JULY 2009

tunnels & tunnelling INTERNATIONAL

FOCUS ON REFURBISHMENT

Build new or refurbish? T&TI looks at the viable alternatives available

FIBRE TECHNOLOGY

The advantages and disadvantages of steel and synthetic fibres is examined

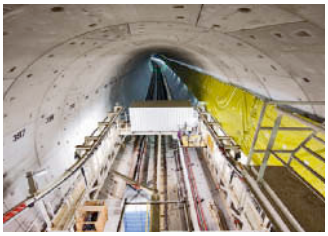
AUSTRIA: DOUBLE BREAKTHROUGH IN THE LOWER INN VALLEY.

An important milestone has been reached as part of the construction of the high speed railway route Berlin-Palermo. Two Herrenknecht tunnel boring machines successfully excavated a total of more than 9 kilometers of tunnel for the new Lower Inn Valley Railway Line in Austria. The S-352 completed the 5,768 meter long "H3-4 Münster-Wiesing" section in the beginning of February 2009. The S-381 reached its target of the "H8 Jenbach" section on April 24 of this year.

The two Mixshields (∅ 13m each) mastered their respective routes safely and quickly with small overburdens of sometimes just 7 meters and in very heterogeneous geologies. The S-381 reached top weekly performances of up to 108 meters, the S-352 even produced up to 163 meters. As a result the construction of the entire route can advance on schedule. Herrenknecht congratulates the ARGE Münster-Wiesing and the ARGE Tunnel Jenbach on this great success.

MÜNSTER | AUSTRIA

PROJECT DATA	CONTRACTOR
S-352, S-381 **2x Mixshield** Diameter: 13,000mm Driving power: 3,200kW Tunnel lengths: 5,768m, 3,467m Geology: S-352: sand, clayey silt, gravel S-381: bunter sandstone with sand and silt, sandy to silty gravels with pebbles	S-352: Arge Münster-Wiesing (Porr AG, Max Bögl Bauunternehmung GmbH & Co. KG) S-381: Arge Tunnel Jenbach (Strabag AG, Hochtief Construction AG, Ed. Züblin AG)



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HERRENKNECHT
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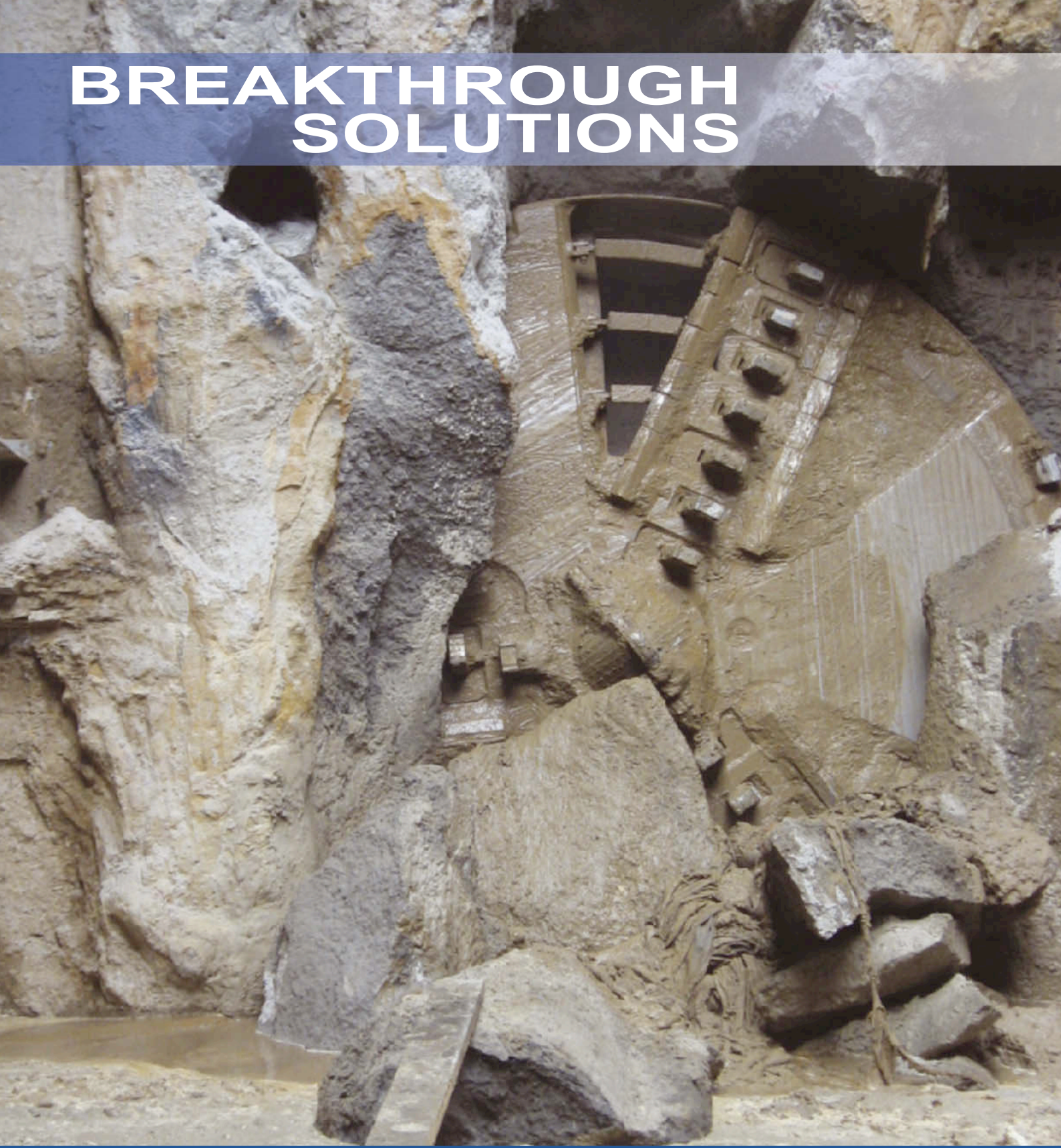
FIBRE TECHNOLOGY

BREAKTHROUGH SOLUTIONS



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Get off your high horse

I'm getting increasingly irritated with environmentalists. Not, you must understand, the educated environmentalists who spend years studying the complex scientific interactions that shape the world we live in today in an attempt to safeguard its future. Indeed, they have my full and utmost respect.

No, it's the bongo beating, generally upper class dog-on-a-string drop outs, who've nothing better to do for a year or two than jump on the nearest anti-anything bandwagon that make my blood boil. Before I'm accused of being anti-protest, which believe me I'm not, hear me out. The reason these often overly militant, woefully un-researched in their subject types annoy me is they taint the serious issues, and those championing them, with a total lack of credibility, and often create an un-necessary backlash against the very things their hearts so apparently bleed for.

A good example of this is the general antipathy towards hydropower. Recently the opening of the Glendoe Hydropower Project near Loch Ness in Scotland was featured on the BBC news. Whilst rightly glorifying it's construction the reporter said that it was unlikely more would be built – due to 'environmental' reasons. Would somebody please tell me what these reasons are? Glendoe was designed to have a minimum impact on the environment, as are most hydropower projects. In many ways the reservoir looks more like an infinity pool, with the dam virtually invisible. The local wildlife by all accounts has remained untouched. So what exactly was the damage people are so upset about?

I witnessed much the same in the rugged Icelandic outback at the Karahnjukar Hydropower project some years ago. Protesters were up in arms about its construction (during the summer of course, and strangely mostly young British), sporadically chaining themselves to plant in a bid to halt construction. The fact is, from an environmental point of view, you would never know it was there, it is genuinely in the middle of nowhere, and doing no damage whatsoever. It does what it is supposed to do – create power with the minimal environmental consequence.

The crux of the matter is this - we need electricity. There is no getting away from it, and denying this is burying your head in the sand. Hydropower is a clean form of renewable energy. Maybe for the protesters we should use the buzzword 'sustainable' as it seems to tick more politically correct boxes.

So the choices are there, you need power, unless you are committed to living in a cave without electricity, never driving a car and existing off the land, a lifestyle for which you would have my everlasting respect, but I suspect most 'protesters' would prefer not to endure.

It is blatantly naïve, dangerous even, to stand in the way of such engineered solutions just for the sake of protest, when these solutions have been created to make the world a cleaner and more 'sustainable' place to live in, for this generation and beyond.

Tris Thomas

COMPANIES IN THIS ISSUE

Gotthard breakthrough

Gotthard Base Tunnel's Gabi 1 TBM broke through the last metres of gneiss in the eastern tunnel between Erstfeld and Amsteg last month, half a year ahead of schedule. The 57km rail project through the Alps is broken into five stretches with the Erstfeld-Amsteg section at the northern end. It is the second to last section to breakthrough.

Left: The Erstfeld-Amsteg stretch is the second to last section to celebrate a breakthrough

The 9.58m diameter Herrenknecht TBM (S-229) bored south 7.2km from Erstfeld at the northern end of the tunnel to the access shaft at Amsteg in 18 months. At breakthrough the tunnel had a deviation of just 4mm horizontally and 8mm vertically.

The gripper TBM bored through an average of some 14m of hard rock a day under mountain overburdens of up to 1,000m. The best daily performance achieved was almost 40m of excavated and secured tunnel.

Renzo Simoni, CEO of AlpTransit Gotthard, said "The breakthrough is a further important milestone in the construction of the Gotthard Base Tunnel."

Gabi 1 had already proved to be a sprinter during its first operation from Amsteg to Sedrun. After being launched in May 2003 and up to full speed by October 2003, the TBM completed the 11.3km stretch by June 2006, nine months ahead of schedule.

After breakthrough at Sedrun, the TBM was disassembled below ground and removed using the mine train. It was then overhauled and rebuilt in front of the north portal entry in Erstfeld. It relaunched on December 4, 2007.

Gabi 2, the sister TBM in the western tunnel, is still on its way to Amsteg. By the middle of June, the 441m giant with a cutterhead power of 5,000 HP had bored 5,908m towards Erstfeld, some 83 percent of the stretch.

A spokesman for AlpTransit Gotthard said the firm was very satisfied with the construction achievements. The Erstfeld to Amsteg is the second-to-last of the five sections to celebrate a breakthrough.

Of the 153.5km of the tunnel system under the Gotthard, 133km or 87 percent have now been excavated. According to the construction program, the final breakthrough between Sedrun and Faido will take place at the beginning of 2011.

Trapped workers rescued

Eight workers trapped inside a collapsed tunnel early last month were rescued after three days underground. The workers were excavating the Yingbin expressway tunnel near Sanya City in Hainan Province off the South coast of China when the collapse occurred.

According to local press reports the eight men were working for Changsha Road and Bridge Construction. Wen Junliang, the chief engineer of the company, told Xinhua news agency on Sunday that the shale sand and erosion common to the area make collapses likely.

