnels, which are being driven by TBM and drill and blast, respectively. The former is being built by a W&F-led JV with a pair of Herrenknecht Mixshields, while the latter is being done by a JV of Porr, Interegger, Ostu/Stettin and Jeager Bau.

The twin-track tunnels are to be commissioned over 2015-17, and will cut the travel time from southern Germany to Berlin.

# Funds cleared for Seattle bore

The state of Washington's share of funds for the large single bore road tunnel to be excavated at Seattle's waterfront have been legally cleared.

Last month the state Governor, Christine Gregoire, signed the bill to commit US\$2.4bn to the waterfront transport improvement project, which will see the seismically-damaged Alaskan Way viaduct

replaced by a 3.2km long bored tunnel excavated by TBM.

A TBM of about 16.45m diameter is envisaged to drive through glacial till and would be among the largest planned. The biggest so far were 15.43m diameter shields on the Pudong-Changxing crossing, below the Yangtze river, at Shanghai.

The project will open up the

waterfront area, includes a seawall replacement, and is estimated to cost US\$2.24bn. Funding will come from the city and county authorities as well as the Port of Seattle.

Construction is to start in 2011 with the tunnel open to traffic in 2015. The state bill also approved a study to raise US\$400M from tolls. Findings will be reported in January 2010.



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# An Icelandic struggle

Ermin Stehlik, project director for Metrostav a.s. Prague and Björn Hardarson, chief supervision engineer for Geotek describe how chemical grouting played a vital role on Iceland's Héðinsfjarðargöng project



Left: Fig 1 - Location map

uninhabited, inaccessible valley and fjord between them.

The shortest trip between the towns by road is 60km but bad weather frequently closes even this route leaving motorists with a 240km journey.

Vegagerdin, the Icelandic road authority, called for a direct link between the two towns to cut travelling time and create a better link between Siglufjörður and Iceland's fourth largest city, Akureyri.

To manage this, contractors would have to tunnel through the two mountains from the only accessible sides on the far east and far west of the project and once through to the Héðinsfjardar valley they would bridge the Héðinsfjardur River.

In 2006 the 14.3km long Héðinsfjarðargöng road project was awarded to a JV of Czech construction firm Metrostav a.s. Prague, which is responsible for the two tunnels, and Icelandic firm Háfell, which is responsible for the bridge and road works, open cuts and E&M installation. By September the same year works had begun on site.

## A breeze at Siglufjörður

Excavation of the 3.6km long Siglufjörður tunnel was launched in September 2006. Drill and blast work progressed with few difficulties and over the next 20 months, workers averaged a tunnelling speed of 200m per month with the record month progressing 302m.

Water inflows were easily managed as the team tunnelled through the relatively good geology. The water that did flow into the tunnel was mostly between 10 and 20°C, in sharp contrast to the much colder water in the Ólafsfjörður Tunnel.

At the start of the excavation the tunnel passed a geothermal area, which supplies the hot water for the Siglufjörður town, but did not cause any disruption to the water flow.

The most challenging section was the 2km long downhill drive towards

Contractors battling to construct a crucial road link between remote towns in the north of Iceland were faced with the harsh reality of the island's exposed landscape. Torrents of water often barely above freezing poured into two tunnels being drill and blasted through snow topped mountains on the Tröllaskagi peninsula.

Site workers had to grapple with extensive pre-grouting solutions needed to prevent the tunnels being overcome by water. In spite of the extreme conditions

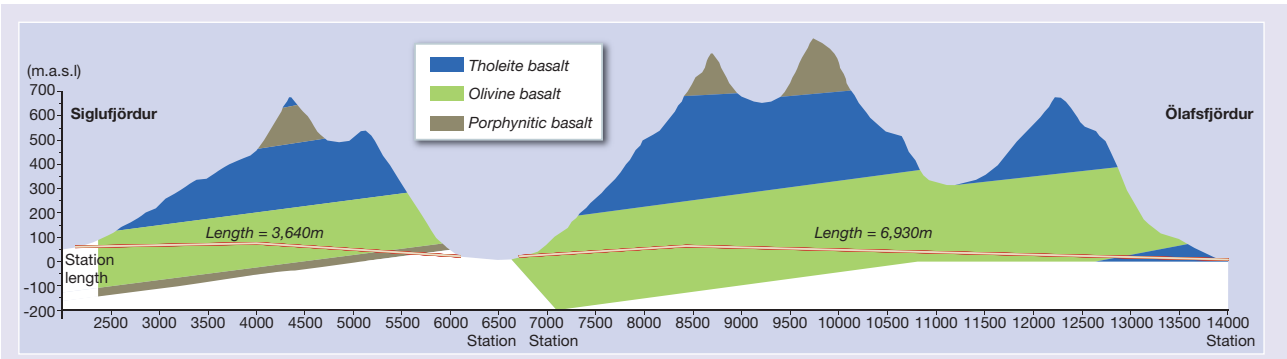
the crews faced, breakthrough was achieved on the 3.65km Siglufjörður Tunnel in March 2008 and on the 6.9km Ólafsfjörður Tunnel in April 2009, just six months behind schedule.

## Distant neighbours

North Iceland boasts a beautiful, rugged landscape with mountain ridge and fjord alternating along the coast. The towns of Siglufjörður and Ólafsfjörður stand just 14km from each other on the Tröllaskagi peninsula but are cut off from one another by two mountains with an



Left: Water at the face in the Siglufjörður tunnel



## Ground conditions along the two tunnel alignments

The Tröllaskagi peninsula is made up of basalt formations with sedimentary interbeds. This volcanic complex is of an early tertiary age, when short periodical lava eruptions alternated with short periods of volcano clastics sedimentation.

The rocks are in sub-horizontal layers and disturbed by dominating

NS tectonics. This layered basalt lava succession with thin scoria and sedimentary interbeds results in mixed face conditions for a large part of the tunnel route. The overburden height varies between 1-5m at the portal areas to 800m under the highest mountain. Some rock spalling occurred where the rock overburden was more than 500m.

Hédinsfjörður where water inflow was a greater problem. A system of provisional sumps with automatic pumps was installed to remove the water from the face.

Two grouting solutions were used to stem water inflows. A total of 460 tons of cement grout was used for pre-grouting on most inflows but in rare cases, when the water remained close to the face despite the regular probe hole application, PU pre-grouting had to be used. The 2km stretch needed 40 tons of PU in total.

The ease of tunnelling through Siglufjörður would give no warning of the mammoth challenge awaiting tunnellers in Ólafsfjörður.

### Trouble at Ólafsfjörður

The Contractor decided it was best to tackle the longer 6.9km Ólafsfjörður tunnel from each side. Work from the Ólafsfjörður site, on the western end of the route was launched in November 2006. The first kilometre progressed with ease as water ingress remained insignificant. There were initial fears that the geothermal zone close to the tunnel alignment at the start of the excavation would lose its natural pressure as water flowed into the tunnel. The loss of pressure would mean the town above would be stripped of its hot water feed. However, these fears were not realised.

It wasn't until the project was a kilometre in that the crews started to experience major water ingress problems. The next 3km required extensive pre-grouting to reduce water inflows from probe holes to within specified limits. It

took nearly 600 tons of chemical grout to manage the stretch.

Although progress through this section in the best month surpassed that on the Siglufjörður tunnel with some 330m being excavated, water ingress and grouting slowed the average rate to just 180m per month.

The water temperature for these 3km ranged between 2° and 4°C until the last few hundred meters before meeting the counter drive, when the temperatures rose to 9°C.

The uphill drive from the eastern end of the Ólafsfjörður Tunnel, from the Hédinsfjörður site, started in early May 2008, after the Siglufjörður Tunnel breakthrough. But in summer 2007 preparatory works in Hédinsfjörður, consisting in preparation of portal sites, were done. This meant transporting equipment over the sea, as there is no access to the valley. The 1.9km long uphill section was completed in January 2009, giving average progress of 210m per month. Geological and hydrological conditions were relatively good, without the need for pre-grouting.

### Digging in

Tunnel excavation was a systematic and repetitive process of drilling usually two 51mm diameter probe holes 25m to 32m into the face with a 6m overlap. The holes detected the presence of ground water and verified the geological conditions.

Based on volume of the water detected, its pressure and temperature, the contractor and supervisor would jointly decide on whether or not to proceed without grouting.

The same Axera Tamrock T11-315TCAD drill rig used for the probe holes was then used for the 48mm diameter blast holes. In both tunnels the rounds were usually drilled to the full length of 5.27m, resulting in a pull length of

**Below top:** Water ingress from the probe holes in Ólafsfjörður Tunnel

**Below bottom:** The portal for the uphill eastern drive of the Ólafsfjörður Tunnel from the Hédinsfjörður side



## Mucking out

The tunnel construction equipment is without its own separate access drive, so to transport it to the tunnel face a dumper had to be used. At the face equipment is braced by shovel, followed by the required positioning. Initially, working with the loader brought a few problems, mainly with operator training and also with a rather high breakdown rate. However, the loader performance is, in comparison to the wheel loaders, unmatched. Moreover, it was used for excavating the invert and also for the first scaling operation. As a back-up, Volvo 180E wheel loaders were available on the site.

The actual mucking out was carried out using the Komatsu dumpers, mostly with a 35 ton capacity. Their number in one tunnel was a maximum of six. The muck was dumped into temporary and permanent dumping sites located close to the tunnel portals. Suitable material has been further treated in a crusher into different sizes and



The Brooyt D600W with the 3.4m³ shovel in action

used for rock fills for the future road works.

The ventilation system was designed as separate blowing ventilation set up. The tunnel ventilation in the Ólafsfjörður Tunnel was provided by 1 x 1800mm and 1 x 2100mm diameter non-reinforced ducts and two axial Cogemacoustic, type T2 180 ventilators. The ventilators have frequency converters allowing a smooth revolution regulation according to the length of excavated tunnel.

between 4.7m and 5m. However, in difficult geological conditions the round lengths were shortened to 3m.

The drill rigs were fitted with a semi-automatic system called TCAD. TCAD is a program used to measure the position and the direction of a drilling bit. Using a laser beam for guidance the drilling pattern and boom positions were correlated with the tunnel alignment coordinates. The operator then hand positioned the boom to accurately drill the pattern.

Blast holes were usually packed with Titan 7000 blast emulsion – now renamed

**Below:** A blast round is detonated



Civec – supplied by Orica Mining Services, formerly Dyno Nobel.

A Mini Site Sensitized Emulsion (SSE) pumping unit completed the charging after being transported to the tunnel face by a small truck. The Mini SSE system meant the emulsion could be pumped into two holes simultaneously. It also allowed the operator to change the charge according to the blast hole type.

The emulsion proved a perfect choice for blasting in hard and brittle rock. In softer rocks, with plastic properties the use of emulsion can be more problematic. When the team came across more porous patches the crew resorted to classic explosives. In some cases the combination of both types of explosives was used.

The 25g Nobel Prime detonator amplifiers were chosen as boosters. These were inserted into the blast holes together with non-electric detonators NONEL LP during the emulsion pumping.

Two Tamrock drilling rigs were used on the Project, one per tunnel, and drilled a total of 40km of holes for pre-grouting and 32km of probe holes - both with 51mm diameter; the total length of the 48mm blasting holes reached nearly 1,500km.

The drill rig performance was very reliable and proved to be a good choice

for the conditions - although the contractor often wished that the rigs had submarine like features during the heavy water inflows!

## Coping with water

Water was the greatest hurdle engineers had to overcome. The 5km long uphill excavation of the Ólafsfjörður Tunnel frequently battled against water ingress, on occasions reaching pressures as great as 32 bar.

Frequent probe holes drilled into the tunnel face helped engineers expose the trouble that lay ahead. When large water inflows of high pressure went beyond set limits pre-grouting procedure was initiated.

An inflow of 600l/min from the two holes was usually a signal to start the pre-grouting – although the supervisor adjusted this limit on site as he monitored the actual conditions.

The low water temperature experienced in the Ólafsfjörður Tunnel ruled out the classical cement grouting after some unsuccessful attempts. A chemical grout was chosen instead, Minova CarboTech supplied pumps and two component injection resins CarboPur WF and WFA together with additives CarboAdd Thix 2 and CarboAdd Fast and fast acting, strongly expanding Geo Foam.

GX-45 II piston pumps were used to inject the chemical components and where larger volumes were required an SK-90 gear-type pump was used. A CT-PM electric pump was ready on site for the most extreme conditions but fortunately was never used.

The grout holes were sealed using BVS-40K hydro-pneumatic packers attached to the injection pipe. In most instances the high water pressures meant they had to be used in pairs. Minova supplied all the equipment.

The pre-grouting procedure was detailed in the original tender but the extreme situation faced on site meant the plan had to be modified. The Contractor called on the help of T. Najder of Najder Engineering, Sweden, who is a pre-grouting works specialist.

The first step was to drill the grouting holes, in many cases creating the complete grouting umbrella, consisting of approximately 20 holes, 12m to 20m long.

A pair of pumps would then drive grout into these holes and the quality checked by new probe holes - which were subsequently grouted and the procedure was repeated if required. In some complicated cases as many as 40 holes were drilled from one face.

The sometimes extreme pressure of the water made the installation of packers difficult. The contractor manufactured aids allowing the installation of packers into the hole e.g. with 60l/sec under 30 bars pressure inflow by boom of Tamrock drill rig.

Working conditions during the 12hr shifts, in the cold, wet environment were extremely tough. But even in the harsh conditions site workers were able to rapidly get a handle on the pre-grouting works helping the project keep a steady pace.

### Finishing touches

As breakthrough on the Ólafsfjörður Tunnel occurred in April 2009, contractors are now working to prepare the tunnels for road traffic. Once completed the tunnels will carry two lanes. They will have a tunnel clearance profile, similar to the Norwegian profile, of T 8.5 and a cross section of 53m<sup>2</sup>. There are a total of 19 emergency bays spaced at approximately 500m intervals and three of them with large turning bays. The cross section at emergency bays is 75m<sup>2</sup>.

Part of the permanent lining – bolts and shotcrete required for safe construction - was installed during the tunnel excavation. Before the shotcrete could be applied excavation had to be carefully cleaned to remove the dust and small rocks.

The shotcrete was then sprayed on using a Meyco Potenza pump and robot arm between 50mm and 80mm thick. The wet shotcrete method used C 35/40 concrete and, where geological conditions required it, SIKA fibre CHO 65/35 NB steel fibres were applied to the shotcrete mix.

Once the tunnel is completely excavated further shotcrete and bolts are applied where needed.

For permanent bolting, contractors are now fitting regular re-bar bolts and CT bolts 3, 4 and 5m long with Combi Coat, the same as used during the tunnel excavation. Galvanized coating and epoxy resin protects the surface.

In areas with water leakage the tunnel will be fitted with a waterproofing and



Above: Breakthrough of the Siglufjörður tunnel and the Northern Lights

frost protection system consisting of PE foam sheets anchored to the tunnel lining and protected by shotcrete. The electrical installations and equipment for lightning, safety and ventilation can then be installed.

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# Blasting through a tight spot

Contractors are sucking in their stomachs as they squeeze conventional drill and blast machinery into a narrow wastewater tunnel near Gothenburg, Sweden. Site workers are having to overcome major logistical challenges in manoeuvring equipment for the 8km long Spillvattentunnel.