At 11.30pm on Thursday 4 June the tunnel collapsed trapping the workers 150m in from the entrance. More than 100 firefighters, police and medics tried to free the trapped men but two initial attempts were abandoned after heavy rains threatened a landslide.

On Saturday morning a 26m hole was drilled into the collapsed tunnel and food, water and a torch were passed down to the men.

Throughout the day a demolition team dug a 22m rescue tunnel to the trapped site. Using steel plates to secure the tunnel the rescuers tried to enlarge the hole so the workers could be brought out one by one.

Some 63 hours after becoming trapped the eight workers walked to ambulances with the help of rescuers. Tang Jinxian, chief physician at Sanya People's Hospital told Xinhua News Agency that six men were in good health while two were suffering from diarrhoea.

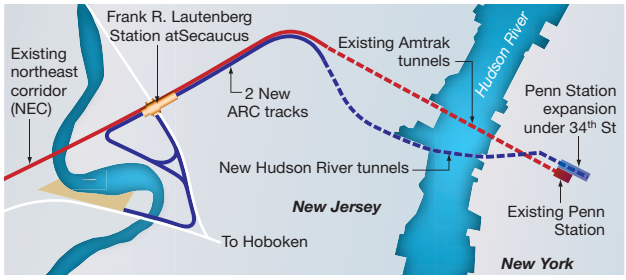
The local government has launched an investigation into the cause of the accident.

THE Tunnel breaks ground as funding committed

New York and New Jersey's Access to the Region's Core (ARC) Mass Transit Tunnel – also known as the Trans-Hudson Express (THE) Tunnel - reached a major milestone when US Governors, Senators and Federal Officials broke ground on the project last month.

"Today this project finally moves from the drawing board to construction," said Port Authority Executive Director Chris Ward.

The US$8.7bn project, being built in partnership with the Port Authority of New York & New Jersey, includes two new 6.5km long, single-track rail tunnels between NJ and NY, additional capacity north of NY Penn station under 34th St in Manhattan, and signal and track improvements. Subway links will also feature.



US Senators Lautenberg, Menendez and Governor Corzine announced a major funding agreement with the Obama Administration that enables the initial phases of the project to advance with federal funding.

The Early Systems Work Agreement (ESWA) provides $1.35bn in funding for the early phases of the project, about half of which is from federal sources including the American Recovery and Reinvestment Act (ARRA).

The 6.5km tunnels have been broken into three contracts: The Palisades Tunnels, the Hudson River Tunnels and the Manhattan Tunnels. Soft and hard ground TBMs will be used on the job.

Pre-qualified contractors for the final design and construction of the Manhattan tunnels were also announced last month. They are:

1) Barnard of New Jersey and Judlau Contracting JV

2) Shea/Schiavone Skanska, JV

3) ARC Constructors - a JV of S.A. Healy Co. and CCA Civil/Halmar International

Work is expected to start next year and completion is scheduled for 2017.

Left: Severe wear has shut down slurry machines on the Brightwater Conveyance Tunnel

Standstill in Seattle

Severe wear has brought both 5.1m diameter Herrenknecht slurry machines to a standstill on the Central contract of Seattle's US$1.8bn Brightwater Conveyance Tunnel, requiring contractor Vinci/Passons RCI/Frontier-Kemper JV to lay off about 60 of its union tunnel workers while repairs are being undertaken.

Shortly after resuming the westbound (BT2) tunnel drive in March, following a previous three month delay for repairs to the cutterhead of 'Helene' (*T&TNA*, March 2009, p9), a machine inspection carried out in mid-May revealed new severe wear to the rear outer rim of machine's cutterhead. The extent of the damage prompted the JV to also carry out an additional intervention on the eastbound BT-3 machine, which revealed similar damage, albeit not as extensive. The exact cause of the excessive wear is still under investigation.

A TBM repair programme for BT-2 is now underway, while a plan for BT-3 is still being finalised. However, with both machines approximately 300ft deep and currently in about 5 bar of pressure, manned interventions into the cutterhead at 5-5.5 bar using Trimix gases are required. Working times at these pressures are in the order of one hour per intervention followed by five to six hours of decompression, resulting in a net productive repair time of just three hours a day.

In addition, BT-2 is currently situated directly beneath an access road to a school. However, now that this is closed for the summer, five screened dewatering wells are being installed from the surface to locally dewater the ground around the TBM. This will allow the repairs to take place in low, or atmospheric, pressures. "The necessary permissions have been obtained and drilling of the dewatering wells began in late June, just after the school closed for the summer," says Anthony Pooley, Project Manager for the Jacobs Engineering-led Construction Management team.

The BT-2 drive is currently about 65 percent complete, with 1,225m remaining, while the BT-3 drive is approximately 49 percent complete, with 3,150m yet to be driven. It is hoped the TBM repairs will be complete by the end of August, but the new delays to these Central tunnel drives pose a big challenge for overall project contract interfacing and scheduling.

The BT-2 machine is due to break through into a permanent shaft called the "Influent Structure" (*T&TNA*, December 2008, p15). Under the original design, the completion of this shaft and the subsequent testing and start-up of the entire Brightwater treatment plant and tunnel system required the BT-2 drive to break through first. Changes to the structural design and piping layout of the Influent Structure shaft are therefore now being made in order to mitigate the delays, so that the shaft can be largely completed and testing and start-up can proceed independently of BT-2's completion. While this strategy still leaves the pressing need to complete the Central tunnels, it constitutes a significant cost and schedule risk reduction for the other elements of the system and for the program as a whole.

Meanwhile, the project's West Tunnel contract (BT-4), being undertaken with a 4.7m Lovat EPBM by the Jay Dee/Coluccio/Taisei JV, restarted in mid-June following a successful planned two-week maintenance stoppage.

End of an era for Lovat

Last month, a few days prior to the Rapid Excavation & Tunneling Conference (RETC) in Las Vegas, Rick Lovat officially resigned as president and CEO of Lovat Inc. Dick Cooper, who has worked within the Caterpillar organisation for over 20 years, will succeed Rick as the president of the company.

The move follows the acquisition of the Lovat family business by Caterpillar in April last year and is said to be a strategic move to ensure that the company fully benefits from Caterpillar's desire to grow and develop the company. "I am excited to join Lovat," said Cooper. "[The Company's] potential for further growth and expansion in both existing and new markets is substantial. I look forward to working closely with our clients and employees to contribute to Lovat's ongoing and future success." Cooper will also continue his role as General Manager of Caterpillar Global Mining Operations for the Melbourne and Burnie facilities.

Above: Dick Cooper succeeds Rick Lovat at the helm

Rick Lovat and his father Richard were both at the RETC event to endorse the change of leadership and to reassure customers and colleagues that they remain committed to assisting the company's future success wherever possible. When asked what he intends to do now, Rick told *T&TI* that he was looking forward to taking some well-earned time off, but will remain involved in the industry.

Tunnel weighed for Jaipur metro

Studies are underway for the proposed metro in Jaipur, in the state of Rajasthan, India, which may see tunnelling works on the project.

The Detailed Project Report (DPR) for Phase 1 of the scheme is being prepared by Delhi Metro Rail Corp (DMRC), and is scheduled to be submitted in early 2010 for assessment by authorities.

Phase 1 of Jaipur metro is expected to be approximately 30km long. DMRC said that the alignment and profile of the route was still being studied, and indicated that tunnels for part of the route remain a possibility. No decision has yet been made on whether the line will be in tunnel, elevated or at grade, or a combination.

DMRC said its was preparing to have contractors and consultants carry out studies for the metro's DPR, covering geotechnical, topographical, environmental impact assessment and both traffic and transport analyses.

Whether the Jaipur Metro will require tunneling or will be elevated/at grade will be suggested in the DPR, which we are likely to submit by early next year. For the site investigation, many of the boreholes, ranging in depths from 5m to 30m depending on competence of the strata, will be done along roads.

DMRC is a JV of the national Government and the Government of Delhi.

Last TBM's for Rome

Preparations were last month being made for the third and fourth machines to get underway on Rome metro's Line C. More than 7km of tunnels had been excavated by the middle of last month by the first pair of the four EPBMs that will work on the project.

Line C is a twin tube line being developed by the capital's metro transportation arm, Roma Metropolitane, and will run from Monte Compatri/Pantano in the south east to Clodio/Mazzini in the north west of the capital. About 17.6km of the route, or a total of 35.2km, will be in bored tunnel.

Parallel 5.8m i.d. drives are the current focus of the bored tunnelling work and are being driven between Giardinetti, in the south east quarter, and San Giovanni station, which is closer to the city centre. Later, to complete the main section of the line from San Giovanni to Clodio/Mazzini there will be larger diameter (approx 10.10m diameter) bores driven.

The current drives are being undertaken by two 6.69m diameter Herrenknecht EPBMs, which are advancing north west from Giarinetti to terminate just beyond Parco di Centocelle station.

Geology along the entire alignment of the underground section of Line C comprises silty sand, gravel and clayey silt.

The first TBM, S-409 and named "Shira", is to drive 5.5km. By 15 June it had advanced 3964m, constructing 2832 precast concrete rings, each 1.4m long with seven segments. Over the preceding four weeks the shield had bored 329m, or 235 rings.

TBM 2 is to drive the same distance and by the middle of last month had progressed 3269m, having built 2335 rings. The shield, S-410 and named "Filippa", had advanced 558m, or 398 rings since mid-May.

The daily advance of each 6.69m diameter machine has been about 16m, in line with the expected range of 8m-12m up to a maximum of 20m. The TBMs are due to finish their drives by September and then be dismantled, removed and refurbished for relaunch in April 2010. They are next to drive the section of Line C from Malatesta northwards to San Giovanni.

Between those separate sections that will be constructed by the shields lies the 5.4km long stretch to be bored by another pair of Herrenknecht TBMs. Their cutterheads were lowered three months ago, at Malatesta, and TBM 3, or S-479 and named "Diana", has just been launched to drive south east.

The fourth machine, S-480 and named "Roberta", is due to be fully operational by September, said the design and build contractor Metro C Spa, which is a JV led by Astaldi. Like the first pair of shields, the latest TBMs will terminate their drives between Mirti and Parco di Centocelle stations.

Line will be Rome's first fully automated tube line. The main section will be approximately 25km long with 30 stations and double the capacity of the network. The first section to be operational, by 2011, is from the south east end of the line at Monte Compatri/Pantano to Parco di Centocelle. By late 2012 the next section, extending north west to Lodi station but short of San Giovanni, is to be commissioned.

North of San Giovani the diameter of the bored tunnels is to be stepped up to 8.8m i.d. to accommodate station needs without the project requiring extensive surface excavations in the ancient heart of the city. That length of line is not due in service until 2015.

Five killed in tunnel crash

Five people were killed when two cars collided head-on and caught fire in the Eiksund undersea road tunnel early this month. Local highway police reported that the accident occurred on the Sunday evening of 12 July.

The Eiksund Tunnel links the Norwegian mainland and Hareidlandet Island, off the Møre og Romsdal county coast. The tunnel is among Norway's longest, at 7.8km, and is also the world's deepest sub-sea road tunnel, running 287m below sea level at the deepest point.

The tunnel carries three lanes of traffic. The average daily traffic through the Eiksund Tunnel is around 1,000 vehicles, 50 percent of which are trucks. At one point, between the tunnel's deepest point and Eika Inlet the gradient is 9.6 percent. According to the European Union (EU), a tunnel gradient should not exceed 5 percent but in Norway, which is not a member of the EU, gradients can reach 10 percent. Steep gradients have been known to deter some drivers from using the tunnel, such as on the Oslo Fjord Tunnel, which has a gradient of just 7 percent.

It is not known whether the steep gradient was a factor in the accident.

The US$78M tunnel opened to traffic on 23 February 2008.

NATM breakthrough on Delhi metro

Contractors on the Delhi Metro last month achieved breakthrough on the first NATM tunnelled stretch of the project to be completed in soft ground. The 185m tunnel south of Saket station was too short to warrant a TBM and the proximity of the Qutab Minar, a world heritage site, was a further deterrent to excavating an access shaft.

The NATM bored section is the final part of the 1.85km stretch linking Qutab Minar station with Saket station on the Central Secretariat-Gurgaon line. For the first 645m the line runs above ground and then enters a cut-and-cover tunnel for 1020m before reaching the NATM section.

A spokesman for the Delhi Metro Rail Corporation said, "A TBM was not used here as the distance was small and lowering the TBM near the Qutab Minar could have been difficult and very expensive."

He added that NATM tunnelling in the soft ground was difficult, as the soil needs to be immediately cemented and strengthened to prevent collapse. DMRC engineers have already used NATM in hard rock condition at Chawri Bazar and the Delhi Ridge forest.

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

Above left: Breakthrough of the NATM tunnel
Left: A view down the 185m long soft ground tunnel

BOMBELA

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 m3/h
- Rolling Stock 900 MM
- FERMEL Utility vehicle
- BOART LONGYEAR Charging Unit
- Grout Pumps CLIVIO
- Agitator Hopper SECATOL: 7m3 - 10 m3
- Gantry Crane: 30 - 40t
- Side tipping bucket GERSTADT. Capacity (3m3 - 4m3)

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GAUTRAIN
FOR PEOPLE ON THE MOVE

Extra shaft to keep Airport link on time

Contractors on Brisbane's US$3.8bn Airport Link last month submitted a request to sink an additional shaft to keep the project on schedule. Ground conditions had proved worse than expected and will slow tunnelling progress on certain sections of works.

To prevent delays in project delivery Thiess John Holland is seeking permission to excavate a 42m deep, 15m diameter shaft on Rose Street in Wooloowin near the Kendron ramps to allow early excavation of the east and west caverns, prior to the arrival of TBMs from Kalinga Park. With additional work launched on Ramp B the new construction program will give TJH three extra workfronts to overcome delays.

According the report submitted in support of the construction sequence change, "After commencement of the project works, further geotechnical fieldwork, assessment and analysis has identified significantly poorer ground conditions than anticipated at initial design."

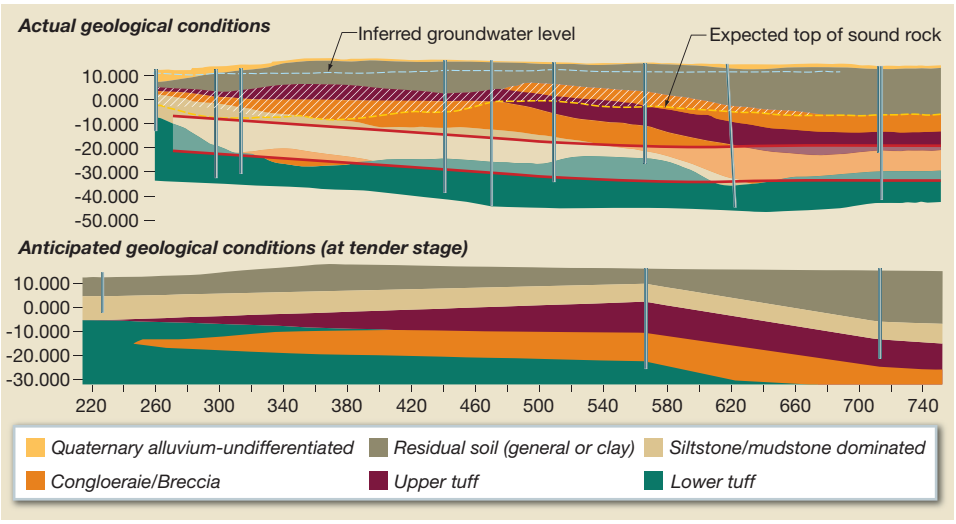
The poorer ground conditions impact not only on the difficulty of excavation but also on the type of support that is needed. The heavier, more robust support that has been detailed for the new geology will also delay the project.

Project client BrisConnections CEO Ray Wilson said, "The proposed worksite will provide temporary access to the Airport Link's tunnel caverns, where the mainline tunnels join with the entry and exit ramps at Kedron.

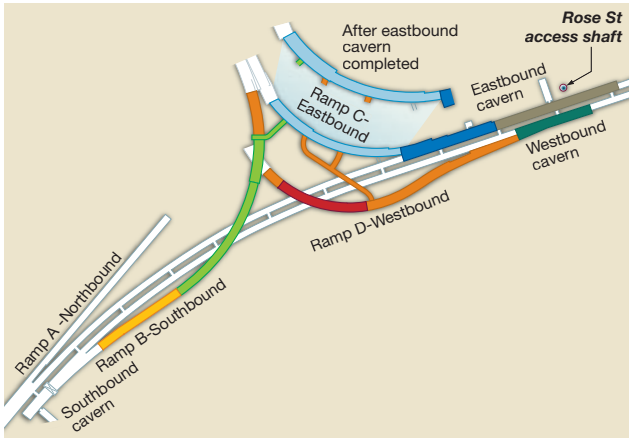
"By establishing this site we can accomplish two crucial objectives: launching our roadheaders to begin excavating the tunnel caverns for the TBMs, and afterwards, delivering concrete to the caverns which will enable the final lining of the tunnels to be completed."

A BrisConnections spokesman said the project was contracted at a fixed cost. Sinking of the shaft will be funded by the contractor.

If the request is granted works from the site could take up to 30 months to complete but the project will remain on schedule for completion in 2012.



Above: **Actual geological conditions proved worse than anticipated**



Austria on track

Excavation works for a major rail project in Austria, at the Lower Inn Valley project, has been completed, and elsewhere in the country the smaller but key rail bore at Hengsberg has also reached a milestone.

With breakthrough of the TBM driving the 3470m long Lot H8 (Jenbach) section of the high-speed rail link completed, the main tunnelling works on the Lower Inn Valley have been completed, said developer Brenner Eisenbahn GmbH (BEG), part of the Austrian rail authority OBB.

The contractor, ARGE Tunnel Jenbach, is a JV of Strabag, Zublin and Hochtief. Excavation started in late 2007.

The JV used a 13m diameter Mixshield (S-381) – "Jenny" - supplied by Herrenknecht, to bore through mottled sandstone, sand, gravel and stones.

The Lower Inn Valley is the northern rail access to the future Brenner Base Tunnel.

Separately, on the rail upgrade being developed by OBB between Graz and Klagenfurt, tunnellers holed through at the 1695m long Hengsberg tunnel slightly earlier than scheduled due to the geology having less groundwater than expected. Drill and blast method was used for about two-thirds of the drive.

Above: **Excavation at Hengsberg peaked at 12m in one day**

New bores for NY ESA

Excavation on the East Side Access (ESA) project, in New York, is getting underway again after the Metropolitan Transportation Authority (MTA) last year awarded Dragados/Judlau JV a second contract, leading to an increased number of bores and change in construction sequence.

Eight rail tubes, double the initial number the JV was contracted to build, are to be bored by the two 6.7m diameter machines on the project – a Robbins mainbeam and a TBM from Seli, which was originally manufactured by Robbins.

The initial contract called for a pair of twin tunnels (2 x 2, Upper and Lower) to be bored to Grand Central Station, or Terminal (GCT). The machines would advance from GCT5 caverns below 63rd St and 2nd Ave and do split drives, boring a 2.1km long Upper tunnel, be pulled back to GCT5 and then excavate a 1.7km long Lower tube.

Geology along the alignments comprises schist with gneiss of UCS 80MPa-200MPa. Tunnel support is in-situ concrete in the worst areas and elsewhere ribs, bolts and mesh.

However, within months of the TBMs getting underway, the JV won the CM019 contract which calls for additional caverns (GCT3) en route. It decided to minimise drill and blast for GCT3 by putting the TBMs to greater use - doubling the number of bores in the area (four Uppers, four Lowers) – and, consequently, also creating four other tunnels to run beyond to the station.

Above/Right: The 6.7m diameter TBMs will bore twice the number of tunnels after a new cavern contract was awarded

To achieve this, each machine would first do Upper tunnels – the initial one planned plus a new one. They would only be pulled back as far as the GCT3 area to be relaunched on the second Upper tube.

Seli's TBM got underway in late 2007 and by the middle of last year had completed 1.7km of tunnel as the approach to GCT3 plus the new Upper tunnel, with an average advance of 15.5m per day. It was retracted to GCT3 and resumed boring in May on a 900m stretch for the second Upper bore, and has been progressing up to 24.4m per day. In total, including the two Lower tunnels, Seli said the TBM has 3.1km of excavation to complete.

The Robbins TBM resumes its excavation this month having previously completed two Upper drives in September 2008 and February, it said. In total, the TBM had bored 2.77km, and it was pulled back to GCT5 for relaunch on its third, Lower tunnel drive, which will be 1.58km long. The other Lower bore is to follow with launch from GCT3.

ESA is being built to join the Long Island Rail Road (LIRR) to a new terminal at Grand Central Station, in Manhattan.

Breakthrough in Ethiopia

The pair of Seli TBMs on the the Gilgel Gibe II hydropower project, in Ethiopia, completed their drives last month to finish the 26km headrace tunnel.

Seli's 6.98m diameter double-shields had radically different experiences on the project in which competent basalt had been expected, but they successfully completed the power tunnel when they met on 6 June.

The DSU-TBM advancing on the outlet drive experienced very good geology, and despite some hot water inflows and several fault zone it regulary achieved advance rates of 500m-600m per month, and even up to 900m in the early stages. In the end, having taken on a bigger share of the excavation, the shield built more than 18km of tunnel.