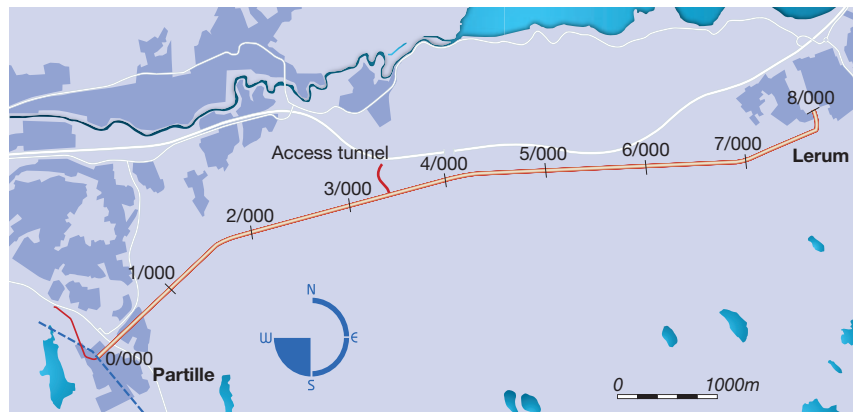
The 12m<sup>2</sup> cross section of the tunnel and its long length has made finding the right equipment a struggle. A lack of machinery that can deliver the speed the project needs in the tight space available has frequently led contractors to compromise on their choice.

Despite added hindrances from Sweden's strict environmental regulations the project, which launched in March 2007, has broken through the halfway mark having tunnelled some 4.65km and is scheduled for completion by the end of 2010.

## The Project

Some 130km of wastewater tunnels have been in use in Gothenburg since the early seventies. The tunnels carry wastewater from the 630,000 inhabitants of the city and the surrounding communities to the Ryaverket treatment plant. Coupled with

Norbert Fügenschuh of Beton- und Monierbau, Sweden, and Mats Strandberg of Gryaab AB Gothenburg describe the challenges of drill and blast tunnelling in a very confined space



the waste from local industry the plant deals with the equivalent wastewater of 826,000 people, making it the second largest treatment works in Sweden.

The Spillvattentunnel will run from Lerum, which is situated on Sweden's west coast some 20km east of Gothenburg, to Partille, which is in the Greater Gothenburg area.

## Drill and blast

Geological surveys along the alignment anticipated mainly granites and gneiss in good to very good quality throughout the tunnel drive. Single disturbance zones with more fractured rock were said to be possible.

During the 3 month tender process the client, Gryaab left the construction method open to two alternative construction methods, accepting bids using a 3m diameter TBM, driven from the Partille side, or others using drill and blast. Austrian contractor Beton- und Monierbau (BeMo) won the \$22.2M (2006/2007) contract with a drill and blast option.

In the tender Gryaab detailed that the finished tunnel should have a functional cross section of just 7m<sup>2</sup>. The competing contractors were allowed to build the tunnel with a cross section of up to 20m<sup>2</sup> for operational reasons but would only be reimbursed for pertinent support and grouting measures for a cross section of up to 12m<sup>2</sup>.

It was the contractor's task to develop a cross section that best fitted the needs and to prepare the quote based on this assumption.



Above: The portal for the access tunnel



**Above:** The junction with the access tunnel

In practice the cross section was developed around the largest items of plant, the drill rigs, plus the 850mm diameter ventilation duct suspended in the tunnel roof.

The result was a horseshoe shaped tunnel 2.8m wide and 4m high. This equals a cross section of a little less than 12m<sup>2</sup>. Side niches at approximately 500m intervals were needed for intermediate mucking and loading to rail carts.

#### Gaining access

The tunnel is being constructed in two drives from an approximate central point between Lerum and Partille at the small village of Jonsered on the E20 motorway from Gothenburg to Stockholm.

From Jonsered a 320m long access tunnel with a 14% fall was driven to reach the actual tunnel alignment approximately 50m below ground level. Here a 286m long, 8m wide cavern was built as a launching site for the two drives stretching 3.5km to the west and 4.5km to the east.

The cavern also serves as a railway station, with twin parallel 900mm tracks, and as a sorting area for spoil. A 50m long workshop tunnel also runs off the cavern to provide additional set-up and maintenance space.

Using computerized Atlas Copco M2C rigs for the blasting and grouting holes, BeMo is achieving regular pull lengths in both tunnels of 3.85m from 4m long drill holes.

The explosive Site Sensitized Emulsion (SSE) is pumped into the blast holes and is initiated by non-electric detonators (NONEL). The Mini-SSE pumping system is being used for charging which gives the contractors the added benefit of string-charging the blasting holes sitting in the tunnel profile and the next row of holes close to it.

The regular drill and blast method is complicated by the Swedish standard for "careful blasting" (skonsam sprängning) which calls for a limit on the explosives in the tunnel profile. The limit is to ensure the

geological disturbance after blasting has a maximum radius of 300mm. In the tunnel invert this radius is increased to 700mm.

These restrictions mean the amount of SSE explosive in the profile holes has to be limited to 350g/m, which is done by using a special retraction unit on the man basket of the drill rig. After pushing the charging hose into the blast hole the hose is pulled out at a specified speed while filling the hole. The system allows for 2 to 5 different types of string charged holes depending on the type of Mini SSE used.

After the blast, scoop trams haul the muck back a maximum 500m to the mucking niches where regular wheel loaders load the rock into railbound tipping trolleys.

Diesel locomotives weighing some 28tons haul the full trolleys to the tipping pits in the access cavern. It takes a train with 8-9 wagons to remove the material from a single 4m advance.

In the cavern the material is crushed down to grain with a maximum diameter of 250mm and transferred to a conveyor belt that transports the spoil 500m to the tipping cone at the surface.

The predominantly good rock conditions mean the permanent support measures will be installed at a very late stage of the project, probably after the tunnel drive has been completed. To keep the working area



Squeezing into a very tight spot



safe, contractors install initial support measures where the tunnel drive enters geologically disturbed zones.

**Above:**  
Mucking onto the spoil train

### Water measure

Environmental restrictions forbid tunnelling projects in Sweden from temporarily lowering the ground water table – not even during construction. Every single tunnel project in Sweden has among others its own requirements regarding:

- Groundwater leakage allowed (in this case 9,0 l/s for the whole tunnel system which equals approximately 6,5 l / 100m x min)
- The method of grouting (in this case cementitious grouting using grouting cement with a  $d_{95} < 40\mu\text{m}$ )
- The mixes prepared or developed (here the grouting is done using a mix with water/cement ratios of 1,0, followed by 0,8 and 0,5). The grout usually consists of grouting cement, water and a stabilizer with a certain percentage of the cement weight
- The properties of the different grout mixes (regarding filter stability, shear strength development, rheological properties, ...)
- The grouting equipment to be used
- The documentation of different parameters of the grouting procedure
- Maximum pressure allowed
- Maximum quantities allowed
- Criteria for commencement and termination of grouting
- The tests to be performed to ensure there is a consistently high quality of grouting mixture

The allowed rate of leakage into the tunnel is project-specifically defined by the environmental authorities and has to be guaranteed not only during the final operational stage but also during the temporary construction stage of the tunnel. If pre-grouting from the tunnel face does not prove to be successful post-grouting steps have to be taken.

BeMo therefore had to employ pre-grouting measures to seal fractures and fissures in the hard rock and minimise ground water flow into the tunnel.

Grouting at the face (pregrout) is done systematically in each case after 4 blasts (max distance between 2 grouting umbrellas

**Right:**  
The mucking belt delivers spoil



= 15.4m). A grouting umbrella consists of between 5 and 25 holes with a single length of 21m, drilled in a special pattern around the perimeter. The permitted deviation is 4%.

The actual grouting is done using Atlas Copco Unigrout pumps on wheeled platforms. The grouting pressure requires attention and is contractually defined as 2.5MPa plus the pressure of the groundwater at each location. In practice this results in grouting pressures between 2.7 and 3.5MPa (27 to 35 bar) depending on the local overburden.

Special attention is required for example, in sections where the tunnel passes residential areas with drilled fresh water or energy wells and below streams. At one point close to the end of the tunnel at Lerum the tunnel passes under an area where the rock overburden is just 5 – 10m.

### Permanent support

The permanent support system varies along the length of the tunnel according to rock class. Four different rock support classes, BFK 1 to 4, were defined in the contract.

Steel fibre reinforced or unreinforced shotcrete will be applied on the tunnel roof in thicknesses between 40 and 80mm. It will also be applied on the tunnel walls where the geologist considers it necessary. Bolting will complete the permanent support system.

In areas of good rock quality (BFK 1 and 2) the geologist will mark the position of each single bolt on the tunnel profile. These selective bolts consist of simple steel rods 25mm in diameter and normally 3m long and are installed in mortar filled drill holes directly into the rock. These bolts do not require an end plate.

The shotcrete shell is sprayed after installation of the bolts to cover them.

It is essential that the rock surface of the tunnel is effectively cleaned prior to the shotcrete installation as this support

system mainly relies on adhesion between the shotcrete and the rock.

Areas of poorer rock quality (BFK 3 and 4) will use systematic bolting. Bolts of the same dimension and same installation method as the selective bolts are installed with uniform spacing, predetermined in the contract and finished with anchor plates and nuts on top of the shotcrete shell.

The systematic bolts support system depends in this case mainly on the bolts. The adhesion between the shotcrete and rock is something to be considered but nevertheless rather secondary. A 30mm layer of unreinforced shotcrete is sprayed over bolt plates after a final visual inspection.

### End game

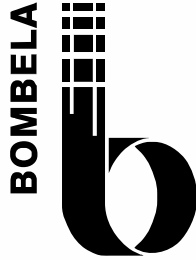
Each end of the tunnel poses its own challenges to the contractors. Both ends pass directly under or close to residential homes so that vibration and noise limitation problems will also have to be taken into consideration.

The tunnel stretch towards Lerum ends at a portal some 100m from a residential housing area. A short 30 - 50m long tunnel drive has to be prepared from the outside prior to the breakthrough in early summer of 2010.

The stretch towards Partille ends in an existing wastewater tunnel. Prior to the breakthrough, which is expected in autumn 2009, the area will need to have concrete works constructed for a wastewater measuring area. These concrete works and permanent support of the new tunnel will then be completed after the breakthrough.

After installation of the permanent support system a V-shaped concrete invert will be installed as the final flowing channel for the sewage water. The challenge during this phase will be the very slight incline of the channel at only 1:1000. Preparation for this phase of works is underway.

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## GAUTRAIN SITE DEMOBILIZATION



Bombela Civil Joints Venture consortium, that consists out of Bouygues Civil Works, Murray & Roberts and SPG is currently busy with site demobilization and the following equipment / plant is available:

- COGEMACOUSTIC Tunnel ventilation fan: 30 to 250 kW
- Shotcrete Robot PUTZMEISTER model: PM407
- PM500
- PAUS Dumper ITC 10000 20t payload interchangeable with Concrete mixer CIFA
- Basket NORMET 9915 BA
- LHD GHH Model 6.3
- Batching Plant COUVROT and ARCEN: capacity from 40 to 60 m<sup>3</sup>/h
- Rolling Stock 900 MM
- FERMEL Utility vehicle
- BOART LONGYEAR Charging Unit
- Grout Pumps CLIVIO
- Agitator Hopper SECATOL: 7m<sup>3</sup> - 10 m<sup>3</sup>
- Gantry Crane: 30 - 40t
- Side tipping bucket GERSTADT. Capacity (3m<sup>3</sup> - 4m<sup>3</sup>)



For more information contact:

[christophe.ollivier@bombelacjv.com](mailto:christophe.ollivier@bombelacjv.com)

Telephone: 0027 (0)11 997 8141

Mobile: 0027 (0) 83 632 9116

Address: 22 Milky Way Avenue

Linbro Business Park

Johannesburg

P.O. Box 1177

South Africa



# Horses for courses

A large number of tunnel boring machine (TBM) manufacturers entered the lucrative market of tunnelling during a period when the world's economic situation was very healthy. However, when the economic climate changed and fewer tunnelling projects were on offer, many of these manufacturers ceased producing TBMs, or that section of their business was acquired by a more competitive, successful rival.

In addition, more and more contractors were re-using old TBMs to save costs. Consequently, manufacturers began offering refurbished second-hand machines as well as new TBMs. This downturn also began to affect companies producing drilling machines.

## All-hydraulic percussive drills

Early models of the all-hydraulic percussive drill were basically similar in concept to the original compressed-air drill. That is, hydraulic fluid (instead of air) was fed first into the front and then into the rear chamber of the cylinder. This caused a piston (its diameter and length during that early period, basically the same as those used in pneumatic drills) to reciprocate back and forth so that it impacted against a tool, which in turn, struck the rock or other material being attacked. Rotary power for the bit was provided by a hydraulic motor via a series of gears etc.

The number per minute, or frequency of blows delivered by the piston and the rotation of the drill bit was regulated by the entry and discharge of the hydraulic fluid through the respective ports. The exhausting of the fluid from the front and back chambers was either through a 'kicker port valve' (i.e. a port which is opened or closed by the movement of the piston in the cylinder) which closed by seating on a flat surface, or perhaps by a sliding or rotating disc, depending upon the preference of the manufacturer and/or designer of the unit concerned.

However, four basic methods are now used to regulate the flow of fluid, which reciprocates the piston in hydraulic drills. These are:

- a) a valve piston (e.g. Gardner-Denver HPR)
- b) the reciprocating movement of the piston hammer itself (e.g. Sullivan JH-2)
- c) a reciprocating distributor ring or slide

Barbara Stack Writer and Editor of The Encyclopedia of Tunnelling, Mining and Drilling Equipment reviews the recent history of the much unsung hero of drill and blast - the drilling machine

- (e.g. Montabert HC80)
- d) a rotating cylindrical distributor ring (e.g. SIG HBM 100)

In air drills, shocks or high kinetic energy waves are automatically absorbed by compression of the air in the front chamber. However, when hydraulic oil was used this was not possible as liquids do not compress – thus equipment was subjected to unacceptable stress and shocks and the flexibility of air was missed. To re-introduce this advantage of gas, manufacturers decided to seek a remedy, which was provided by the installation of an accumulator.

The accumulator in the rear chamber was designed to impart extra energy to the piston on the forward impacting stroke. It consisted basically of a nitrogen-filled compartment or chamber, which was separated from a compartment containing hydraulic fluid by a flexible diaphragm. So far as the front accumulator was concerned, this was put there to cushion the drill against any high peak pressures which could be caused by an erratic action of the piston when it is thrown forward.

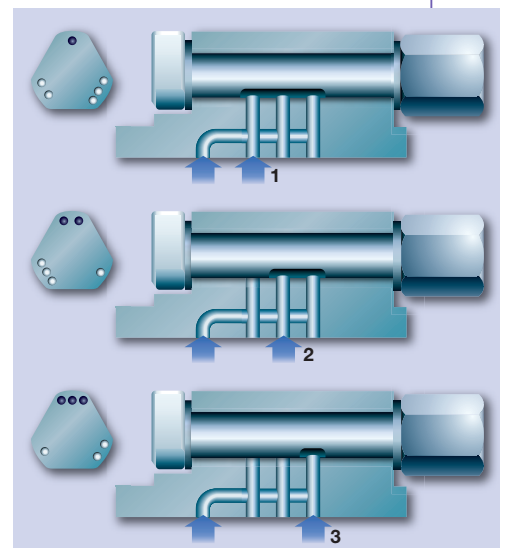
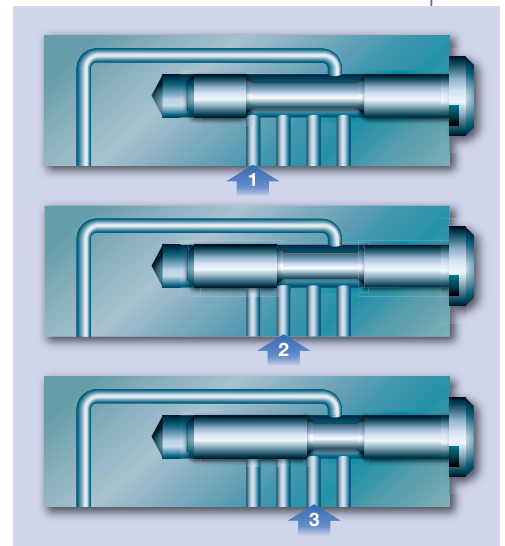
Similarly, as design engineers came to grips with the difference between air and liquid as the driver, the piston was gradually reduced in diameter to better suit the new power source.

Apart from the reciprocal motion, it is also necessary for the drill bit of a percussive drill to be 'indexed' or rotated in the hole with each stroke. This rotary movement assists in clearing away cuttings and enables the bit to attack a new section of the hole bottom.

At about the same time that hydraulic percussive drills were evolving, there was

also an up-surge in the development of the purely hydraulic rotary drill, which is used in soft and broken ground formations.

Despite the vast changes effected by the introduction of hydraulics (i.e. slimmer pistons, etc) there still remained only two fundamental methods by which a drill bit drilled rock – by scraping (shearing) and by indentation (crushing).



Right top: Fig 1 – Drawing depicting Atlas Copco Regulator Plug System, using three different plugs with varying waist lengths. (Courtesy Atlas Copco MCT AB);

Right bottom: Fig 2 – Drawing depicting new improved Regulator Plug System. (Courtesy Atlas Copco MCT AB)



The Atlas Copco COP 1838 drill

In rotary drilling the bit 'scrapes' against the rock and, provided enough 'thrust' is applied at the same time, a section of the rock 'chips' or breaks off. In percussive drilling on the other hand, a blow is delivered to the rock, which indents the surface creating a 'notch', if a v-shaped bit is used, or punctuated dents if a button type bit is used. The effect of the intrusion is to heave the adjoining surface, causing chipping.

In essence, therefore, the rotary drill can be said to break rock by 'fast chipping' the percussive drill by 'indentation and chipping' and the rotary/percussive drill by 'indentation and fast chipping'.

In a mixed face, a trade off occurs between the rotary and rotary-percussive modes of rock drill in terms of fine tuning for particular conditions encountered or, alternatively, to achieve the best average performance.

Moreover such fine-tuning can only be achieved within the range of capabilities of the drill itself.

The importance of selecting the correct drill for specific ground conditions was made abundantly clear to the author of this article when she was researching material for Volume 3 of the Encyclopaedia of Tunnelling, Mining and Drilling Equipment. During a brief visit to a drilling site she was surprised to discover no less than five different drilling machines lying about idle. Apparently, the terrain through which the crews were drilling was so diverse, consisting of layers of both hard and soft rock mixed with broken vuggy sections that neither the powerful hydraulic percussive units nor the rotary hydraulic machines could cope alone with these conditions.

Aware of this problem, some manufacturers began producing heavy hydraulic percussive drills which could operate in more than one mode. That is, they were able to cope with softer or broken ground conditions, which would normally call for drilling in the rotary mode, by switching the drill to 'high frequency' or 'vibro' drilling\*.

Atlas Copco's hydraulic percussive drills, which followed the valve piston design concept, were therefore capable of variable stroke. Originally this was effected by

means of a regulator plug which allowed the operator to vary the stroke length of the piston and thus the impact rate and impact force. In earlier models of the COP 1038, this was achieved by the replacement of the regulator plug with one of appropriate waist length for the desired performance, combined with a correct adjustment of oil pressure (figure 1 & 2).

Three plugs with different waist lengths were provided. The plug with the longest waist allowed for the operation of all of the regulating ducts leading to the valve piston.

Therefore when the impact piston reached No. 1 duct the valve piston received an impulse via that duct, which restricted the hammer piston to a short stroke.

When the regulator plug with the medium waist section was selected, the piston operated in the normal or standard mode. The regulator plug with the shortest waist section forced the piston hammer to move further before the valve piston received an impulse. This produced the longest piston hammer stroke.

In later models of the COP 1038 the three regulator plugs were replaced with a single plug which could be turned one-third of a revolution at a time to present three different facets and so control the piston stroke.

Numbers on the head of the plug indicated which stroke had been selected. This improvement was subsequently incorporated in the COP 1238 drill.

Although as stated earlier a low impact energy was more suitable for drilling in soft rock, this applied specifically to drilling with 'small' bits as in drifting. A high impact energy was required for drilling with 'large' bits as in bench work. Nevertheless, in both cases, better results are obtained if the impact energy is reduced to match the drilling when in soft formations.

When the COP 1838 was introduced, at the turn of the year 1992/3, a new type of back-hammering unit was included. This was particularly useful in poor ground where stuck bits often meant the loss of the total drill string. In addition, rotation torque was increased from a maximum 500Nm (COP 1440) to a maximum of 740Nm and 980Nm for COP

1838 ME (Medium Impact Energy) and COP 1838 HE (High Impact Energy) respectively. COP 1838, which was a larger version in terms of weight, length, width and height than COP 1440, was also reputed to be capable of 50% higher impact power and penetration rates than COP 1238. It was designed for tunnelling, drifting and production work in 38-64/51-102mm hole diameters.

### Recoil dampener

After the piston struck the drill steel, the energy imparted by the piston travelled down the string to the bit which, in turn, impacted against the rock. Some of this energy was reflected up through the string and back into the rock drill. One of the problems experienced with percussive rock drills was that the intensity of this reflected wave varied according to the depth of the hole and type of rock being drilled but, under extreme conditions could be as high as 40 – 50 tonnes.

A consequence of this was the fracturing of side bolts, increased internal wear on the chuck bushing and other difficulties. To overcome the problem, Atlas Copco equipped its original COP 1038 with a special shock absorber. The shock absorber consisted of a hydraulic piston, (or damping cylinder) positioned immediately behind the rotation chuck bushing. The rear end of the hydraulic piston was connected to the high-pressure accumulator.

When energy was reflected through the drill string, this caused the shank adapter to impact against the rotation chuck bushing, which in turn, hit the hydraulic damping cylinder. The hydraulic 'spring' of the high-pressure accumulator then acted to retard the rearward motion of the damping cylinder and so absorb the shock.

When COP 1238 was produced, the unit was fitted with an improved system incorporating a floating hydraulic dampener. This protected the drill from the damaging forces of reflected shock waves and prevented vibration being transmitted through the feed, boom and drill rig.

Later (2004), when COP 1638 was introduced, it featured a double damping system. At the time, Atlas Copco advised that the new 16kW drill superseded the original 12kW COP 1238 introduced in 1983. It was intended for use in face drilling, rock bolting and underground long-hole production work.

Apart from its greater power, and thus increased penetration rates, the new COP 1638 is said to also provide 20% longer shank adapter life.

**Rotary and rotary/percussive hydraulic drills**

Although several drilling machine manufacturers either directly or indirectly were severely affected by the worsening economic situation, the wider use of TBMs and roadheaders, especially in softer ground conditions, made a big dent in the market so far as those companies that specialised in drills designed for the lower compressive strength range were concerned.

These included amongst others Perard Torque Tension (PTT) and SIG Swiss Industrial Company. Such companies were well known for their excellent range of rotary and rotary/percussive drills capable of drilling in either the rotary or the percussive mode.

The Perard Torque Tension Ltd's rotary/percussive and percussive drills utilised the valve piston principle of operation. The SIG Swiss Industrial Company's HBM 100 (in the middle of the SIG drill range) was remarkable because it did not utilise a conventional valve system to control the impact rate of the piston.

Instead this was achieved by a control valve or distributor cylinder, which was linked via a drive shaft directly to the rotation motor. The control valve rotated within the distributor housing.

Oil was fed to the rear chamber of the drill through inlet ports in the distributor housing and thence through ports in the rotating control valve (or distributor ring).

This produced the forward stroke of the piston. The return or back-stroke of the piston was effected by oil which was fed to the front end of the piston under constant pressure. There was no link between this feed line and the control

valve or distributor housing. Two oil circuits were used - one for the rotation motor and the other for the piston via the distributor housing and the control valve (distributor ring).

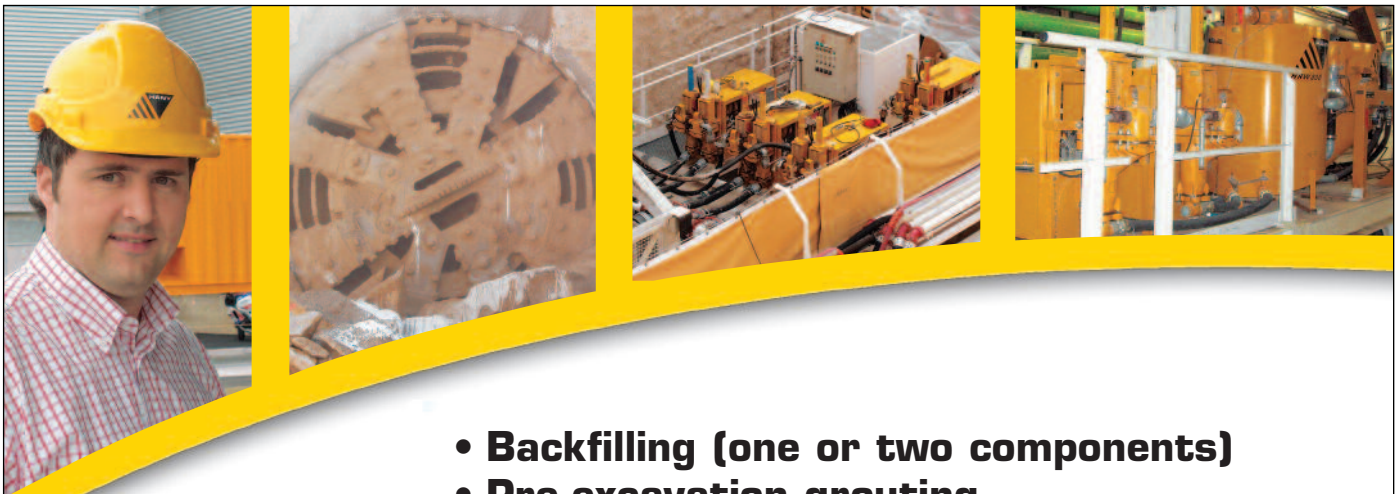
Thus, as the rotation motor's speed was increased (which increased the rotation of the bit) so, too, was the stroke rate of the piston increased.

The HBM could therefore be set to operate in three modes:

- percussive
- rotary/percussive (with high frequency or vibro drilling), and
- rotary drilling.

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\* Note: Some manufacturers refer to 'vibro' or 'high frequency' drills as being 'rotary/percussive'. However, they are no more nor less rotary/percussive drills than conventional independent rotation percussive drills. This is because when the drill is operated in the vibro or high frequency mode – that is, at a higher blow rate, the bit must be turned at a correspondingly faster rate to compensate for the faster percussion rate, or regrinding will occur, adversely affecting penetration rates. Therefore it will be found that some drills [(whether vibro or not) and depending upon the hole diameter and current rock conditions], tend to operate more as percussive units with some rotary work being done, while others will operate more as rotary units combined with some percussive action.



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## Doka in form

The widening of Austria's main "Westbahn" east-west railway to a four-track width between Vienna and St. Pölten is one of the biggest infrastructure building projects underway in the country. The centrepiece is a new twin-tube tunnel running for more than 13km beneath the hilly "Wienerwald" district between Hadersdorf and Klein Staasdorf. On the 11km long Western Section, two TBMs were in service. The much shorter 2.3km single-tube Eastern Section was constructed by mechanical excavation and blasting, using NATM and requires the tunnel lining to be cast-in-place concrete. An over 10m high and 35m long emergency ventilation cavern set at 90° to the tunnel constitutes the transition zone between the two contract sections. The emergency ventilation cavern is one of the most difficult casting sections of

the Wienerwald Tunnel from the formwork point of view. To construct the reinforced-concrete inner shell in and around the cavern a comprehensive formwork solution was adopted from Doka.

The cavern is intended to ventilate the Tunnel in the event of a fire. Following shotcreting of the excavated cross-section, the cavern is being lined with a 500mm thick reinforced-concrete shell. In the first, 6m high casting step, the site crew are forming the up to 10m high end-walls using a combination of Doka supporting construction frames and rentable standard panels from the rugged Framax Xlife framed formwork system. Above this, the high-load Doka dam formwork D 15K, also fitted with Framax Xlife panels, is in use on the second, 4m high casting step. For concrete placement, the formwork panels are equipped with



filler necks.

The 35m long sidewalls were formed with large-area elements of Doka Top 50 formwork on 6m high Doka supporting construction frames Universal F. For the difficult intersections with the tunnels, Doka planned intersection elements which were tailored to the complex geometry of the structure. Based on Large-area formwork Top 50, these elements were prefabricated with complete dimensional accuracy by the Doka "Ready-to-Use" Service.

A Doka tunnel-formwork traveller, consisting of 3 sections in the longitudinal, is in action for pouring the cavern vault. The unit is

built from rentable standard components of the Heavy-duty supporting system SL-1 and fitted with Large-area formwork Top 50. Thanks to the system's high proportion of rentable system components, and its pre-assembled parallel truss segments, it can be finally assembled very quickly on the site, ensuring fast and efficient construction progress. Using custom-built intersection elements, it was also possible to form and pour the transition zone between the vault, the sidewalls and the tunnel tubes quickly and accurately.

**Doka**  
**Web:** www.doka.com



## Smoke detection

D-Tec – part of AD Group – has launched a new, more capable, version of its award-winning FireVu VSD (Video Smoke Detection) system to offer both CCTV-based smoke and flame detection in tunnels.

A number of key changes have been built into the new model of the NetVu Connected FireVu, which combines VSD with video over IP, for enhanced performance and ease of installation. The most notable changes implemented, as a result of the FireVu product development programme, include: an advanced flame detection algorithm – for the first time on FireVu – and, crucially, new and improved smoke detection algorithms which also benefit from

the increased performance of the unit's chipset.

As well as the internal changes, the new 8 channel system, which supports 24 outputs, comes in a much slimmer unit – dropping from 3U to 2U in terms of the rack space required – compared to the original FireVu.

When it comes to ease of installation, a tailored engineering interface has also been created for the new FireVu which should simplify the commissioning process.

This will also assist long-term maintenance and system updates can now be provided via the unit's USB port.

**D-Tec**  
**Web:** www.dtec-fire.com.

## Brisbane win

At the end of March, Swiss company Ceresola TLS AG was awarded the contract for the provision of formwork technology for the construction of the Airport Link Tunnel in Brisbane, Australia.

The Airport Link Tunnel in Brisbane is the focus of the largest PPP (Private Public Partnership) project ever to be carried out in Australia, with an investment of approximately US\$3.5bn. It involves the construction of 2 parallel tunnels, each with an approximate length of 6.7km. This task will be carried out partly with tunnel drilling machines and partly with selective cut heading machines. Complex connecting structures with entrance and exit ramps present fierce challenges for the formwork technology for tunnel lining.

During the bid submission phase, Ceresola TLS AG presented a range of solutions for these complex challenges. After months of negotiations, the Thiess/John Holland JV awarded the supply contract to Ceresola TLS AG to provide a total of 8 arched formwork structures. Various international form supply

firms competed for this most challenging contract.

In addition to simple formwork to support the North and South Tunnel, the special formwork required for lining the ramps presents a particular technological challenge. A special drive train will be used to combat an inclination of up to 7%. The 10-15 m long formwork must have full hydraulic controls to expand the forms from a 2-track tunnel to a max. 4-track tunnel. And this must be achieved with as little time spent underground as possible. The formwork can also be reconstructed underground to line the expanding caverns. Another challenge posed by the project is the narrow radius of some of the ramps which is as little as 160m in places.