At the inlet drive the tunnelling experience was very difficult and became progressively worse, calling for chemical grouting at the face plus bypass digs and overcutting to counter squeezing ground before the worst problem hit that stopped progress in this part of the project for almost two years.

In October 2006, only 4.2km into the bore, a major fault was encountered with 40 bar flowing mud which pushed the machine back, destroyed a few metres of 250mm thick hexagonal segmental concrete lining and partly-filled the tunnel for some distance.

To overcome the adverse geology and impact on the equipment, the remedial works included 230m of bypass tunnels, mucking out of almost 40,000m^3 of mud and boring 1600m of drainage/exploratory holes. The recovered TBM was dismounted, pulled back a few hundred metres and reassembled behind the fault.

Last August the DSU-TBM was relaunched on a different alignment that bypasses the fault (*T&TI*, August 2008).

Seli started the works in mid-2005 under a subcontract to Italian group Salini Costruttori, which is building the hydropower project for a national energy utility, the Ethiopian Electric Power Corp (EEPCo). The headrace is scheduled for hydraulic test and operation in September.

Elsewhere in the country Seli has also had two machines working on another hydropower project – the Beles Multipurpose Scheme ("Beles II"). The TBMs, a DSU and also one of Seli's most advanced machines, an EPB-DSU, were used on the tailrace and headrace tunnels, respectively.

Above: Last month's breakthrough was hard won

WHEN PERFORMANCE MATTERS...

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NFM opens in Shenzhen

A branch office of NFM Technologies has been established in Shenzhen, China, to support the 18 supply contracts it has for TBMs in Guangdong province.

NFM said the new office – its third in China – has been set up with its sister company Shenyang Heavy Machinery Group (SHMG). The other offices are in Beijing and Shenyang.

The office is called the NFM-SHMG TBM Shenzhen Service Center. Both NFM and SHMG are owned by China's Northern Heavy Industries (NHI) group.

In a statement, NFM said the new office would enable it to offer better support at the various stages of project development and site work, ensuring operational performance of the machines and also reducing lead times.

Of the 18 TBMs that NFM is providing to projects in Guangdong, 14 are currently on projects – four on the Shiziyang rail project and 10 spread over two metro schemes: Guangzhou (4) and Shenzhen (6).

Four additional machines – 6.28m diameter EPBMs – are either being assembled on site or manufactured in Shenzhen for supply to Line 2 of Shenzhen metro this year, and orders have recently been received for another two shields.

Two TBMs have been ordered by CRCC-B13 for drives of approximately 3km, respectively – one is being assembled on site, the other is in workshop tests. The other two were ordered by Hydro-B2, each to drive 1.65km long stretches of line, and are due for workshop tests in the third quarter.

Two further orders for 6.28m EPBMs to use in the Shenzhen metro system were received in May, from SHMG.

TBMs currently excavating on Shenzhen metro include four 6.28m diameter EPBMs on drives of at least 3km on Line 3 – two for BUCG and one for B1 – plus a shield for CSCEC Shenzhen, which is well advanced on a 1.5km drive.

On Line 2 of Shenzhen metro, EPBMs of the same size will be used by CSCEC Shenzhen and Shenzen Tianjan on drives of 1.5km and 2.3km, respectively. CSCEC Shenzhen also recently started a 1.7km drive with a 6.28m diameter EPBM on a project to extend Line 1.

Four "Benton Air" shields are well advanced into their drives, each at least 4.5km, on the Shiziyang rail project. Customer B12 has two 11.12m diameter TBMs, and CRTG has another pair.

On Shenyang metro, by last month SHML1 was 200m into a 1.4km long drive using a 6.28m diameter EPBM.

Two further shields are soon to excavate on Shenyang metro, on Line 2, each on drives of just over 1.1km, respectively.

Separately on Line 2, customer CRTJ is two-thirds into a 3km bore with a "Benton Air" TBM, and the machine is passing below the river Shenyang.

BrisConnections wins survival vote

Last month, only weeks after roadheader tunnelling moved to 24-hour operations on the Brisbane Airport Link and Northern Busway project, the concessionaire BrisConnections won the votes needed to defeat a move by a unit trust investor to remove it from the project.

BrisConnections said the move against it was stopped on 22 June when three resolutions were defeated – to remove and replace it as the responsible entity on managing unit trusts, and to defer a payment due from unit trust holders as part of the fundraising for the major transportation scheme.

Two key unit trusts that are helping to fund the toll road project are managed by BrisConnections Management Co Ltd (*T&TI*, April, p).

BrisConnections comprises Macquarie Capital Group, Thiess, John Holland, Arup and PB. Design and construction of the link is being done by a JV of Thiess and John Holland under a fixed-price, fixed term contract for completion by 2012.

Tunnelling started in March with two roadheaders, and at peak the job will have 11 units and two TBMs. In total, the project will involve 11.8km of main tunnel, including 5.7km long twin tunnels.

More design jobs at Crossrail

Mott MacDonald has won a second design contract on Crossrail tunnelling work among the second batch awarded by the developer, which also last month appointed an Implementation Director.

The consultant was awarded the Tunnel and Shafts Aerodynamics and Ventilation contract (C124) while Scott Wilson picked up both the Farringdon station and Pudding Mill Lane Portals design contracts (C136, C152).

Motts success follows the award of the design contract for sprayed concrete lining (C121). Other winners among the first batch of design package awards at the end of May were: Capita Symonds to do the Royal Oak Portal (C150), and, a pairing of Arup and Atkins for the bored tunnels (C122) and Tottenham Court Road station (C134).

Main construction on the US$26.2bn project is to begin in 2010 and tunnelling of the 6m i.d. twin tubes in 2011 for rail operations to begin in 2017.

David Bennett has been appointed to the newly created post of Implementation Director and will liaise with the Project Delivery Partner - Bechtel, supported by Halcrow and Systra. He was Deputy Crossrail Project Representative for Crossrail sponsors Department for Transport (DfT) and Transport for London (TfL).

Jacobs Engineering UK with KPMG is Project Representative for DfT.

Crossrail recently appointed Andrew Mitchell to be permanent Programme Director, and Transcend, a JV of Aecom, CH2M Hill and Nichols Group, is Programme Partner (*T&TI*, June, p14).

Robbins' Mexico branch

Robbins has opened a branch office in Mexico as part of a push of EPB TBMs in the country, where it will have four machines in the capital working on two major projects – a metro line and a major sewer scheme.

The national operation is headed by Roberto Gonzalez, who noted a large volume of work coming up in the country and added it is 'an important new market for us'.

The branch offers project management services, TBM field services, conveyors systems services and sales.

Robbins said it may replicate the regional office system to provide extra support to projects in other regions of the world, though for other Spanish-speaking parts of Latin America will use the Mexico office.

The new office offers project management services to the Emisor Oriente sewer scheme, to which Robbins will supply three EPBMs for launch in 2010, and Line 12 of the metro, which will receive a 10.2m diameter shield later this year.

The 8.93m diameter TBMs for the 62km long sewer scheme have been ordered by JV contractor Constructora Mexicana, which includes CICSA. The contractor has also ordered three EPBMs (2 x 8.7m diameter, 1 x 8.89m) from Herrenknecht. The client for the scheme is Conagua, the National water Commission.

A JV including ICA and CICSA are to build the 6.2km long western section of Line 12 on Mexico City's metro (*T&TI*, November 2008, p8).

Ceneri tunnel works award

A contract to construct Lot 852 of the Ceneri Base Tunnel, in Switzerland, was awarded last month to an Italian-Swiss JV for US$908M.

The consortium comprises Italian firms Societa Italiana per Condotte d'Acqua and Cossi Spa Sondrio, and Swiss company Cossi SA Lugano. The JV beat four rival bids, the nearest being more than US$64M, or about 7% difference, from a consortium of Austrian firms Porr and G Hinteregger und Sohne with Italian companies Shella and Cooperativa Muratori Cementisti.

Work on the package calls for the Condotte-Cossi JV to drive twin, 11.5km long single track tunnels. The drives will proceed both north and south from the intermediate adit at Sigirino.

Geology comprised schist, molasses and orthogneiss.

Following set up of site starting in the third quarter, the JV plans to begin tunnelling in around the second quarter of 2010 for completion of the twin bores by 2015.

Separately, water processing for groundwater and soiled water is being undertaken by the Pizzarotti SA Passavant Impianti Spa consortium, which signed the contract (Lot812) in late 2007.

Excavation of the 2.4km long adit at Sigirino was completed in November 2008 (*T&TI*, December 2008, p10).

The adit was bored by a 9.7m diameter refurbished Robbins main beam TBM, and intersected the installation caverns had been carved out in the middle of the main tunnel route from a 2.7km long earlier exploratory tunnel, also at Sigirino.

The JV contractor on the adit was CSC, Lugano, Frutiger, Thun, Rothpletz, Lienhard + Cie and Aarau.

Ceneri Base Tunnel is due to be operational by late 2019 and, in total, will have twin 15.4km long tubes. The client is AlpTransit Gotthard Ltd, which is also developing the Gotthard Base Tunnel. A major tunnel breakthrough was achieved on the project last month.

Cairo Line 3 next stage

The JV of Vinci, Arab Contractors, Bouygues and Orascom Construction Industries (OCI) has been awarded a further package of civil engineering work on Line 3 of Cairo metro, where they are currently building the first phase.

In the Phase 2 package the Vinci Construction Grands Projets-led JV will involve construction of twin-track, single bore tunnel and four underground stations. The 51 month contract is valued at US$453M, said Vinci, and the next stage of Line 3 is to be in service by the fourth quarter of 2013.

The contract was awarded by Egypt's National Authority for Tunnel (NAT), which is part of the Ministry of Transportation.

In early 2007 the JV won the construction contract for the first phase of the Line 3 works in the capital.

The rescheduled Phase 1 civil works started in late 2008 and involve excavation of a 4.2km of single bore tunnel from Abbasia to Attaba using a refurbished, 9.5m diameter Herrenknecht slurry shield previously used on Phase 1A and IB of Line 2. Five box stations (25m wide and 22m-32m deep) are also being built – Attaba, Bab El Shaaria, El Gueish, Abdou Pasha and Abbasia.

Geology along the alignment comprises surface backfill with alluvial deposits, including sand, clay and gravel, and the groundwater profile varies markedly. Lining to the TBM excavation consists of 8.35m i.d. rings (5 + 2 counter) of 400mm thickness. Cover is 7m-35m due to surface variations. Tunnelling was to have started in March 2008 but is expected to be finished by early 2010.

Also recently, but separately, another part of the Vinci Group, Eurovia Travaux Ferroviarires, is part of a JV with OCI that has just won the track and power rail package for Phase 2. Further electromechanical work on Phase 2 is being undertaken by a consortium of Colas Rail, Arab Contractors, Alstom and the Thales Group.

In total, the east-west running Line 3 could eventually to be up to 33km long with 29 stations, be mostly underground. Vinci and Bouygues were involved in earlier metro construction in Cairo in the 1980s.

Wirth rebrand

Wirth Europe has been rebranded as Aker Wirth GmbH following the takeover by the Norwegian group Aker Solutions.

The acquisition process began almost two years ago with a 50% stake being taken in the German tunnelling and oil & gas drilling equipment manufacturer. Aker's stake was recently increased to give a qualified majority holding of 75.1% (*T&TI*, April, p12).

The name change at the end of last month follows the successful integration of Wirth into the new parent group, Aker Solutions said.

A year ago, Aker Solutions was itself rebranded having been Aker Kvaerner. The company is part of the Aker group.

MTRC set for WIL, Shenyang

MTR Corporation (MTRC) has received approval for funding of the underground West Island Line (WIL) in Hong Kong, and has also signed a deal to take forward involvement in Shenyang metro.

Last month the Executive Council of Hong Kong endorsed the scheme and once the Legislative Council also greenlights the funding then construction can get underway shortly, MTRC said.

The 3km long link from Island Line to Kennedy Town, with intermediate stations at Sai Ying Pun and the University of Hong Kong, is due to be completed in 2014.

The Government approved the WIL metro scheme in March. As the cost-benefit balance of the scheme is not sufficient on revenue terms alone, the Government is to give a capital grant of US$1.64bn, Net Present Value (NPV) to a baseline of June, to cover the cost of the strategic link.

Originally, based on the January 2006 cost estimate of only about half as much, the Government then had a smaller bill to cover. But increase in the scope of the project as well as price escalation lead to the jump in costs and required cover by a much larger grant.

Significant ground treatment is required for the project, and the two-stage tender process for the tunnelling contract C703 is to be concluded in the third quarter (*T&TI*, September 2008, p13).

MTRC has also called for submission from consultants to prequalify as independent environment checker (C806) for the Express Rail Link (XRL) project to link Hong Kong with Guangzhou province in the mainland of China.

Separately, the company has signed an operation and maintenance concession for Lines 1 and 2 of Shenyang metro, China. The lines will be 28km and 22km long, respectively, coming into service next year and 2012. A number of NFM shields will be used on metro excavation in the city.

A deal was signed the deal with Shenyang Metro Group Co Ltd, which is owned by the municipal government and will hold the controlling (51%) stake in their JV. MRTC is also exploring investment opportunities in the planned north extension of Line 2 and the proposed Line 4. Shenyang plans to have 11 metro lines built.

BORING THROUGH FUTURE

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Cutting risks with inspections

Left: **Fig 1 - Llocation and topography**

Mohammad Jafari, Ph.D., P.E., CDM, Francois Bernardeau, P.E., CDM, and Michael Gilbert, P.E., CDM explain how tight financial times call for careful ranking of repair requirements

Heroes Tunnel is the only highway rock tunnel in the United States state of Connecticut. The tunnel is part of the Wilbur Cross Parkway, a scenic connection between Hartford and New York. Originally constructed and opened to traffic in 1949, the tunnelled portion of the parkway passes through the West Rock Ridge. Originally named West Rock Tunnel, the tunnel was re-designated as Heroes Tunnel in 2003.

Located within the town of Woodbridge and the city of New Haven (figure 1), the tunnel is approximately 0.4km long and consists of two 8.5m wide and 5.8m high tubes. Due to the natural formation of the igneous basaltic rock (known as trap rock), the tunnel intercepts a significant amount of underground water flow.

The Connecticut Department of Transportation (CTDOT) recognized the risks involved with aging infrastructure — particularly, and vitally, potential safety issues to the vehicular traffic caused by the groundwater — which are compounded by the severe New England winter weather patterns. During a typical winter, ice builds up and icicles form and drop, creating treacherous icy patches on the roadway.

To begin the tunnel rehabilitation processes, CTDOT called on CDM to conduct an inspection of the tunnel. This thorough inspection will enable them to take an organized approach to the specific tasks required for the tunnel rehabilitation, including managing risk and financial implications of the necessary repairs.

Identifying risk

The model utilized by CTDOT was ideal. Expert engineers were able to assess visible and non-visible issues associated with aging infrastructure and mitigate these issues. The risks associated with transportation tunnels can be defined into three general categories:

1) *Lack of understanding of the original design and construction criteria* – Just as the materials, means, and methods of tunnel construction have changed, so have design standards. Since the time that Heroes Tunnel was constructed, we now have a better understanding of the ground/lining interaction and better capabilities to evaluate changes to the tunnel that will affect the lining. With the more complicated finite element programs in use today, it has become evident how the construction sequence can affect the tunnel lining.

The first category of risk requires a search and review of as-built data and potential construction progress photos. It is important to know how the tunnel was constructed, what material specifications were used at the time of construction, and if any phasing was used during construction. Prior to any inspection being conducted, the inspection team must be briefed on the original design and construction of the tunnel to understand the makeup of cold joint, liner and geological formation, as well as groundwater conditions before and during construction. Other elements of the tunnel, such as the aeration system, mechanical, electrical and drainage systems must also be reviewed. The associated risks are:

- Lack of information, with archives non-existent or in a deteriorated state
- No geotechnical details available
- No as-built record of construction

2) *Lack of knowledge of the minimum actual standard requirement for the*

design and construction of a transportation tunnel - What served as the standard many decades ago is now obsolete. If there is any geological/geotechnical data available it most likely does not present the level of detail that is expected today from the practice exploration program of actual conditions in the tunnel and surrounding ground.

The second category of risk requires a clear understanding of what would be the technical requirement if the tunnel was designed and built today. A comparison chart should be developed and discussed with the inspection team. Based on this chart, inspection criteria can be developed and inspection methodology can be established. The associated risks are:

- Lack of knowledge of the latest minimum design criteria from the client or standard practice in the tunnel industry, including structural, electrical, mechanical, drainage, and tunnel inside dimension clearance
- Lack of knowledge of material standard requirements
- Lack of definition of acceptable conditions
- Lack of experience from the inspection team

3) *Misinterpretation of existing conditions* – Even today there is a sufficient amount of educated guesswork that has to be done to interpret conditions. This risk can be mitigated during the on-hand and visual field inspection as well as during post-inspection engineering evaluation and recommendations by using experienced staff who can guide and train junior staff during field and office evaluations.

The third category of risk is related to the misinterpretation of the existing conditions and the final engineering evaluation and recommendation. It requires establishing the preparation of criteria to be used during the inspection. Field note notations and abbreviations are needed for any elements such as steel, concrete, liner, stone or brick masonry, air system electrical, pavement and drainage. Terminology needs to be established for rating the conditions during inspection. Leaks through the lining need to be defined based on the intensity of the leaks and potential deposit. The associated risks are:

- *Lack of methodology in advance of conducting the inspection* – Not only is it expensive to close down a portion of a transportation tunnel, but that closure or partial closure also creates potential public safety issues. It is important to have both a plan and methodology developed prior to doing the inspection to increase efficiency and the opportunity to gather all of the necessary data, efficiently and safely
- *Lack of access during the inspection* – There will be areas of any tunnel that are difficult to access. These conditions need to be evaluated prior to inspection so that a judgment can be made on the worth of the data versus the cost of the equipment and time required to obtain the data
- *Lack of proper lighting* – Most inspections are carried out at night to mitigate the impacts on the public and public safety
- *Missing details or anomalies during the inspection* – The human reaction is to be concerned with getting a certain amount of inspection footage completed on each day of the inspection. It becomes important to have the experience to know what is considered normal so any abnormalities can be detected quickly. Having an adequate number of inspectors and aides on site to facilitate the inspection can mitigate this risk
- *Lack of post inspection engineering evaluation* – This can be a major risk and liability item. There is no excuse to perform an inspection, collect data, and then do nothing with it. A more hidden detail is to be aware of the complexity of the ground/lining interaction and that re-evaluating the geotechnical conditions of the tunnel using the appropriate modeling software often needs to be performed to complete the engineering evaluation

The highest risk in the inspection of a transportation tunnel is to miss existing conditions and not evaluate the conditions based on the original tunnel design and adapt old and new standard requirements to remediate the tunnel. The risk can be mitigated by a thorough risk management plan that includes a well establish inspection methodology and tunnel inspection guidelines.

Mitigating Risk at Heroes Tunnel

Because this was the first comprehensive inspection of Heroes Tunnel, CTDOT did not have a formal procedure to follow. Therefore a multi-phase inspection and evaluation program was developed. The initial step was to review existing data, followed by conducting field studies to identify tunnel characteristics, constraints, and limitations that could affect the inspection process. An intensive testing process, which included two forms of geophysical testing—ground penetrating radar and ultrasonic measurements — as well as detailed visual inspection and hammer sounding to determine the integrity of the 0.65m thick tunnel liner was performed.

Prior to the field work, an internal workshop was held to identify the probable risk items that would be present, based on the review of the existing data. The evaluation found water leakage is the major concern and the source of most of the troubles in the tunnel. Leakage through tunnel lining in conjunction with frost would cause deterioration of the lining. This leakage mechanism results in:

- Reduction of the size of the tunnel opening by the formation of ice barriers
- Icing of the road pavement
- Obstruction of ventilation and other service ducts and shafts
- Hazards from icicles forming in the tunnel roof
- Frozen drains can cause groundwater to find or create a new path to enter the tunnel
- Frequent freeze/thaw cycles at joints and cracks accelerate the deterioration of the concrete lining

Water leakage would also adversely affect the tunnel lining. It was projected that leakage would:

- Cause a loss of cement by effervesce, reducing the strength of the concrete lining
- This same effervesce would also increase the permeability of the lining and accelerate the deterioration of the lining
- Water leakage would also trigger the corrosion of the reinforced concrete lining, resulting in cracking and spalling
- Seepage water would transport fine dust that could result in dust traps. Certain

Below: Sonic/ultrasonic survey for tunnel side walls

Above: **View of Heroes Tunnel north portal wall**
Left: **Deterioration at tunnel joints**

combustion gases can result in high acidity of the water and be very corrosive of the ambient moisture in the tunnel
- Water leakage causes corrosion of fixture, destruction of lighting cables

This tunnel has experienced typical wear and tear over the last 60 years. As expected in any structure of this age, repairs need to be done. The financial climate can make identifying the necessary funds to perform all the repairs a challenge. Adding to this challenge is the fact that the technology of tunnel design, in regards to drainage, ventilation, and lighting has changed dramatically during this time period. As a result, the ability to design and implement modifications to the existing infrastructure without affecting roadway clearances and traffic flow adds to the restrictions and increases cost of remedial measures. Therefore, it is even more critical to identify the repairs and rank them by cost, impact to safety, and life expectancy in regard to a serviceable element of the tunnel.