All project management and formwork construction design tasks will be executed in Switzerland, whilst production will be carried out in North Italy by Ceresola TLS s.r.l. The formwork is scheduled for supply from November 2009 to June 2010.  
**Ceresola**  
**Web:** www.ceresola.com

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Hard-rock TBM



Soft ground TBM



Dual mode TBM



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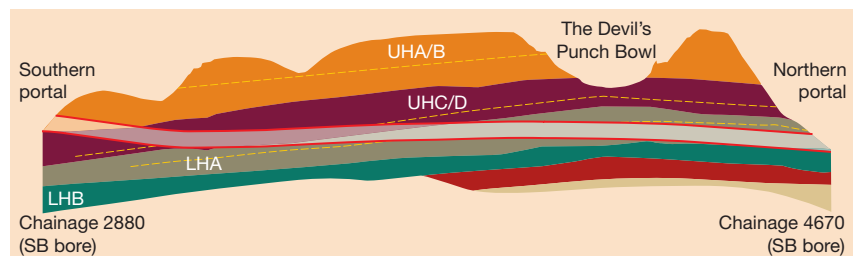
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# A3 Hindhead Road Tunnels

In this Harding Prize runner up paper, Bethan Haig, tunnel engineer and shift geologist, Mott MacDonald, describes the design and construction of the UK's Hindhead Tunnel



Above: Fig 1 - Simplified stratigraphy along the tunnel long section

Around halfway along one's current journey from London to Portsmouth on the A3, three things will happen. The first is that the road will narrow from a dual carriageway to single carriageway. The second is that the view will improve greatly as you pass alongside an 'Area of Outstanding National Beauty' known as the Devil's Punch Bowl and through the surrounding National Trust land. The final thing to occur is a dramatic reduction in speed, as congestion builds up from the traffic signals at the Hindhead crossroads on the far side of the Punchbowl.

When the A3 Hindhead road improvement works are opened in 2011 it will be the end of a journey that commenced in 1983 to improve this situation. The chosen solution benefits the local environment, allowing the reunification of the wildlife area currently bisected by the road, and serves the needs of the commuters and local residents whose lives are effected by the current gridlock. Further expected benefits include reducing the numbers of accidents on the A3 and those caused by traffic travelling on alternative winding country roads.

To achieve this, the road has been realigned and, as part of the A3 Hindhead Improvement Scheme, traffic will now pass under the Punch Bowl in twin-bore dual-carriageway tunnels. These 1.8km long tunnels have a sprayed concrete lining in a horseshoe shape and are joined by 16 cross passages (at just over 100m spacing) and a low point sump.

## Design principles and geology

The ground investigation at Hindhead was carried out in several stages, most of which

were hampered by the difficulties inherent with access to a Site of Special Scientific Interest with unusual topography and the nature of the local geology. The project passes through the Hythe Beds, made up of sedimentary deposits ranging from loose sands and damp clays through very weak to moderately strong sandstones to chert. The units are often thin, interbedded or gradational making it very hard to interpret geophysics, which relies on distinctive boundaries between adjacent strata. The Hythe Beds are regularly split into key strata.

The tunnels' vertical alignment was chosen to maximise the length to be excavated in the Lower Hythe A; which from logging of cores was found to be the most consistent of the strata. The tunnel portal at the southern end is located in Upper Hythe A and B, found to be predominantly sands. Between the UHA/B and the LHA lies the Upper Hythe C/D, the most variable of the strata. Just below the tunnel alignment in places is the Lower Hythe B, again a weak sandy stratum, overlying the Atherfield Clay. The sandstone encountered is generally on the border between the BS 9530 descriptions of weak to very weak rock, with typical UCS values of between 2 and 5 MPa.

The weak and jointed nature of the ground led to a design that used soft ground tunnelling techniques throughout; immediate installation of support at the face after an advance and no rock bolts. The tunnels differ from many others in that the sprayed concrete applied at the face, the primary lining, is also the permanent structural lining. This approach can be applied following advances in sprayed concrete mix design, particularly accelerators which do not result

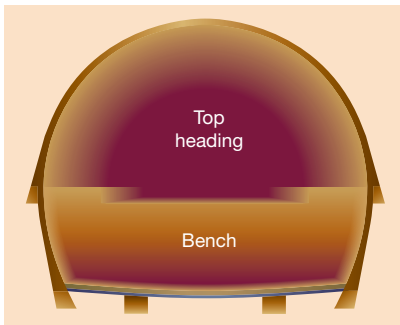
in a loss of durability or concrete strength over time. To further enhance the durability of the lining at Hindhead, common sources of corrosion, such as steel reinforcement bars and lattice girders, were designed out where possible.

The tunnels were modelled to assess; the required thickness of lining; that the axial load could resist all the moments in the lining (there would be no tensile reinforcement beyond the steel or structural polypropylene fibres included for short-term flexibility and crack control); the appropriate excavation lengths; and the required foundations - the widths of the top heading and bench "elephants feet".

## Developing the ground model

The chosen tool for modelling the ground structure interaction was FLAC - a finite difference program that assumes the ground acts as a continuum. To maximise the scenarios investigated it was decided to do the majority of the modelling in 2D, where changes in ground conditions and topography could be quickly and easily altered. To increase the accuracy of the 2D analysis a 3D model was used for calibration. For the majority of the modelling the geological units were given average descriptions for simplicity, with parameters which reflected the balance of rock and soil. For example LHA contained 90% sandstone and 10% sand/soil so the strength parameters for the unit were weighted accordingly.

Unlike the London Clay, there is little published evidence or applicable experience in the Hythe Beds which could inform the geotechnical interpretation for a tunnel.



Above: Fig 2 - Cross section of typical tunnel lining proposed

Modelling at this stage was therefore used to assess and develop the ground model to make it appropriate for use in the design process. Initial parameters had been developed using the Hoek-Brown failure criterion to derive rock mass strength values. A non-linear stiffness model had also been derived, based on a direct normalisation with overburden. Results at this point indicated that the ground failed at rock mass strengths significantly lower than those predicted by the Hoek Brown criterion.

Further assessment of the parameters suggested that the range of in-situ stresses encountered along the alignment, which has such varying overburden, made it more appropriate to include the actual overburden at every point in the analysis. The Hoek Brown criterion was then also programmed directly into the model, rather than being used as a tool to calculate the inputs. This was also found to misrepresent what was known about the ground, indicating failure at strains less than 0.5%, while 1% was considered a more realistic value.

Mohr-Coulomb failure criteria, based on uncorrected strength parameters from direct sample tests, combined with a consistent stiffness model, were found to give the most realistic behaviour; despite the strength values being lower than those devised from Hoek Brown in the original model. To confirm this approach it was proposed that further testing be carried out at the tunnel axis level, i.e. plate bearing tests after the portals had been excavated which could corroborate/inform the stiffness model.

### Detailed design

The design opted for maximum consistency in the tunnel lining shape and thickness, and so one robust lining type was used for the tunnel driven through the LHA and UHC/D from the north, while a different approach was used at the portals and through the weaker and looser material at the south. Analysis of the ground acting as a continuum showed that the 200mm thick primary lining could be constructed in a full

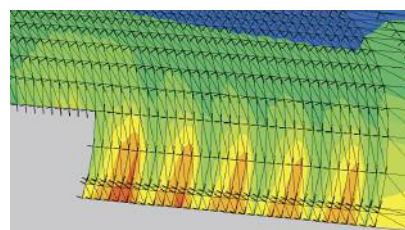
width heading (around 11.6m excavated diameter), with suitable capacity for variance in the encountered ground. The bench was expected to follow at a distance practical to the construction sequencing selected, but typically no less than 50m from the face.

In total 35No. 2D sections were analysed at critical locations; cross passages; points of significant difference in overburden, and; points of particular proximity to ground water level/weak strata.

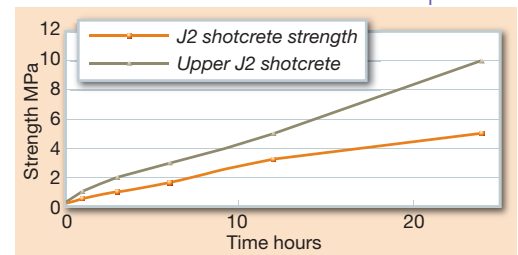
Additionally, sensitivity analyses (assessing variation in the geotechnical parameters and the effects of non-symmetry in the ground, tunnel shape and topography) and analyses to identify the trigger levels for deflections in the tunnel lining were carried out at a few key locations.

A time element and third dimension were needed to investigate the effect of changes in advance length and differences in the development of sprayed concrete strength/stiffness with time. Avoiding overloading of the young sprayed concrete was particularly important because the primary lining provides the permanent support. Several sprayed concrete strength gain curves were investigated in the FLAC model, including the J2 curve. This is a sprayed concrete strength-gain curve defined in the sprayed concrete guideline "Osterreichischer Betonverein", March 1999, for sprayed concrete with rapid load build-up due to rock pressure, earth pressure or gravity loads. The J3 curve, defined in the same document, is indicated for use only when the concrete is under special circumstances, as the cement has to react too fast and does not hydrate as more durable concrete, like the J2 would, making it unsafe for long term load cases. A curve known as the Upper J2 lies between the J2 and J3.

The relationships were included in the model via the stiffness of the sprayed concrete, which was defined by the strength to stiffness relationship suggested in "Influence of early-age properties of sprayed concrete on tunnel construction sequences – Chang and Stille –Shotcrete for Underground Support VI - Proceedings of Engineering Foundation Conference 1993". The choice of strength gain curve has most impact for the arches of completed sprayed



Above: Stresses in a FLAC model of the tunnel lining



Above: Fig 3 - Sprayed concrete strength gain curves

concrete just behind the face. If the strength of the concrete does not increase quickly enough the excavation rate may have to slow. Having a rate fast enough was considered particularly important at the south portal where work can only take place during the day due to noise restrictions. For this reason, despite indications that the lower stiffness at very early age of the J2 curve results in lower final axial loads and moments in the lining, the Upper J2 was selected for the tunnel as it optimises the pace at the face with long term loading.

The Bieniawski 1989 Rock Mass Rating classification was applied by the Geotechnical team, based on the logging of the drilled cores, and typical values for the tunnel length estimated. The majority of the mass was expected to fall between RMR values of 40 to 50.

The 3D FLAC investigation into different advance lengths was based on a model that was considered to be the most onerous load case in the tunnel. As well as being a point of maximum overburden, Chainage 4420 also had the LHB located just below the invert; approaching the Devils Punch Bowl from the Northern Portal. Combining the results of these analyses with empirical tables relating RMR to predicted stand up times for different excavation sizes, some predictions were derived for appropriate advance lengths in ground in different conditions.

- For RMR > 50, it was thought that advance lengths of up to 2m would be suitable.
- 45 < RMR < 50, suitable for advance lengths of up to 1.5m
- RMR of between 40 and 45, suitable for advance lengths of 1m only

For RMR values of less than 40 it was decided that additional support would be required to help with short term stability in the crown for 1m advance lengths. Based on the RMR estimations mentioned above it was thought that up to a third of the LHA would be suitable for 2m excavations.

### Additional support measures

As mentioned earlier, 250m of tunnel driven from the southern portal was designed for a

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Above: Removal of muck via a belt conveyor

high percentage of soil and short-term stability issues. To counteract these it was specified that 12m long, 114.3mm diameter steel tubes were drilled into the ground around the tunnel, forming a canopy of support and reducing the requirement for the ground to arch longitudinally from the face to the sprayed concrete arch. The canopy tubes are designed to be angled slightly outwards; so that the shape expands along the length. This increases the size of the tunnel, allowing a further set of tubes to be installed inside the former, whilst remaining outside the excavation envelope and the tubes to overlap, providing a continuous umbrella of protection.

During the design phase the same canopy tube approach was indicated for the initial 20m to be excavated from the north portal. After this point any further crown instability could be addressed by the use of an appropriate additional measure:

- Self drilling glass-fibre reinforced plastic (GRP) dowels to be installed above the tunnel crown to help control overbreak. Designed to be angled upwards like the canopy tubes to allow further rounds to be installed without a break. They were detailed as mandatory around the layers of stiff clay known as the Fuller's Earth and where the RMR is less than 40. It was expected that up to a third of the type 1 tunnel support type would include spiles
- Face dowels; 12m long GRP dowels installed in a grid to prevent slip failure of the face
- Drainage through probe drilling: although the tunnel lies above the historical water table it was expected that there would be perched water present, particularly above the clay. It was proposed that regular probes above the tunnel profile would identify and release water at pressure before excavation, and
- Face sealing layer: a thin layer of sprayed concrete on the face during the installation of the lining. This would prevent the ground from drying out and becoming more friable and raveling from the face

## Foundations

The Heading and Bench of the tunnel are each supported on Elephants' Feet. These are where, in the case of the heading, the shape diverges from a perfect semi-circle and widens out to spread the load onto the ground. The size of these feet was calculated using the FLAC modelling of the lining as well as empirical methods for predicting movements of ground in pad footings and foundations. The percentage of soil within the zone of influence of the footing would obviously have a large effect on these predicted ground movements. In order to avoid redundancy in the majority of the footings it was decided to optimise the design and have a range of solutions that base the footings on the conditions actually encountered below them. The layers of sand in the stratigraphy were expected to be avoided by digging the foundations deeper, to the more competent ground beneath. If a footing proved inadequate, as evidenced by significant movements identified in the tunnel monitoring, an invert strut could be included at both heading and invert level.

If the amount of sand below the tunnel were to be such that digging a deeper tunnel became impracticable, it was proposed to use nano-silica mineral grout to improve the condition of the ground. On-site trials were expected to identify the most suitable method for carrying this out and, if need be, the method could be applied to any running sand encountered.

In the case of the tunnels at the Southern Portal, where there was no rock to bear on, the solution was to complete a full ring as quickly as possible and a curved invert was included.

The bench excavation was designed to be completed only 2m behind the heading and the invert completed 2m after that. The ring would therefore be complete before the full ground loading could come onto the lining and into the foundations. As the units of rock come up into the lower part of the face, the invert is removed and the transition to the standard lining type at the north is indicated.

## Site experience

The site team consists of engineers from the contractor; Balfour Beatty, the contractor's designer; Mott MacDonald and the Highways Agency representatives on site; Atkins. Excavation is divided into two parts, the north (excavated 24/7 by three rotating teams of miners, engineers, surveyors, mechanical and electrical teams and a geologist) and the south (excavated only during the day, Monday to Saturday by its own dedicated team).

Typically, the tunnel is excavated by a Liebherr 944, with loading shovels moving the excavated material onto a conveyor to muck piles outside the portal. The majority of the excavated material is used directly, as fill for the approach to the tunnels. The lining is sprayed using MEYCO Logica spraying machines. These machines are capable of scanning an excavation profile and installing a prescribed thickness of lining, although in practice, due to the ground conditions, it is often quicker and more practical to use the skills of the miners.

By removing steel reinforcement during the design process, the need to approach the face is minimal and a minimum 3m distance from any unlined ground or freshly applied sprayed concrete is maintained for all personnel in the tunnel. Closer access to the face for inspection/probing requires a protective cage/basket. Profile control is carried out via target-less total station surveying techniques, avoiding the risks involved in installing lattice girders before spraying the lining and avoiding other associated problems such as shadowing.

The sprayed concrete was prepared 24/7 on site, at a batching plant next to the northern portal. The decision to use the Upper J2 curve for the early age strength gain could be viewed, with hindsight, as slightly too onerous. The design limited further advances until the lining 3m back from the face was of a sufficient strength, > C5/6. Considering the excavation cycle, the J2 curve probably would have also been sufficient to meet these criteria, without the need for the additional additives needed to get to higher strengths at very early age.