The tunnel portals consist of reinforced concrete retaining walls with a masonry stone façade. The materials available today to reduce inflow and direct the occurring inflow out of harm's way were not available at the time the drainage system was constructed. As a result, the drainage system has deteriorated to the point that it now allows water to seep through construction joints and cracks, leading to extensive cracking and spalling, particularly at the section joints. In addition, groundwater seepage has caused damage to the mechanical ventilation equipment and shaft, and plagued the tunnel with roadway ice and hanging icicles impacting on safety.

With a good understanding of the probable deficiencies in the tunnel, an inspection team consisting of geotechnical, structural, mechanical, electrical engineers and HVAC specialists was assembled. In addition, specialists to perform geophysical surveys were also included on the team.

To minimize tunnel closures and negative impacts on traffic, schedules were developed with CTDOT as well as various inspection groups to determine available access times for inspections. When possible, night inspections were conducted, diverting traffic into a single tunnel using traffic control and signing patterns to ensure driver safety.

A summary report detailing the results, including the recommended rehabilitation work and associated construction costs is in progress. Although the report will recommend repairing the concrete, waterproofing options are still being researched to ensure that water leakage will be significantly reduced in the future. Code issues related to ventilation, lighting, and emergency detection are also being included in the report that details options for compliance with national fire protection codes and additional codes to be identified.

After submission of this draft report, a risk/cost matrix will be developed with input from both CTDOT and the engineer. This living document will present the existing conditions of the tunnel, alternatives for remedial work, and ranking of importance and cost. This matrix will serve as management tool for design development and implementation of remedial work.

The final report — detailing tunnel conditions, as well as rehabilitation priorities and associated costs — is scheduled to be completed this summer. This report will also include recommendations for roadway design and intelligent transportation system components, such as video surveillance, variable message sign applications, in-pavement sensors, lane-use signals, and vehicle height sensors to ensure public safety.

Agie determines future repairs

As our infrastructure ages, it is extremely important to understand the unique aging mechanisms of each tunnel and how they affect the structure. The implications of aging are not always visually apparent for tunnels; therefore it is important to infer damage based on secondary assessment information. As with Heroes Tunnel in Connecticut, understanding the materials used during construction, building sequence, and soil/rock structure interaction can help predict aging issues that are not visible to the naked eye. T&T

Speed up a long way.

Niagara Falls/Canada. For the construction of the 10,500m long Hydro Power Tunnel the conveyor providing company H+E supplies a continuous conveyor system allowing a fast transport of the excavated material. One Booster is used to reduce the forces exerted on the belt along the route; with the pleasant side effect to guide the belt save in front of a vertical curve.

The naked facts:

Tunnel diameter:	14.4m
Conveyor length:	10,500m
Belt width:	1,000mm
Capacity:	1,600 t/h
Installed power:	4 x 360kW (head) 2 x 360kW (booster)
Belt storage capacity:	600m of belt
TBM:	Hard Rock Gripper
Installation:	2006
Contractor:	Strabag Inc.

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Extending pipeline life expectancy – Part 1

There are few things more annoying than roads being dug up to access or replace utilities and other assets. Ian Clarke looks at recent developments aimed at negating this extreme urban irritation

It has only been over the past 40 to 50 years or so that the buried service network and pipeline industries have really taken seriously the idea of refurbishing a pipe system by anything other than complete 'new lay' pipe installation. Prior to this much lower traffic density and the population's belief that 'this was only way to do it' meant that there was little drive to find other less disruptive ways to do things.

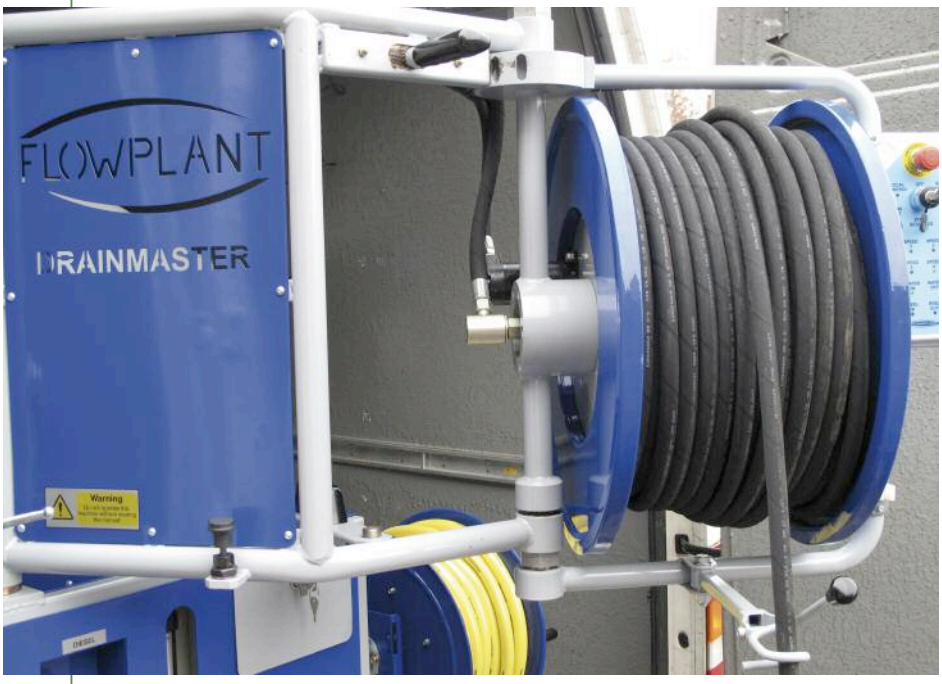
However, the world changed somewhat when increasingly the family car became the 'norm' and people started to get upset if not a little angry at the delays caused by the major road works that are required to bury new pipes and services.

Increasing costs also led utilities to look at more cost effective ways of completing necessary works.

The Japanese, for example, whilst having utilised the system for some time started to introduce microtunnelling on a broader scale than had previously been used as population densities rose and traffic congestion increased. In terms of refurbishment, this was followed in the UK in the early 1980s with the appearance of the embryonic pipeline 'lining' renovation systems.

In the context of this series of articles refurbishment can be considered as anything that is not 'new lay' installation. This could of course cover everything from a simple clean to pipe repairs, localised lining, manhole-to-manhole lining and for any in-situ pipe replacement systems such as pipe bursting, pipe eating/reaming and pipe extraction (the latter being covered more fully in Part 2 in *T&TI's* September 09 issue).

Below: **Flowplant Water Jet , the hose reel of a typical high pressure water jet unit**



Cleaning

Many pipelines, be they pressure pipes of gravity systems, perform at less than their optimum due simply to a lack of on-going maintenance. For example sewer pipes blocked with silts, fats, grease, general litter and rubbish simply do not have the carrying capacity of a fully open bore. Pipes in a poor state of repair can also exhibit similar problems when deformation, cracking and misalignment of joints cause blockages or material build up at the defect site.

The simplest way to see the problem is to clean it and inspect it. As much of the inspection aspect of this process has been covered previously, this article will just look at the cleaning operation. The most common way to clean out a pipe line is to use high pressure water more commonly known as water jetting. The high pressure water dislodges and flushes away any material caught in the pipeline or stuck to the pipe wall. There are many types of jetter unit available to the market, far too many to go into detail on here, but they are widely available across the world either for sales hire or through specialist jetting contractors.

Below: **Fastflow Truck Main, the Truck Main Cleaning system in action**

In one case, for larger diameter pressure pipes, a UK company has developed a special jet cleaning unit known as the Truck Main Cleaning system. The unit is designed to position a high pressure jet very close to the pipe wall to maximise the cleaning potential whilst being able to clean long lengths of pipe in a single run. This is an option which, at larger diameters, is not always possible with jetting heads sitting in the centre of the bore spraying water onto the pipe wall.

Another more recently developed cleaning option for gravity pipes is the system known as 'Flusher'. Developed in the UK this is a gate system which can be installed at any convenient point in a pipeline and preset to retain flows upstream of the gate until a certain level is reached. The gate then automatically opens to release the retained flow into the pipeline. The water surge created cleans the pipe both upstream and downstream of the Flusher gate.

In pressure pipes, blockages tend to be more in the form tuberculation, a build up of relatively hard material which grows into the pipe bore from the pipe side. In this instance, whilst jetting may be effective, a more active cleaning system may be needed. This is where rod driven flails may be used. Inserted from surface at a convenient access point, the flail is pushed into or pulled through the pipe attached to a spinning rod (provided rod access is initially available through any blockage). The disadvantage here is that the interaction between flail and pipe can cause further damage to the pipe wall if not properly controlled. Waste is then flushed out to clean the pipe fully.

Renovation and repair options

Of course once clean, any damage within the pipe must then be assessed and a repair or renovation or replacement option chosen which will offer the best refurbishment back to the required operational level. This can be done on various levels.

Where the damage or defects are extensive, larger scale renovation options are usually adopted, often on a manhole-to-manhole scale.

One of the more widely known techniques is CIPP (or Cured In Place Pipe). This system comprises the use of a felt, woven or glass fibre tube which is impregnated with a resin, the type of which is dependent on the system being used. The liner tube can be either inverted into the host pipe, using a head of water pressure, or compressed air. It can also be winched through the host pipe and

Above: **Trelleborg epros drum, loading an inversion drum with a liner prior to installation**
Right: **Prokasro UV cure, a demonstration of UV light curing on a CIPP liner**

subsequently inflated prior to curing. To invert the resin impregnated liner with water pressure the head of water pressure can be applied by using a scaffold tower erected over the launch access or manhole. With increasing emphasis on safety when working at height several systems and manufacturers also now offer inversion drums. Here the resin impregnated liner is loaded into a drum and then water or compressed air is applied within the drum to force the liner out and into the host pipe. One manufacturer has also developed a 'free air' compressed air inversion system where the liner does not have to be confined within a drum when using compressed air inversion. This system is designed for larger liners where drum confinement would seriously limit the length of liner that could be installed.

Once inverted into the host pipe the liner must be cured to form the final hardened liner within the host pipe. When using Hot Water Curing, the water used to invert the liner is heated by boilers to the required temperature and circulated through the liner for a specific period of time, which is dependent on the liner thickness and resin type used. Alternative curing options include UV (Ultra Violet light), steam and ambient cure. For UV curing a special resin is used that hardens under exposure to UV light. The light source is a train of UV bulbs that is generally winched through the inside of the liner once it has been inserted into the host pipe and inflated.

Steam curing uses the high temperature of steam to cure the liner and ambient curing simply allows the resin to cure at its own pace under the ambient temperature conditions within the host pipe. Each resin type brings with it its own limitations in relation to shelf life after impregnation. Ambient cure is generally the shortest as it starts to harden immediately after impregnation. Refrigeration and protection from natural light sources will improve shelf life of the other systems.

Some CIPP liners have been developed that are designed to stem higher levels of infiltration than the standard systems by creating a very close fit with the host pipe. These would tend to be utilised where the flows of groundwater may affect the curing process of the standard liners.

In the right circumstances CIPP linings can be used on a localised scale to repair smaller defects using inflatable bladder to position and cure the liner section. In another option CIPP liners have also been used for manhole rehabilitation.

The latest addition to the stable of liner is the 'Melt-In-Place-Pipe' liner, known as

Aqualiner, winner of the ISTT Award for Innovation in 2009. This liner utilises a Glass Fibre (GF)/polypropylene (PP) woven tube which when a specially designed heat source is applied to the inside of the inflated liner allows the PP to melt and flow between the GF matrix. Once cooled after the heat source passes the PP resets to a solid state forming the completed liner.

Another form of lining is Sliplining. Here a standard PE pipe is pulled into the existing pipe. There will of course be a loss of capacity as the thickness of the sliplining pipe wall will reduce the original pipe diameter, often considerably. With sliplining it is sometimes necessary to grout the annulus between the liner pipe and the host pipe to create a structural final lining within the pipe. In some instances jacking pipe lengths of a suitable diameter are pushed through the host pipe to form the liner instead of using whole-length PE pipe. This would require the construction of a jacking pit at one end of the host pipe which can increase costs considerably.

A modification to the basic sliplining technique is Modified sliplining. One technique is often known as 'Fold & Form'. Here the liner pipe, which is generally either PE or PVC pipe, has its nominal diameter temporarily reduced in order to simplify the insertion process. The 'Fold' technique takes the originally round pipe and passes it through a machine which makes the pipe into a 'C' or 'U' shape reducing the nominal diameter considerable. Once installed, water or air pressure is the applied to cause the folded liner to revert to its original round shape and form a close fit with the inner wall of the host pipe. Otherwise another form of Modified sliplining is to reduce the nominal diameter of the liner pipe by passing it through a reducing die under tension. Maintaining this tension as the liner pipe passes through the host pipe keeps the reduced diameter constant. Releasing the tension allows the liner pipe to revert to full size forming the liner in the host pipe.

Another product that may be classed as a Fold & Form renovation system is the Thermopipe system, which is used for pressure pipe rehabilitation. Thermopipe is designed for the rehabilitation of distribution water mains and other pressure pipe systems such as sewer force mains, fire water mains and industrial pressure applications. It is supplied as a factory-folded 'C' shape liner, which is winched into the host pipe from a reel located at one of just two main access pits required for an installation. Once winched into place, the liner system utilises air pressure and steam which is applied to the inside of the liner to revert it to its fully round shape within the host pipe. Special ferrules can be used to reconnect the now lined pipe to any service connections.

In gravity networks other liner systems can be utilised. Ferrocement liner can be formed insitu and comprise the application of ferrocement compounds to a former which creates the shape of the liner required.

Spiral lining systems are a form of slip liner where a flat PVC section with special jointing edges is passed through a winding machine. The edges are pushed together as the winding occurs to form a pipe shape which is passed into the host pipe. There is an option to use a winding system that allows the liner pipe to be passed through the host and anchored at one end. The winding then continues and the liner expands itself out to form a close fit to the host pipe.

Preformed GRP (Glass Reinforced Plastic) liners can also be used as pipe liners. With this system the liner units are factory made, often to order, to the required dimensions, be this round, egg or other shape. Each section is individually installed with male/female end joint making the seal between each unit. Because the sections have to be manoeuvred within the pipe they tend to create an annulus which must subsequently be grouted to complete the lining. GRP Liner can also be manufactured for the refurbishment of Manholes.

In some pressure water pipes where the damage is slight or where refurbishment is required more for water quality purposes or corrosion prevention Spray lining can be applied. Spray types include Cement Mortar, Polyurethane, Epoxy compounds which are generally applied using a high speed rotating nozzle which, depending on the speed of advance through the host pipe, creates the desired lining thickness. These systems do not provide the structural element of some of the liners outlined previously. Spray lining options are also available for manhole renovation.

Whilst the liners can be used to repair and even improve the structural state of

Left: Insituform, creating a Fold & Form liner and inserting the reduced nominal diameter liner into the host pipe
Below: Insituform GRP, factory-made to size, GRP liners can be utilised in pipeline rehabilitation

Right:
Trelleborg epros packer, a typical inflatable packer used for resin seal installations

deteriorated pipes, another system which claims to seal not only the defects in the pipe but also consolidate the ground outside the defect in the surrounding ground is the Flooding technique. Here the defective pipeline is flooded, first with one chemical which is allowed to seep through cracks etc into the surrounding ground. This chemical is quickly pumped out and replaced with a second chemical which reacts with the first to create a solid seal in the defects as well as consolidating the ground outside the defect with a concrete-like structure.

In gas mains where renovation is required a technique known as 'Live lining' has been developed. This allows the main to be refurbished without taking the customers off-supply. Special access glands, gas feed heads and liner pipe installation techniques are used for this.

Localised refurbished

If the damage is localised and possibly not too serious, the option of utilising localised repair systems is available. There are however, many different options available.

Resin sealing can be achieved on a localised basis using inflatable packers. In this option the inflation of the packer occurs at either end to seal off the defect being repaired. Sealing resin is then pumped into the packer under pressure where it fills the defect and cures, sealing the crack or misaligned joint. The unit is then moved to the next defect and positioned using CCTV and the process repeated.

Resin sealing can also be used in manholes. Here however the walls of the manholes are first drilled to create resin injection points through which the resin is pumped.

In pipelines robotic sealing of defects has also been long established. Here a robotic unit or multiple robot system guided by CCTV first cleans the defect. Sealing resin is then pumped into the defect to form the seal and in some cases the robot uses remotely guided paddles to smooth the finished surface to minimise friction losses.

Localised rubber/steel spring seals can also be applied over defects to form a repair seal. The repair is achieved by positioning a shaped rubber seal over the defect which is pressed into place using an expanding sprung steel collar which locks into place.

In a further advance in technology a fairly recent development based on the processes in the human blood circulation system has been applied to pipelines. This is the use of Platelets. When a pressure pipe shows signs of leaking specially designed Platelets are injected into the flow within the pipe. In the same way as platelets in blood stem blood flow from a cut, the Platelets in the pipeline seal any leak by building up over the defect. The Platelets system is designed to provide an immediate yet reasonably long lasting seal in order to provide engineers with time to design and apply a longer term solution to the leak point. T&T

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Combating neglect and deterioration

Ageing underground space should be brought up to date and its useful life maximised through reconstruction or refurbishment. Maurice Jones examines some issues affecting the choices

There are a host of reasons why a tunnel structure may need to be refurbishment, but the main ones are:

- Inadequate capacity, with possible refurbishment to avoid new construction
- Structural deterioration threatening safety, capacity or continued usability
- Change of use
- Improved or new technology developed that can be used with advantage in tunnels such as for energy saving, accident prevention, and better handling of emergencies
- The need to meet higher national and international safety standards, mainly in transport tunnels

Considering the existing structure, tunnel refurbishment often requires original thinking and custom-built designs of new equipment and structural alterations compared to the standardisation possible with new construction. Selection of the correct method is no easy matter with funding invariably in short supply. However correct spending can produce large long-term savings in operational costs and necessary capital even without possible incidents and consequent damage.

Since each tunnel refurbishment requirement is practically unique specialist expertise is usually required. Ceo of specialist ventilation consulting engineers HBI Haerter, Dr Rune Brandt, comments, "We like tunnel refurbishment projects because the complexity of most situations makes greater demands on HBI's skills in ventilation and control."

Safety drive

In relation to the last reason for refurbishment listed above, the well documented fire incidents of recent years have given a major impetus to improving safety standards

The European Union Tunnel Safety Directive was adopted in 2004 with the aim of tunnels meeting the necessary standards on key routes by 2014 in most cases.

Initial European Union funded surveys of highway tunnels on the Trans-European Network (TEN) from 1999 showed that the safety standards of the majority were far from adequate. Frequently traffic loads were increasing without corresponding improvements in operational standards. There were often difficulties in withdrawing public users safely and in fire-fighters being able to access the seat of the problem quickly and effectively.

The situation is rarely static. Austria had had a relative good safety record for its tunnels since inspections were introduced but last year the Austrian Automobile, Motorcycle and Touring Club (ÖAMTC), as part of EuroTAP, found that the five tunnels tested in Austria came out the worst in five years. Two tunnels, the Wolfsberg and Karawanken linking the A11 with Slovenia, were rated only 'Sufficient'. The latter came in for particular criticism with ÖAMTC spokesman Willy Matzke stating, "The tunnel cannot be considered safe in its current condition. A single-bore tunnel without emergency galleries is a ticking time bomb."

Heavy goods traffic is a major factor in the safety rating of tunnels even without recognised hazardous loads. The Trebesing Tunnel was marked down due to 22% of its traffic being freight, usually with a high fire fuel load. The best TEN tunnel for safety in all Europe was deemed to be the Pont Pla Tunnel in Andorra, but this has no freight traffic.

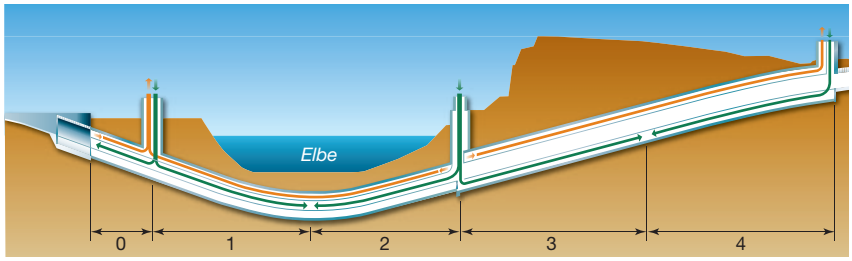
However, Austria's performance is still relatively good. In the same year the tunnels of Italy and Norway completed three years of poor results on most tunnels surveyed. Commenting in 2008 Caroline Ofoegbu of the FIA European Bureau said, "The fact of the matter is that there are still many tunnels in Europe which need to be upgraded and refurbished in order to fulfil the minimum standards of the EU Directive on safety in road tunnels."