The author's role on site was that of a Geological Face logger, mapping all excavations carried out during a shift to allow determination of the advance length, and proposing the addition of any measures required for short-term stability. This involves remote logging of each face during excavation as well as periodic close examination from a safety cage. Information fed back to the daily review meeting includes the condition and orientation of any joints, the stratigraphy and amount of water in the face. The attendees of the meeting (including

representatives from the three engineering teams; BB, MM and Atkins) review this data along with the monitoring results and produce the Required Excavation and Support Sheet (RESS), which sets out the agreed requirements of the tunnel support measures in the following 24 hours. The in-tunnel team, including the geologist, can add conservatism to these mandatory minimums as required. Initially the footing foundation depth was determined at the face before each advance.

During excavation of the northern portal a series of faults was discovered and it quickly became obvious that the ground in this area would not necessarily behave in the manner predicted. The 20m of canopy tubing from the portal was extended to around 50m, allowing the teams to build up a level of experience in the material whilst mitigating chances of a collapse. The geologist role expanded to include some level of prediction of any major geological features that might lead to ground instability. By interpreting the probe holes, drilled to release perched water, and examining any changes in angle of the stratigraphy it was possible to identify when the tunnel approached any major changes of ground condition and through making active decisions at the face, put in place the appropriate measure ahead of time.

Faulting in this initial zone was typically subparallel to the tunnel face and so the zone of gauge/disturbed material (up to 1m thick) would travel across the face from left to right. Advances were limited to a maximum 1m in length and were often completed in stages according to agreement between the geologist and the foreman/lead miner's preference. Despite these planes of weakness it was possible to remove one of the additional support measures from the excavation sequence; the arrays of 12m long

GRP face dowels. The drilling and excavating of the dowels caused some localised raveling, but there was no indication that they were required/working to hold back the mass from a circular slip failure. Their removal reduced a source of delay in the excavation cycle, with no negative safety impact.

The tunnel had been designed for the ground to be heavily jointed and for the material to be on the rock/soil border, so while progress in the first four months was often slow, no real changes were needed to be made to the design principles. The UHC/D, which the faults and grabens brought down into the face, was often variable and when combined with open jointing perpendicular to the face some larger falls did occur. In the rarer cases when holes extended much beyond the tunnel profile, these were filled, and grout was used to stabilise the area before tunnelling recommenced. As the prevalence of faulting diminished with progression into the ground, the advance lengths were able to increase and productivity increased accordingly.

Results of the plate load testing, which was relocated to inside the tunnel due to the faulting at the portal, corresponded well to the stiffness of the ground assumed in the design. On review, some of the other design assumptions were found to be inaccurate and changes were agreed amongst the team and implemented in the tunnel. In particular, it became clear that a direct relationship could not be drawn between the RMR and the most suitable advance lengths and support measures. This was because the tunnel face was often divisible into distinct behavioural sections. For example, while the RMR might be lower than 40 in the base of a heading, the crown might be in very good condition and the installation of spiles would be an unnecessary delay.

The RMR also assumes that a more fractured, weaker material is less stable. At Hindhead some of the stronger rock encountered, with fewer joints but at a wider aperture, was associated with greater overbreak and instability than comparatively weak material. This was because the interbedded weakly cemented sands and sandstones often had less persistency in their jointing and the planes of weakness were more often interrupted. The Fuller's Earth, a soapy clay that had been predicted to lead to instability, also did not have such a great impact. Whilst local instability occurred in the material just above it, which was often slightly damp to wet, this instability was within acceptable limits and no further measures were needed. Taking all these factors into account the length of tunnel that



Above: Detailed face logging

needed spiling was greatly reduced.

A further change to the original design was the abandonment of footing optimisation. The presence of the faulting highlighted the need for a more consistent footing which could bridge over sections of weakness, as regularly changing the depth could lead to soil inclusions and difficulties in excavation. This was particularly popular with the miners and geologists as the excavation and logging of foundation inspection trenches was no longer required.

Excavating under the A3 and the Devil's Punch Bowl proved for the most part uneventful, but when the UHD came into the tunnel crown, further issues had to be tackled. A channel feature of varyingly cemented, often free running sand was located along the base of the UHD and travelled down to various depths into the tunnel face. Although quite often stable in an arch during excavation, this proved a particularly difficult material to apply the lining to, as the newly sprayed concrete was often too heavy for the underlying sand, which would peel away.

It was noted that rather than using spiles, alternative methods for increasing the stability also proved effective. These included; having an angle on the face, so the top of the heading could lead the elephants' feet by up to 2m; reducing the advance length to less than a metre, and; excavating the face in sections, with immediate application of a sealing layer.

Progress through this section was slow, but without the need to drill and grout, it was continuous and steady. The option to return to a canopy support was always available but not required. The ground has since become much better, and 1.5m advances



Above: Excavating underway under the canopy tubes

are once again the norm. The northbound bore is expected to break through in February 2009, on programme, with the southbound bore following soon after.

### Conclusions

A comprehensive ground investigation and modelling process can result in a design that is robust enough to cope with changes in expected ground conditions, without the need for re-design and the associated delays. Having a team in place on site that is adaptable and responsive, (and through early contractor involvement already has a good relationship with the contractor and understands their priorities) can lead to optimisation on site that is not possible beforehand. At the same time, it should be recognised that some optimisation during the design process may not always lead to the most practical situation on site.

Designers should strive to maintain the balance between fine-tuned design, which reduces redundancy but requires more on-site decision-making and supervision, and less refined but more pragmatic approaches

on site that can save time and avoid risks.

By removing the requirement for installation of reinforcement, the lining can be installed more safely with no man access under an unlined section of ground. The cross passages have been built concurrently to the main bores, with no need for complicated breakouts and programme advantages. The experience of the A3 Hindhead tunnel has shown that SCL is applicable to tunnels in variable soft rock. Ground settlement under the A3 and movements of the tunnels themselves have all been within expected limits.

Using the primary lining as the permanent lining has maximised the benefits of advances in material and equipment technologies and the skills of the teams involved. The option chosen for the next stage of construction, to use a sprayed

The views expressed in this paper are those of the author and should not be attributed to the Highways Agency or the other organisations involved.

water-proofing membrane and sprayed secondary lining, will push forward the boundaries of tunnel construction in the UK again, particularly for the Highways Agency.

The teams from Mott MacDonald, Balfour Beatty, Atkins and the Highways Agency are all working closely together to bring this state of the art tunnel in on programme and budget.

T&amp;T

### ACKNOWLEDGEMENTS

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# Australia's largest busway tunnel

The 630m long, 15m excavation width x 8m excavation height Boggo Road Busway in Brisbane, Australia, is set to open having marked the driven tunnel's excavation breakthrough in late September 2008 after just over a year's excavation time. Apart from being Australia's largest dedicated busway tunnel, combining 430m of driven and 200m of cut and cover tunnel, the success associated with constructing the structure was dependent upon integrated design and construction practices. The final alignment and construction methodology had to overcome numerous challenges, including:

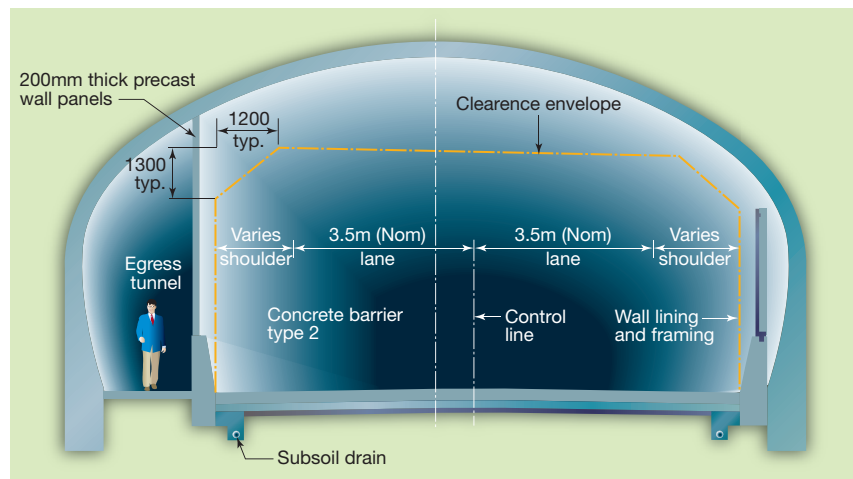
- Varied geology within a short distance
- A shallow vertical alignment
- Stringent settlement monitoring expectations due to heritage-listed Boggo Road Jail at surface

Added to this were the proximity of work to sensitive stakeholders such as MS Society care facilities; a local primary school; a heritage-listed cemetery; a dual gauge and domestic railway line and a neighbouring construction contractor.

## Project overview

The US\$185M Boggo Road Busway is a dedicated public transport link to Section 1 of the Eastern and future Eastern Busway at Buranda and provides the connection to Eastern and Southern Busway corridors to the University of Queensland, with a total

David Alt, Driven Tunnel Construction Manager, and Ted Nye, Driven Tunnel Designer, Boggo Road Busway Alliance describe the design and construction of Australia's largest dedicated busway tunnel



Above: Fig 2 - Typical Standard Tunnel profile

travel length of 2km (figure 1).

The busway driven tunnel profile includes 2 x 3.5m bus lanes with 1.6m shoulders on both sides of the road pavement together with a 1.5m wide emergency egress passage along one side of the tunnel (figure 2). The road pavement to tunnel crown is around 7m in height. Four jet fan niches which required over excavation of the tunnel

crown to accommodate three 1.2m diameter jet fans at each fan niche location. The jet fan niches were completed outside the jail buildings within the driven tunnel.

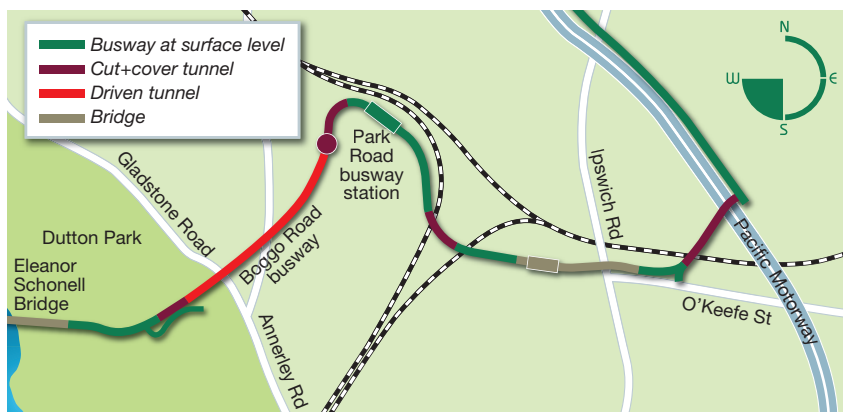
The Boggo Road Busway project and the first stage of the South Eastern Busway has been designed and constructed using the Alliance method of project delivery. The Alliance team members were Queensland Department of Transport and Main Roads (the client), Thiess (construction contractor) and Sinclair Knight Merz (designer).

## Geology and alignment under jail

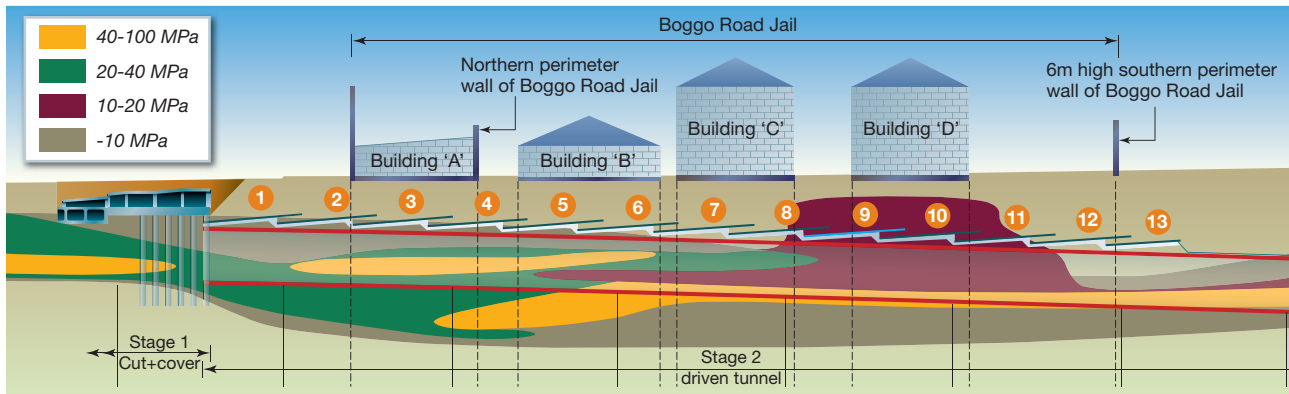
The driven tunnel was excavated using an ATM105 roadheader in two stages, a top heading and a 1.5m high bench.

The complexity of the project was evident by the use of five different levels of ground support, including 117m of canopy tubes.

The geological profile typically comprised soil/fill up to 2m depth over residual soil up to 4.5m depth over weathered rock from the Brisbane tuff formation. The Brisbane tuff formation generally comprised breccia (2m to 6m thick) over the both non-welded



Above: Fig 1 - The Boggo Road Busway alignment



Above: Fig 3 - Geological and tunnel profile under the jail structures  
 Right: Table 1 - Type 5 support, minimum shotcrete strengths vs time

(claystone tuff) very low to low strength (0.5 to 5m thick) and welded tuff (ignimbrite) that was high to very high strength and jointed with clay seams (ranging in thickness up to 10m thick). The Brisbane tuff (welded) joint system is considered random. Underlying the Brisbane tuff, the tingalpa formation of very low to medium strength, comprising siltstone/sandstone and conglomerate, was found (figure 3).

Ground water monitoring piezometers were installed and packer tests were performed during the site investigation. The groundwater encountered comprised a perched water table (at approximately 8m depth) and a deeper confined aquifer within the tingalpa formation (at 10m to 16m depth). Actual ground water inflows encountered during tunnelling were for practical purposes insignificant.

**Initial tunnel support under the jail**

Minimal surface settlement was achieved by the forward installation of canopy tubes and tunnel face fibre glass dowels and most importantly by the early application of the full thickness of 350mm shotcrete over the



Above: Typical lattice girder shadow shotcrete trial

**Table 1**

At Time	Minimum Strength	Test Applied
3 hours	1 MPa	Initial Strength - Meyco Penetrometer
12 hours	6 MPa	Sprayed Beam Compression (ASTMC116)
24 hours	18 MPa	core compressive strength (AS1012)
3 days	26 MPa	core compressive strength (AS1012)
7 days	35 MPa	core compressive strength (AS1012)
28 days	40 MPa	core compressive strength (AS1012)

tunnel arch. Early strength of the shotcrete was also critical to the success of this design and construction approach. Table 1 from the shotcrete specification gives the strength requirement of the shotcrete from as early as 3 hours after application, together with the tests used to measure the shotcrete strength with increasing time from the application of the shotcrete.

No damage was caused to the surface heritage-listed buildings traversed by the tunnel below.

**Final tunnel lining**

One of the options considered for the final lining, during design development, was to use a combined lattice girder and shotcrete lining and not have an in-situ concrete lining. There were obvious cost savings on the formwork, given that the tunnel was only 430m long.

Shadow shotcrete trials on test panels, with sections of lattice girder, however, did not prove satisfactory because it could not be demonstrated that the lattice girder reinforcement would be fully embedded in the shotcrete. This was considered an unacceptable long-term durability risk given that the required design life of the structural elements of the tunnel was 100 years.

The final tunnel lining adopted consisted of an in-situ 300mm thick reinforced concrete arch with a sheet waterproofing membrane over the tunnel crown and walls in the standard tunnel profile. At each of the four 19m long jet fan niches a

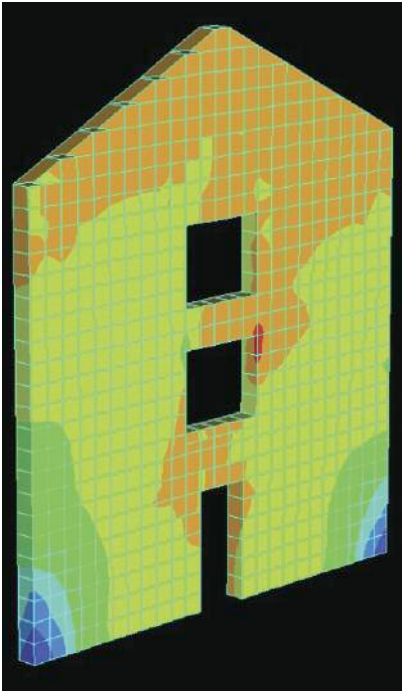
combination of permanent rock bolts and shotcrete with a spray on waterproofing membrane, was used.

**Settlement**

Detailed analysis of settlement under the jail prior to tunnel excavation were carried out using 2D Finite Element Analysis (FEA), and to determine the tolerance of the surface structures to differential movement 3D FEA was used. An example output from the building FEA analyses is given in Figure 4. Stress concentration points around openings were obvious locations of concern.

The ground cover over the tunnel under the jail varied from a minimum of 5m at the north portal to a maximum of 8m at the southern perimeter wall of the jail (refer to figure 3).

Tunnelling under two identical three-storey cell block buildings with similar ground cover and the same tunnel support, but slightly differing geology, is a unique case study in itself. Prior to construction the predicted maximum settlement along the tunnel alignment under the jail buildings was 10mm. Under the first three storey cell block building, with the worst geological conditions above the tunnel crown, the actual maximum surface settlement was 12mm while under the second building and with "improved" geological conditions the maximum recorded settlement was 7mm. Under the second cell block building, however, the left hand side of the tunnel



Above: Fig 4 - Output of 3D FEA analysis of end wall of cell block building

intersected a significantly weathered clay stone at tunnel springline level and consequently a 1m wide “elephant foot” shotcreted wall beam, anticipated in the design for these ground conditions was installed. The final length of this wall beam along this one side of the tunnel was 60m.

It was recognised at the design stage that surface settlement could also occur as a result of vertical movement of the arch footings as well as the more usually anticipated tunnel crown. Arch footing settlements were of the order of 1 to 3mm and inwards tunnel convergence readings were of the order of 1mm at tunnel springline level. Optical targets in the tunnel crown recorded vertical downward movements of around 5mm. These latter readings were only accurate to +/- a few millimeters, compared to precise level surface readings of within +/- 1mm.

#### Conclusions

While not described in this article the extent of site investigation works was considerable for the short length of driven tunnel. The effort put into developing the

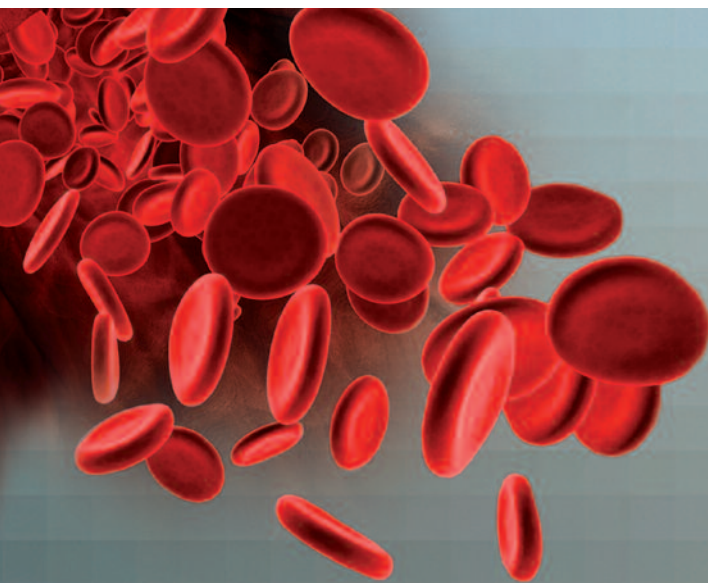
geological model prior to construction contributed significantly to the success of the project.

Close co-operation between the designers and the construction team also contributed to the final successful outcome. A “Permit to Excavate” procedure was also adopted for this tunnel which ensured that the design and construction teams met every 24 hours throughout the higher risk excavation phase of tunnel construction. This demonstrated to all those involved with the driven tunnel (both directly and indirectly), that on complex tunnel projects, tunnel design and construction are definitely not mutually exclusive.

T&T

#### ACKNOWLEDGEMENTS

For permission to publish this paper and creating a great working environment we thank and acknowledge our Alliance partners, the Department Main Roads and Queensland Transport, Thiess and finally our work colleagues at Sinclair Knight Merz. John Braybrooke of Douglas and Partners, Sydney, developed the initial geological model along the driven tunnel alignment.



10  $\mu\text{m}$

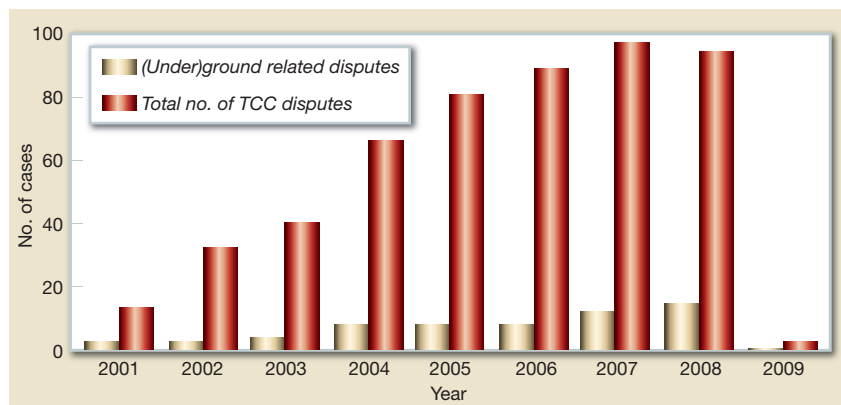
Size of a Human red blood cell and the measurement uncertainty of a coordinate when measured with the Laser Tracker used in VMT's industrial measurement system.

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# Disputes in construction and tunnelling projects -

## Part 1

At the British Tunnelling Society's March 2009 meeting, Dr Nigel Legge and Garry Crossley from Navigant Consulting, and Caroline Pope from Berwin Leighton Paisner considered project risk issues and the common causes of contractual disagreements on construction projects in general, and tunnelling schemes in particular. Methods of addressing these issues and techniques to minimise disputes on future projects were presented



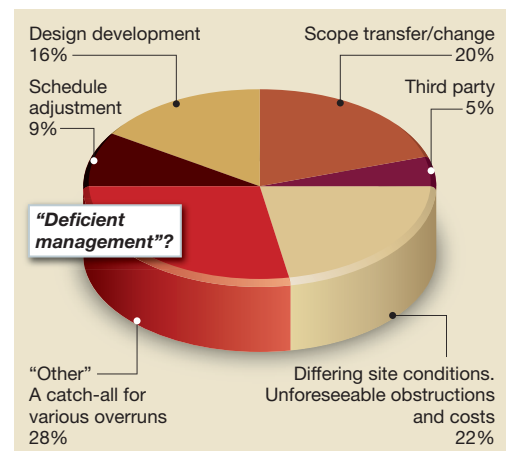
**T**he inherent risks associated with construction, and with underground infrastructure in particular, are evident not only in past and more recent high profile failures but also in the increasing numbers of disputes. This presentation gives an overview of project risk issues and then looks at disputes and how to avoid them from the project and legal perspectives.

Construction activity was 10% of UK GDP in 2007, valued at over £80bn across all sectors. Although not easy to quantify, estimates indicate that up to 5% (equivalent to £4bn in 2007) may be lost annually due to failure-related issues. Included in this sum are the indirect costs associated with disputes. It should be noted that the consequential costs associated with delay and quantum issues can be significantly greater than the original construction defect or standard of care failure.

The construction industry and the legal profession have done much over the last

10-15 years to actively address risk in the key areas of procurement, project organization, delivery and risk management<sup>[1,2,3,4]</sup>. Despite these developments however, a recent survey for the credit ratings agency Standard and Poor's identified tunnelling as "... inherently a higher class of risk than any other type of construction"<sup>[5]</sup>.

A significant number of disputes in underground construction have traditionally been associated with 'hard' project risks. These may be related to the ground, design and construction issues or the operation and performance of major plant such as TBMs. For most engineers these are the principal issues on a given project and they tend to be the main focus of risk assessments and registers. The Clients' priorities however are generally delivery to time and budget, and overall functionality and performance during operation. Differences in approach and emphasis here have the potential to result in disputes. In their role of



Left: Fig 1 - Disputes on the rise over the last decade

Above: Fig 2 - Deficient management can play a big part in cost overruns, example shown from the Boston Big Dig

identifying, mitigating and managing risk engineers need to consider broader issues, which may result in disputes as well as those typically associated with engineering failures.

With the increased size, complexity and multiple interfaces typically associated with modern underground infrastructure, there is an increasing focus on 'softer' organizational issues and their role in project distress and disputes. A key event was the Heathrow collapse in 1994, significantly described by the HSE as an 'Organisational failure'<sup>[6]</sup>. The contemporary focus is on wider 'systemic' project risk issues, defined as those '... not related specifically to an event, but ... to the manner in which an organization, or project, is managed or organised'<sup>[7]</sup>. Another area currently receiving attention is the importance of knowledge transfer and learning from past experience. This is particularly relevant for large underground infrastructure projects: In a special issue of the Proceedings of the ICE 'Learning from Failure' it was

noted that the human interface is '... perhaps the riskiest of all'[8] and that '... large organizations of people have no memory whatsoever'[9].

In the last 20 years a range of Alternative Dispute Resolution (ADR) options has developed in the UK. The various ADR options aim to deal with disputes quickly and cost effectively, reducing the number which result in more formal legal proceedings such as adjudication, arbitration and litigation. ADR mechanisms, frequently incorporated into the contract, are informal and focus on finding a solution, which is acceptable to the parties.

Despite the development of more flexible dispute resolution options, the number of disputes being heard in the Technology and Construction Court has risen steadily in the last 10 years (figure 1). Over the last 12 months, exacerbated by the current economic situation, there has been a greater increase in formal contract disputes: In the last quarter of 2008 more disputes resulted in formal adjudication than in the whole of 2007 [10].

### Project perspective

Evidence suggests that a significant proportion of projects overrun their budgets and programmes through non-engineering related issues which are under the control of the Engineer. In a 2001 study, owners reported that cost and programme overruns on more than half of large underground engineering projects were due to deficient management, as opposed to typical underground engineering risks.

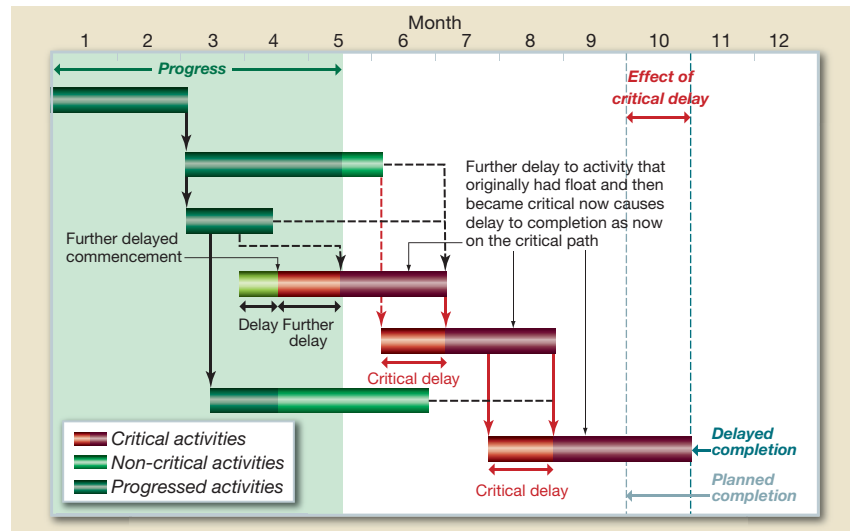
Figure 2 appears to confirm that traditional engineering risks do not account for the majority of the cost overruns, though they do play a significant part. Vast majority of oversight committees gave the reason of management issues, in particular lack of adequate oversight, as the primary cause for the cost overruns.

### Protective measures

Limiting risk involves instigation of protective measures in a proactive manner, in particular through proactive project planning. Risk is often best handled by arranging for it to be carried by the party best able to understand and control each risk.

### Limiting risk - project planning

An area of risk that is often marginalised in major underground and tunnelling projects is project planning.



Above: Fig 3 - Critical path program method analysis

Effective project planning should be used to employ protective measures in order to limit risk and exposure to issues such as deficient management and strategy. As such, well thought out planning gives all stakeholders the control needed to deliver projects on time, on budget, and with a high level of quality. However, the critical phase of successful project planning is the actions taken after the initial plan has been created. The crucial issue is that a plan needs to be flexible, but more importantly, be constantly managed.

The Boston Big Dig initially placed a significant amount of focus on the management of the plan. From the outset, the project managers intended to manage and coordinate the project very carefully. Nevertheless, despite the best of intentions, the initial effort lost its focus due to the plan not being constantly managed (figure 2).

Therefore the key point is that good and continuous planning involving all stakeholders is absolutely critical if it is to be ensured that all major underground and tunnelling projects are to be completed to budget and on time.

### Limiting exposure – maximizing or minimizing damage

It can be accepted that being proactive and limiting risk means considering what risks exist, allocating them to the party best suited to manage them, and constantly monitoring them during the project life cycle.

Nonetheless, instances where a risk event occurs and a loss is incurred will no doubt arise on projects. Cost overruns, claims, and disputes have unfortunately

become a regular occurrence on a number of large projects.

If one is to investigate further, it can be seen that the common driver of the loss, and in most instances the claim and dispute, is unplanned delay. Unplanned delay is undesirable in terms of additional cost, delayed payments, negative cash flow and loss of revenue, all of which impact on the parties involved. Notwithstanding this, on large underground or tunnelling projects, there can be multiple overlapping or concurrent delays which may be attributable to both the owner and the Contractor.

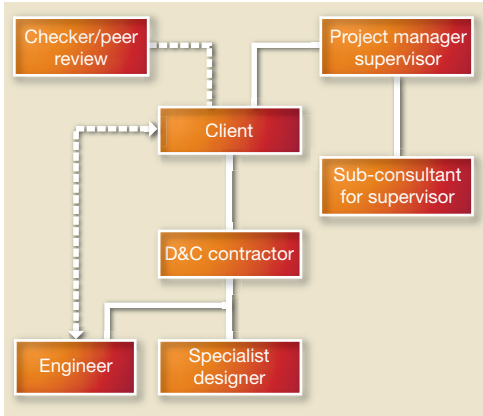
From a management perspective, the key point is that the allocation of responsibility for project delays is essential to the resolution of project disputes and ultimately in controlling the risk of exposure to damages. Therefore a thorough analysis of project progress and delay is essential.

As such, critical path method programme analysis is a powerful tool for the evaluation of the impact of delays and apportionment of responsibility for those delays (figure 3).

One of the points that can be made from this is that because the planned and actual schedules can change, the critical path can also change accordingly i.e. a non critical activity becoming critical.

Changes in float (and hence the ability to absorb delays) lead to complexities in pinpointing the root cause of a delay.

Nonetheless, when performed properly and objectively, critical path method programme analysis can be very persuasive in demonstrating an owner's entitlement for liquidated damages, or a



Above: Fig 4 - Party relation on a project

Contractor's entitlement for reimbursement due to excusable delays.

The process of establishing links between events and subsequent programme impacts is acutely complex. Often this critical element in the development or defence of a claim is poorly conducted. This consequently does not limit the risk of exposure of the owner or contractor to damages.

The applied methodology of "cause and effect" is aimed to produce a clearer view of the reasons, and responsibilities, for programme delays.

Regardless of whether a Contractor is submitting a claim, or an owner is defending against one, the element of proof is the same; what was the cause of the problem, who was the responsible party, and what was the effect? If cause and effect cannot be established, the claim evaporates.

In any event, it is essential to create a balance between the costs incurred in the process of limiting risk and exposure, and the benefits that will be reaped from it, not just in respect of the typical engineering related risks that are commonly expected on underground and tunnelling projects, but also in respect of those other non typical engineering risks that Engineers can help to control and manage, for instance project planning.

### The legal perspective

After being involved in a large number of tunnelling disputes, it has become apparent that there are 5 recurring legal contractual pitfalls that have caused or

exacerbated conflict between interested parties. These are:

- Lack of clarity of responsibilities
- Risk register
- Ground conditions
- Use of provisional sums
- Early use by Purchaser

### Lack of clarity of responsibilities

An instance of where this can be problematic can be illustrated in an example involving a recent Design and Build contract. The parties were related to each other as shown in Figure 4.

The Designer was initially part of the Purchaser's team. On award of the D&C contract, the Designer's appointment was novated to the Contractor. The Designer gave the Purchaser a collateral warranty, so they continued to be liable to it for the performance of their services. The Contractor also engaged a specialist Designer. The Purchaser engaged a project manager, to project manage and supervise the scheme. That consultant in turn sub-contracted the supervision to a sub-consultant. In addition, given the interface with a major infrastructure third party provider, the Purchaser appointed a checker to peer review and approve the permanent and temporary works design, as required by the third party agreement.

Hence the Contractor, its Engineer, the specialist Designer and the checker all had responsibilities for design.

A method statement was produced by a specialist sub-contractor and reviewed and approved by the Contractor, its Designer, the project manager and the checker. However, none of them appreciated the significance of the proposed sequence of work on the overall design. The only consultant who would have realised the potentially devastating impact the methodology might have, was the specialist Designer, who was not asked to review it.

The problems were then exacerbated by the sub-contractor failing to follow its own method statement. No party picked it up on site.

The central theme is that assigning responsibility to many different parties in an attempt to increase levels of redundancy does not always work. It can lead to complexity with the involved

parties adopting a silo mentality, thinking that others were doing tasks, when they too had responsibility to undertake the same roles.

One way to avoid this would be to appoint an over arching Engineer who understands the totality of the scheme. Alternatively, there should be a clear allocation of responsibility in contracts to ensure that roles and responsibilities overlap as little as possible, clear and careful wording to ensure that all parties are clear on what is required from them, and communication to all members of the team, so everyone knows what everyone is meant to do.

### Risk Register

Risk registers are now a fundamental part of the risk management process on projects, particularly with the ever sharpening focus on health and safety. Nonetheless, care has to be taken that they do not intentionally or unintentionally become a means of contractually allocating risk.

In one project, the NEC contract was amended to make the risk register one of the documents defining the contractual risk allocation. This meant that although it was a design & build contract, with all the main contract clauses placing responsibility for the design and construction of the tunnel on the Contractor, the risk for a significant element of the tunnel design was transferred to the Purchaser through the risk register.

It may be reasoned that this was logical, given that the Purchaser was carrying project insurance. However, the Purchaser was not best placed to manage the risk, which was clearly an issue for the Contractor and its team. Moreover, just because there is a policy of insurance in place, it does not necessarily follow that the insurer will cover the risk.

In this instance this lead to a considerable argument, particularly as the language used in risk registers is brief due to it being processed in tabular form. This made it even trickier to interpret the extent of the risk intended to be allocated.

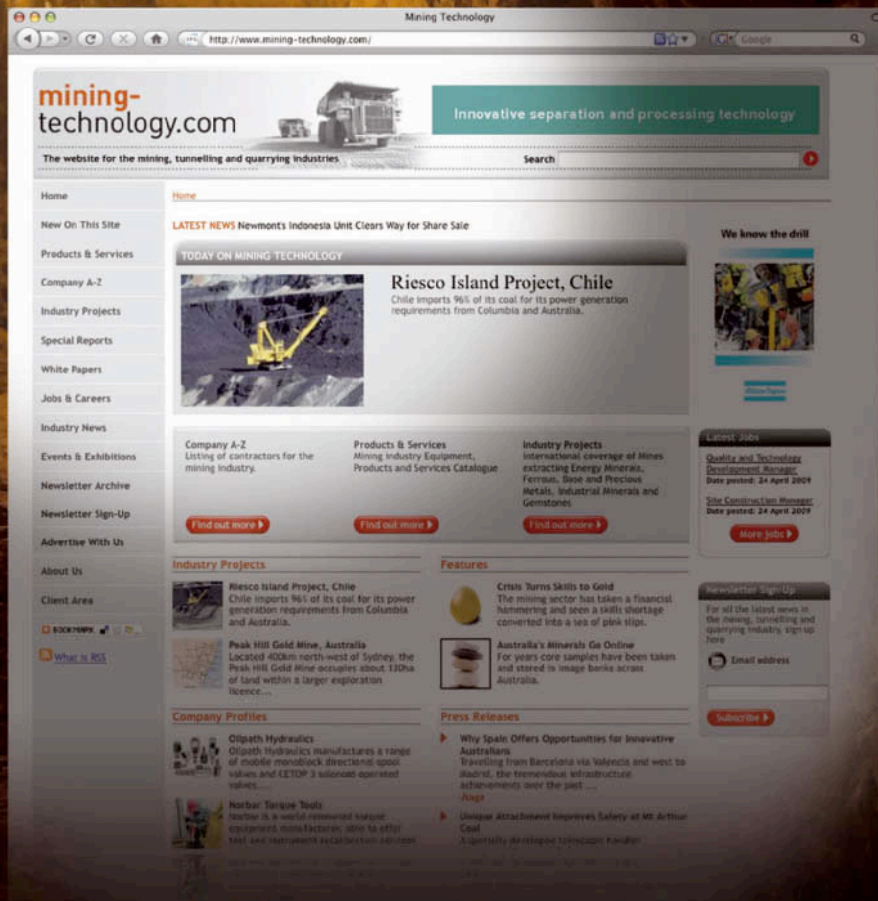
The key lessons to overcome this are to ensure the risk registers are not: Used as a way of contractually allocating risk; or Inadvertently incorporated into the contract in such a way as to allocate contractual risk.

They should maintain the status intended for them under contracts such as the NEC i.e. as an essential risk management tool.

## IN PART II IN THE JULY ISSUE

In next month's *T&T* we will publish part II of this paper where we will deal with ground conditions, the use of provisional sums, early use, conclusions, and also the questions that arose from the floor at the meetings. A full reference box will also be included.

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# Trenchless key to success

Buried service and utility maps can leave a lot to be desired in terms of accuracy. This of course has led to many a conflict when excavators have severed a pipe or cable whilst digging a trench. Ian Clarke looks at ways to combat this serious problem

In this modern age where roads need to be kept open for ever increasing traffic flows, where health and safety requirements are tougher than ever before, the need to know accurately where things are has grown immensely. This allied with the propensity for individuals, companies affected by loss of service or whose plant has been damaged, injured workers (or the relatives of those unable to do it for themselves) or simply those inconvenienced by the works to sue those responsible, has also seen the costs soar of not knowing where buried plant is located.

In an attempt to rectify this situation, organisations around the world are involved in programmes to accurately update existing plans to show those needing to dig or simply pass through the sub strata just where everything is.

One such programme is being run in the UK. The project is known as 'Mapping the Underworld' (MTU). MTU is a partnership between UK research funding bodies, universities and the private sector. Rather than simply trying to improve current techniques, MTU is actively developing new, multi-sensor, detection equipment allied to state-of-the-art utility data-basing and visualisation techniques. MTU enjoys funding and practical support from the UK Engineering and Physical Sciences Research Council (EPSRC) and UK Water Industry Research (UKWIR). By bringing together seven leading UK universities it is attempting to combine improved detection, location, integrated mapping and data visualisation into a single integrated, and stakeholder friendly, asset management system. The research areas being addressed by each university include:

- University of Birmingham - Geophysical properties of soils and low frequency

electromagnetics

- Southampton University - Acoustic and passive magnetic field detection methods
- University of Bath - In-pipe ground penetrating radar
- University of Oxford - Pipe tagging techniques
- University of Nottingham - High accuracy global positioning systems
- University of Leeds - Integrated asset data management and mapping
- Sheffield University - Condition assessment and test facilities

According to the MTU team, these research areas are novel and far reaching. While their work naturally concentrates on the UK problems, the outcomes should be much more widely applicable. Therefore, the MTU team welcomes contact from relevant organisations across the world.

## Mapping systems

As well as looking to the future of buried service mapping we must look at what is currently available. For some 30 years now innovative companies have been developing systems, which can locate with a relatively high degree of accuracy the buried position of services and utilities in 3 dimensions using a number of physical attributes of the service.

Electromagnetic or EM Systems utilise an antenna at surface to locate the signal generated by electricity running in a cable or a signal applied to a metallic pipe using a signal generator (known by many the Cat & Genny system after one of the more commonly used products on the market although others exist across the globe). Where a current is running in a cable this generates its own readable signal but where, as in a metallic pipe no naturally occurring signal is present, a signal



**Above:** A signal generator is attached to a utility for the location purposes. (picture courtesy of Infotec)

generator is attached to the pipe at a convenient point producing a signal that can be located over a significant length of the pipe. Where the pipe is of a material that does not transmit such a signal, a signal emitting sonde similar to that used in HDD tracking, may be pushed through the pipe to provide the tracker with a signal to pinpoint. Developments in the systems now allow the locator operator to establish the route of a service in two dimensions for plotting on a plan, whilst also establishing an estimate depth allowing those referencing the route to know what proximity it has to any other service in the vicinity.

Whilst this system is extremely useful in localised mapping works, it can be limited by the signal strength of the generator signal. In terms of how long a length may be tracked before the signal dissipates too much an alternative system may be required.

One survey consultant in the UK offers an in-pipe locator system that runs autonomously without the need of surface monitoring, recording and storing location data as it travels through the pipe being



**Left:** The PipeTrack system for long run location surveys from within a pipe without need for surface access except at the end points. (picture courtesy of Infotec)

**Below:** A typical map showing the location of pipe and cables (picture courtesy of Infotec)

surveyed. Known as PipeTrack, the gyro-based system can be launched from one access point of known position, pulled or pushed through the pipe to another convenient known location access. The data from the survey run, which comprises direction of travel, pitch of the system etc is then downloaded to a PC or laptop and cross referenced with the known end points to provide the route and depth information for the length of pipe surveyed. Multiple passes with the survey system can bring very high accuracy results for a survey, much more so than those available from surface locator systems.

In instances where access is not possible or the pipe is too small a diameter or where there is some question of whether unexpected or uncharted services exist other techniques may need to be used. One such technique is that of Ground Probing Radar (GPR). Whilst the system can be used as a direct survey system in the same way as the EM system described above it can also be used to verify EM data and sometime uncover the unexpected. GPR uses radio wavelengths to punch a signal into the ground beneath the transmission antenna which is reflected by obstacles in the ground. Over the years since the development of the first systems, special software has been developed to recognise specific reflection signatures of buried services of different size like cables and pipes, which is displayed for the operator on a real-time screen on the survey unit. The data is also recorded for downloading at a later time for further analysis and plotting to existing maps. Several manufacturers provide GPR system and recently units have been made available which can not only provide the survey capability but which can also be linked to GPS positioning systems to establish the precise surface location for the information. The depth of the buried service is also calculable from the reflected signal data again providing a 3-D location.

### Inspection

Of course having now found the buried service it is time to work out what to do with it. Again, as with mapping systems, there are several options with



which to establish the current state of repair of a system.

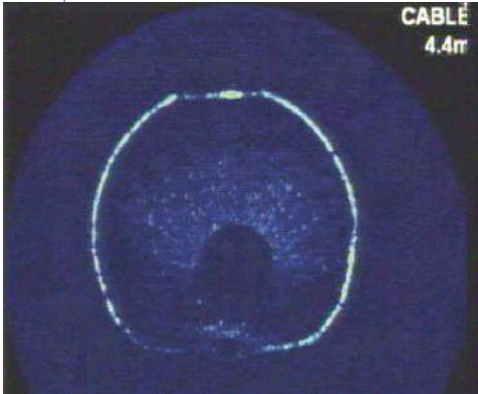
The first again is visual inspection by personnel, but again this required any pipeline to be of man-entry size. A major advantage of this technique is that the human eye sees any defect first hand. However, as most pipes are not of man-entry size, this is not always a viable option.

So, the first alternative is to send in a piece of equipment that will do our seeing for us, for example CCTV. For most of the life of pipeline inspection CCTV systems the camera has been forward facing with the camera body being mounted on a skid frame which is pulled or pushed through the pipe by a cable or rod system or mounted on a wheeled crawler which propels the camera forward through the pipe using onboard drive motors.

The system is connected to surface umbilically, relaying the image data back to the control centre for observation and recording for later use. Many camera/data recording systems enable observation comments to be input onto the screen/record view by the operator to note defects observed and other comments. In an attempt to 'kill two birds with one stone' some CCTV systems can also be fitted with a locating sonde which enables the camera to be tracked through a pipe using the EM antenna described above so giving a plot of the route for the pipe at the same time as the survey is completed.

Where lateral connections join pipes the simple forward facing cameras were at a disadvantage in that they could not inspect the connection fully. This led to the development of what has become known as the Pan & Tilt camera where the camera head rotates left/right/up/down to enable the observer to view the lateral more directly. A further extension to this ability to view laterals was also developed with the production of remote access camera heads which whilst remaining attached to the main camera body can be extended into the lateral connection to view for a limited distance into the joining pipe to establish the condition of the joint itself. This information may have a significant effect on the choice of replacement or renovation techniques used at a later date within the pipe.

Over the past 10 years a further development has occurred in CCTV system with the introduction of 3D scanning CCTV systems. These systems are able to scan the whole of the 360° inside of the pipe wall from a single camera often using a form of 'fish eye' lens. The scan data is processed by special software which can produce a flat image of the whole of the pipe inner wall, pinpoint potential faults in the pipe wall, highlight potential failed joints, etc all to within a claimed accuracy of 1mm. The most recent software can also relate the position



**Above:** Sonar results showing a 25% build up of silt debris in a pipe. (picture courtesy of 365 Environmental Services)

**Right:** A worker sets up remote fault finding for damaged cables. (picture courtesy of Ditch Witch)



of the defects to the surface plan of the pipe, making the observation more relevant to the 'real world' above ground.

Where pipe lines have significant silt build up or flow full for most of the time, yet still need inspecting a system of Sonar survey has been developed. The sonar system utilises sound waves to penetrate any silt layer in the base of a pipe to give an image of the pipe wall below it. In cases where the pipe is running full and a standard CCTV camera does not have the capability to see through the water the sonar reflection gives a view of the state of the pipe wall showing defects and displaced joints as it passes through.

In some cases the inner wall profile of a pipe can be important when considering the type of renovation technique to be employed. Some rehabilitation techniques require that the minimum 'diameter' of the pipe be used throughout such as the application of some GRP liners for example. In this instance a survey technique using a Laser Light line can establish the overall shape of the pipe and the degree of deformation that exists at any given point as compared to the expected 'nominal diameter'.

In a very few recorded instances GPR radar systems have been used as a pipe inspection technique but its use is limited and often at present expensive. What in-pipe radar can offer, compared with other inspection techniques, is the ability to 'see through' the pipe wall to establish if voiding has occurred outside of the pipe due to ground movement through leakage of product from it. This information can be useful when deciding what rehabilitation or replacement technique will be utilised in the future.

In some specialist fields such as long distance oil and gas transfer main inspection, EM-based pipe inspection rigs have been developed for use in metal pipes. Recording data to onboard storage systems over very long distance runs, changes in EM field have been found to indicate changes, corrosion, thinning etc in pipe wall. Where catastrophic failure of such pipe could cause serious damage to property and people and loss of a very costly product in some often very remote areas, the ability to gain knowledge of these potential problems in a pipe at an early stage is vitally important.

### Fault finding

As well as condition assessment, where problems may already exist there are some 'fault finding' systems available on the market. One system comprises a hand-held frame which when applied to the surface is able to locate damage to direct buried, unshielded power-carrying cables by pinpointing the power 'leakage' field around the fault. This enables precise access to the fault to be made without the need for excessive excavation over long tracts of the cable looking for the fault.

In pipe carrying fluid, mainly water pipes there are several options for finding leak points. One is the use of noise correlation systems which when applied to different points on a pipeline note the signal generated by water passing through a

defect or leaky joint. By correlating these readings from different points the estimated position of the leakage point can be established and excavated or repaired accordingly.

For specific leak detection, one system developed some years ago is Sahara. This is an internal leakage detection system which passes a sensitive microphone through the pipe using the motion of the water within it by means of a 'parachute' within the flow stream. Starting from a known location the microphone passes along the pipe feeding noise data back to the monitoring point via an umbilical. The distance into the pipe is constantly measured and as the microphone passes a leak the noise level changes so pinpointing the leak position. With the microphone tracked from surface using a locating beacon the precise position of any leak can be plotted and repaired or a decision to replace the pipe as a whole can be made if necessary as the full extent of the leakage problem can be ascertained from the one survey.

So, as with most technologies these days whilst the existing systems have ongoing relevance to the modern utility location and inspection sectors, continuing technological advances mean that data can be more easily obtained in greater volume, to greater accuracy and with less environmental and population disturbance than ever before.

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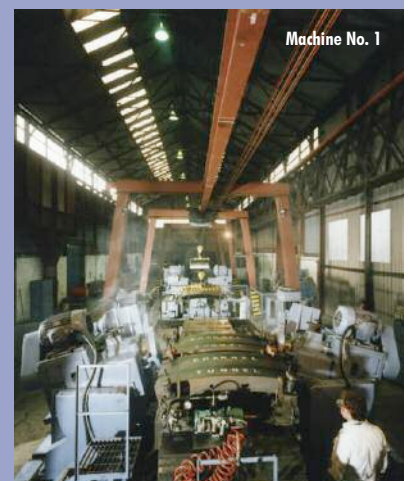
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# Dates & Events

**07-10 JUNE**

## **Shotcrete for underground support XI Davos, Switzerland**

Engineering Conferences International, in conjunction with the ITA, the Swiss Tunnelling Society and several other European Associations is sponsoring the Shotcrete for Underground Support XI. Bringing together specialists from around the world, state-of-the-art of shotcrete methods will be discussed. Contact: ECI; email: [info@engconfintl.org](mailto:info@engconfintl.org); web: <http://www.engconfintl.org/9as.html>

**14-17 JUNE**

## **RETc 2009 Las Vegas, Nevada, USA**

RETc is recognised as one of the world's leading international tunnelling event for contractors and engineers. Last year, conference attendance exceeded 1500 professionals from more than 30 countries and the exhibition sold out in record time. With a venue of Las Vegas, 2009 is sure to be even more of a success with delegate numbers already looking very healthy. Contact: SME; web: <http://www.retcc.org>

**17-19 JUNE**

## **Swiss Tunnel Congress '09 Lucern, Switzerland**

Held in Lucern, the event spans two days at the city's Culture and Congress Centre and a final day of field excursions. Day 1 features a training conference with TBM tunnelling in soft ground as the topic. Day 2 sees presentations given from local and international tunnelling projects. Contact: Thomi Btäm; email: [fgu@thomibraem.ch](mailto:fgu@thomibraem.ch); web: <http://www.swisstunnel.ch>

**22-25 JUNE**

## **5th Symposium of Strait Crossings Trondheim, Norway**

Organised by SINTEF and the Norwegian University of Science and Technology, this major symposium aims to act as a forum for the exchange of information, research, new technology and recent experience. The event will also include an exhibition. Contact: NTNU; email: [sc09@adm.ntnu.no](mailto:sc09@adm.ntnu.no); web: <http://www.straitcrossings.com>

**09-11 SEPTEMBER**

## **IBTTA 77th Annual Meeting Chicago, USA**

The International Bridge, Tunnel and Turnpike Association's (IBTTA) 77th Annual Meeting and Exhibition will once again bring together more than 1000 toll agency professionals for 3 days of networking and current innovations in the toll industry. Contact: IBTTA; Tel: +1 202 659 4620; web: <http://www.ibtta.org>

**13-16 SEPTEMBER**

## **EURO:TUN 2009 Bochum, Germany**

The 2nd International Conference on Computational Methods in Tunnelling is organised by the Institute for Structural Mechanics and promising interesting presentations from leaders in specialists in the field. Contact: Conference Secretariat; Tel: +49 234 32 29051; web: <http://www.eurotun.rub.de>

**13-17 SEPTEMBER**

## **9th International Symposium on Rock Fragmentation by Blasting, Granada, Spain**

Organised by the Universidad Politécnica de Madrid, this conference will cover all aspects of the blasting process. An accompanying exhibition will also be present. Contact: Scientific Coordination, Prof José Sanchidrián; Tel: +34 913367060; web: <http://www.fragblast.org>

**29 SEPTEMBER**

## **Tunnels and Tunnelling Conference 2009, London, UK**

T&T with the British Tunnelling Society present a one day conference packed with cutting edge site reports and technical content. Speakers include Martin Herrenknecht, Barcelona Metro Line 9, and a special presentation by key members of the Crossrail team that will include a Project Update, TBM requirements, Settlement and Monitoring Strategy, and the establishment of the Crossrail Academy. More TBA soon. Contact: Natasha Denney; tel: +44 (0) 208 269 7833; email: [ndenney@progressivemediagroup.com](mailto:ndenney@progressivemediagroup.com)

**08-09 OCTOBER**

## **58th Geomechanics Colloquy 2009 Salzburg, Austria**

The popular annual two day event will be held in the Salzburg Congress Centre with session topics including Projects in Austria, Grouting in Rock, Deep Tunnels, and Reuse of tunnel excavated material. Contact: OeGG; email: [salzburg@oegg.at](mailto:salzburg@oegg.at); Web: <http://www.oegg.at/events/geomechanics-colloquy>

**NOVEMBER 2009**

## **Hong Kong Tunnelling Conference 2009, Hong Kong**

With more than 10 major infrastructure projects currently at the design and planning stage for the region, the Institute of Materials Minerals and Mining is organising this conference. Date and speakers TBA. A call for abstracts will be issued soon. Contact: Email: [secretary@iom3.org.hk](mailto:secretary@iom3.org.hk)

**6-27 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](mailto:technologieakademie@unileoben.ac.at); Web: <http://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](mailto:info@stuva.de) web: <http://www.stuva.de/>

## **BRITISH TUNNELLING SOCIETY**

**18 JUNE: The Pinheiros Station collapse**

Lessons learned from the station collapse in Sao Paulo will be explained by Prof A Assis, and Dr J Barros from the Sao Paulo Institute for Technical Research. 6pm start at the ICE

**17 SEPT: Seismic Response of Tunnel Linings**

Segmental lining radial and circumferential joint behaviour during seismic activity and mitigating designs are discussed by Gary Kramer, Hatch Mott MacDonald. 6pm start at the ICE

**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](mailto:anders.lonnermark@sp.se); web: <http://www.sp.se/en/units/fire/news/ISTSS2010/>

**14-20 MAY**

## **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: <http://www.wtc2010.org>

**8-10 JUNE**

## **InterTunnel 2010 Turin, Italy**

Tunnelling exhibition aimed specifically at those involved in the construction of and equipping and operation of tunnels. Contact: Mack Brooks Exhibitions; web: <http://www.intertunnel.com>

## **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: Tris Thomas, 'Tunnels & Tunnelling International', Progressive House, 2 Maidstone Road, Sidcup, Kent DA14 5HZ, United Kingdom. Fax: +44 208 269 7840 Email: [tthomas@tunnelonline.info](mailto:tthomas@tunnelonline.info) Web: [www.tunnelonline.info](http://www.tunnelonline.info)**

# Contacts

**HEAD OFFICE**  
**Progressive Media Markets**  
Progressive House  
2 Maidstone Road  
Sidcup, Kent  
DA14 5HZ  
United Kingdom

**WEB**  
[www.tunnelsonline.info](http://www.tunnelsonline.info)

**TEL**  
+44 20 8269 7789

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+44 20 8269 7840

## HOW TO CONTACT US

### EDITORIAL

**EDITOR**  
**Tristan Thomas BSc (Hons)**  
Tel: +44 20 8269 7893 Fax: +44 20 8269 7840  
Email: [tthomas@tunnelsonline.info](mailto:tthomas@tunnelsonline.info)

**DEPUTY EDITOR**  
**Jon Young**  
Tel: +44 20 7336 5254 Fax: +44 20 8269 7840  
Email: [jyoung@tunnelsonline.info](mailto:jyoung@tunnelsonline.info)

**CONTRIBUTING EDITOR**  
**Patrick Reynolds MEng**  
Tel: +44 20 8269 7748 Fax: +44 20 8269 7840  
Email: [patrickjreynolds@hotmail.com](mailto:patrickjreynolds@hotmail.com)

**DESIGN**  
**Natalie Kyne**

**TECHNICAL ILLUSTRATOR**  
**Nick Stenning**

**PRODUCTION CONTROLLER**  
**Loraine Lee**  
Tel: +44 20 8269 7799 Fax: +44 20 8269 7840  
Email: [lle@progressivemediagroup.com](mailto:lle@progressivemediagroup.com)

### ADVERTISING

**GROUP ADVERTISEMENT MANAGER**  
**Gary Tween**  
Tel: +44 20 8269 7849 Fax: +44 20 8269 7840  
Email: [gtween@tunnelsonline.info](mailto:gtween@tunnelsonline.info)

**NORTH AMERICAN MANAGER**  
**Steven Caming - Granite Media Services**  
Tel: +1 603 447 1187 Fax: +1 603 447 6166  
Email: [granitemediaservices@yahoo.com](mailto:granitemediaservices@yahoo.com)

**EUROPEAN MANAGER**  
**Randolf Krings**  
Tel: +49 611 5324 416 Fax: +49 611 5324 519  
Email: [t&t@emcmedia.de](mailto:t&t@emcmedia.de)

**ITALIAN OFFICE**  
**Ediconsult**  
Tel: +39 02 477 10036 Fax: +39 02 477 11360  
Email: [milano@ediconsult.com](mailto:milano@ediconsult.com)

### PUBLISHING

**PUBLISHING DIRECTOR**  
**David Wildman**  
Tel: +44 20 8269 7778 Fax: +44 20 8269 7840  
Email: [dwildman@progressivemediagroup.com](mailto:dwildman@progressivemediagroup.com)

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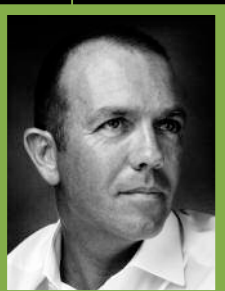
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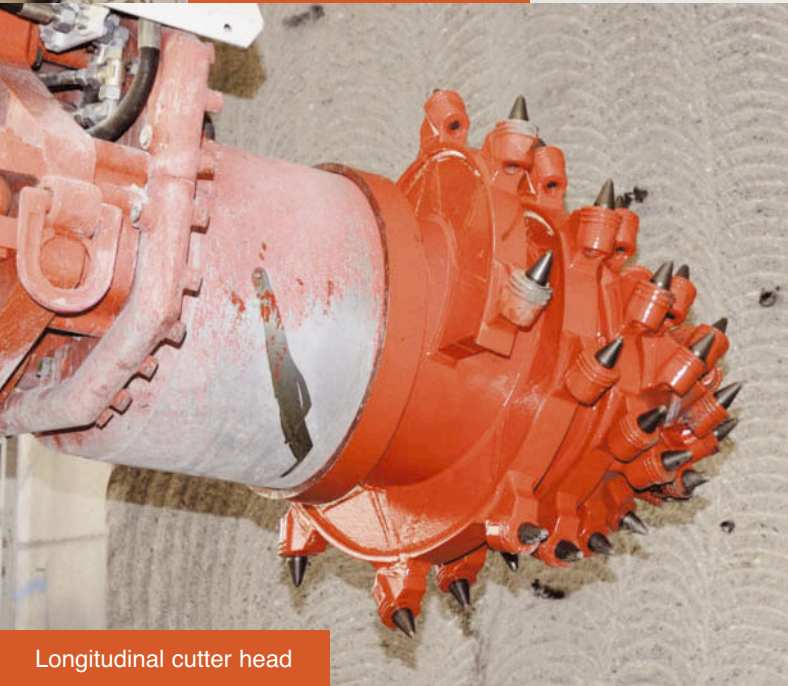
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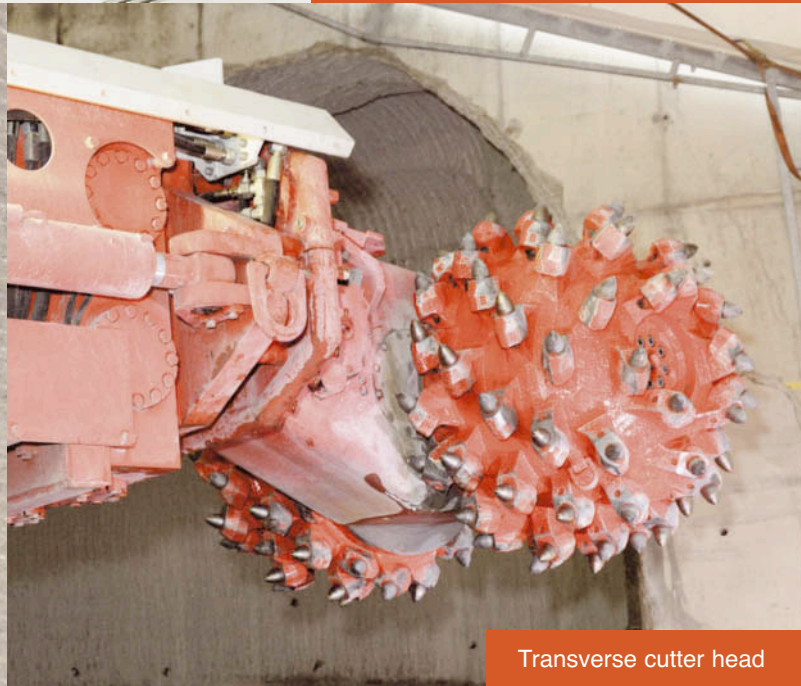
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