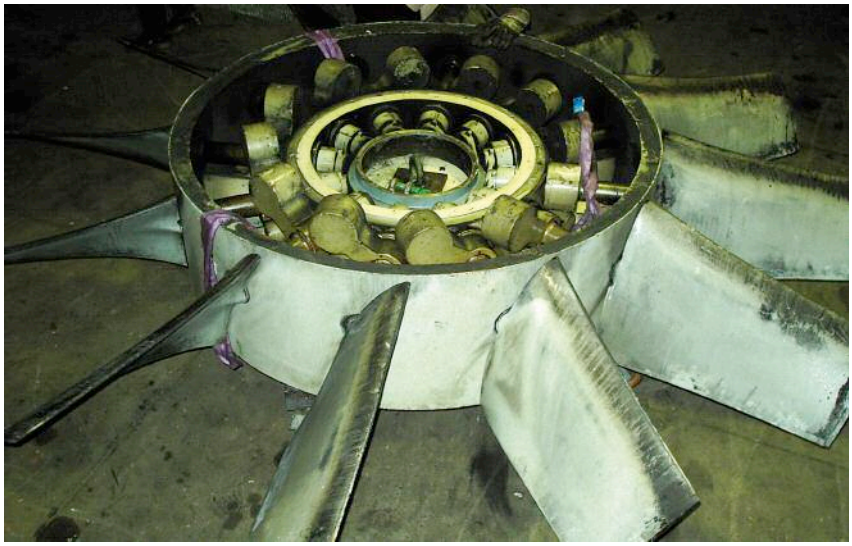
This year less tunnels were tested for the stated reason that it would be unfair to include the many tunnels now under refurbishment. Those tested received generally good reports.

Materials

Choice of materials, and recognising the properties of existing tunnel structures, are particularly important in tunnel refurbishment for safety improvements. Use of passive fire protection can preserve the structure of the tunnel, or at least minimise damage. Prevention of the spalling of concrete affected by extreme heat may be important for the safety of fire fighters dealing with an incident and any other personnel trying to make an escape. It is now widely recognised that the use of the correct size and proportion of polypropylene fibres in concrete mixes (sprayed or cast) can melt in high temperatures to create free passages for the relief of high pressures that would otherwise cause spalling.

Reinforced sprayed concrete with its well-known characteristics of operational flexibility, viability for smaller areas, and suitability for irregular profiles is well suited to tunnel refurbishment and repair such as for the improvement of structural characteristics. Elasto-Plastic Concrete supplied BarChip synthetic macrofibres as sprayed concrete reinforcement in the conversion of an underground ice-cream store to a car park at Årstadal, south of Stockholm city centre, Sweden. Frigo Entreprenad's project's involved three large caverns varying in size within 7-8m high, 16-20m wide and with lengths of 85, 125 and 195m, representing a total area of around 7400m^2. Before installing precast concrete decks for a second level of parking, the caverns were heightened in some areas and passages for cross-





Left: **Fig 1 - The necessarily complex ventilation scheme of the three old tubes under the River Elbe**
Left: **An impeller from one of the old fans replaced in the ventilation refurbishment of the old Elbetunnel tubes [Photo: HBI Haerter AG]**

passages excavated.

A dose of 10kg/m^3 of BarChip Shogun 48mm fibre was used in the sprayed concrete applied to a depth of 40-60mm. This achieved the specified flexural strength of at least 4.0MPa and a residual strength of 2.5MPa at 3mm deflection.

Ventilation

Before the series of fire incidents there was a tendency for ventilation provision to concentrate on the day-to-day needs of removing air pollution, supplying oxygen and cooling the tunnel if necessary with minimum expenditure of energy. Even if there were provision for smoke or fume extraction in the event of a fire it often failed to take into consideration the very special circumstances of a major fire incident. Modern transport tunnel ventilation and its control needs to be integrated with other services used in emergency such as communications and alarms, illuminated signage for escape routes, and fire-fighting systems all within a structure resistant to the actual temperatures generated in the fire.

Many traditional crossing points of physical barriers utilising tunnels have had to expand capacity whilst still employing old structures. One such is the River Elbe crossing in Hamburg where there are now four tunnels, or seven tubes, to handle an average daily traffic flow of 110,000 vehicles. Since HBI Haerter had been working on the ventilation of the new fourth Elbetunnel, it was also asked to plan the refurbishment of the three old tubes still in use to bring them up to current safety standards. Schindler Haerter (now HBI) also designed the original ventilation system in 1975 (see Fig. 1) when the old three tubes were last put into service.

Each old tube is 2.8km long and carries two lanes. The existing ventilation and control buildings were utilised, together with the same ducts, but with new fans and dampers to replace the 18 fresh-air and exhaust fans housed in three ventilation buildings. (see left pic for old fan impeller). The air ducts are situated between the traffic tubes in the submerged section and below or above the traffic space in the bored sections. The duct sections were optimised according to the operating costs of tunnel ventilation. The new dampers were designed and installed to achieve point extraction of smoke from any incidents. Within a normal transverse ventilation system a possible extraction capacity of 300m^3/s will be achieved by using all the new exhaust fans in case of fire.

In another major tunnel refurbishment undertaken by HBI Haerter the ventilation system of the Isla Bella Tunnel has been replaced as it did not comply with the new Swiss safety standards. Another stated motivation was that the higher capacity of the old system is no longer required due to the improved exhaust emission levels now in action. The 2450m long, single-tube, bi-directional Isla Bella Tunnel is on route N13 in Switzerland linking Lake Constance through the Rhine Valley and San Bernadino to Bellinzona on Lake Maggiore.

The Isla Bella's existing ventilation system was of the semi-transverse/transverse type and included a false ceiling with two separate ventilation ducts. Two axial flow, dual-speed fans, controlled automatically in

Below: **Isla Bella Tunnel south portal before ventilation refurbishment [Photo: HBI Haerter]**

normal operation according to four combined carbon monoxide (CO)/turbidity sensors. There was also a provision for operation according to a fixed schedule. Distribution of fresh air through the tunnel was not even, with fresh air openings adjusted to increase supply in the middle of the tunnel and a lower supply at the portals.

The refurbishment projects includes major civil works such as demolition of 200m of false ceiling to allow installation of two groups of jet fans, cutting of 21 further openings in the false ceiling for smoke dampers, necessary structural support adjacent to these openings, cutting of openings to connect two ventilation ducts, closure of existing fresh air and exhaust openings, and structural alterations to the fan station to ensure adequate local ventilation after the main ventilation direction was changed.

The new equipment installed included a fully automatic control system allowing normal operation in pre-set modes including 'longitudinal ventilation', 'mid-point extraction' and 'extraction at the location of peak concentration'. In emergency operation the modus is determined according to the detection of any fire location. If local smoke extraction is required the general longitudinal flow can be controlled by the operation of up to six jet fans of 1250mm internal diameter in three groups of two. Two new axial exhaust fans were installed to operate in parallel. The 21 smoke dampers each have a free are of 2.6m^2. Monitoring installed included three turbidity sensors and two combined turbidity/CO, six airflow sensors in two groups of three, and 24 smoke detectors. The new Isla Bella ventilation is fully operational.

Which control?

The more complex and busy a transport tunnel is, the more complicated the control system will have to be, especially during emergency situations. In their refurbishment of the Loppertunnel HBI Haerter analysed the new ventilation system and the requirements for a sophisticated control system. Although the Loppertunnel is a single-tube, 2-lane, bi-directional road tunnel, the control system is now linked to that of the recently completed Kirchenwald Tunnel and its connections including a ramp with the Loppertunnel. During the refurbishment the tunnel was available for traffic at least in one direction with HBI's specialist site manager for ventilation and smoke management system being involved in the management and minimisation of closure periods.

When upgrading a control system to cope with increased traffic levels and modern safety standards there are many professional discussions about whether manual over-ride should be catered for. Dr Rune Brandt of HBI Haerter is in favour of automatic control for almost all circumstances due to the complexity of the many scenarios that could occur, especially in emergencies. A pre-programmed computerised control system can have all scenarios stored in the memory together with a hierarchy of control commands according to the progress of an incident. Such a hierarchy commences with traffic signals preventing the entry of any more vehicles, and monitoring of sensors to confirm whether the first alarm is a true indication of a fire or other dangerous incident. Ventilation patterns can then be put into the best combination to deal with the incident and clear, as far as possible, escape routes and access for fire fighters.

Safety is not just a matter of getting the commissioned system correct at handover. Brandt points out, "We need the same level of safety assured throughout refurbishment work, whether for the users if the tunnel is kept operational, or for the project workers' security. In order to cater for the transfer of equipment, for example, non-operational equipment 'windows' are strictly limited. In Switzerland there is a 72hr limit or the safety level is downgraded."

Problems continue

Despite the latest positive results by EuroTAP many technical observers are still not happy that enough is being done on the broader front for tunnel safety. Slovenian fire expert and professional architect Andrej Cufer of OrbiPark maintains that many tunnels are still being operated under hazardous conditions and that much refurbishment is needed to bring them up to modern standards for firefighting safety and incident escape. Together with partner companies, OrbiPark offers economical refurbishment solutions to improve ventilation in hazardous tunnels, especially from the points of view of smoke extraction and fire fighting.

The 3K/SafeConstruction system of triple ceiling ducts and louvered extraction points, developed by Ekovent of Croatia, enables incident intervention and escape to both directions from the centre of a fire etc without the need for a separate escape tunnel. The fire zone is normally limited to only 100m (200m if under a ventilation inlet) by air curtains rather than being allowed to spread in one direction. The 3K system switches rapidly to fire mode, approximately 1-3 minutes

Above: **Smoke extraction testing of the single-point smoke extractions system that replaced a distributed exhaust system in the single-tube Loppertunnel, Switzerland [Photo: HBI Haerter AG]**

Above: **New jet fans at the entry portal used installed during the refurbishment of the Schweizerhalle Tunnel on the A2 highway in Switzerland [Photo: HBI Haerter AG]**

Below: **The same portal of the Isla Bella Tunnel at night with new jet fans [Photo: HBI Haerter AG]**

Above: **Using point smoke extraction with fresh air supply from both ends fires fighting and escape can be accomplished more safely. This 3K system from Orbipark and can be retrofitted to existing tunnels using ceiling ducts**

after confirmation of an alarm, compared to other smoke point extraction systems. This type of ventilation is integrated with other fire control measures into the SafeTunnel concept.

Communications

Another frequent important feature of refurbishment to upgrade tunnel services is better communications, especially in view of the confusion exhibited by tunnel users in event of emergencies. Clear signals, signage and in-vehicle verbal communications can all help.

Following successful tunnel refurbishment installations in the UK (e.g. Dartford, Rotherhithe and Blackwall Tunnels) Tyco International's Fire & Integrated Solutions have recently been engaged in new installations for two tunnels in Poland. The first, completed in 2007, was for the twin-bore Katowice tunnel with comprehensive rebroadcast coverage of local radio services including police, fire and ambulance emergency services. This meets another requirement of the European Directive on Tunnel Safety specifying that tunnels over 500m on key routes should have radio rebroadcast facilities with emergency voice break-in. This is achieved with Tyco technology that now includes digital audio broadcasting (DAB) broadcasts as well as FM and AM. Tyco and local partner M/A-Com were sub-contracted for the installation by civil engineering contractor Carboautomatyka. Recently Tyco has also been working on the Lalike Tunnel on the same route.

Tyco specially designed the UK's first PA system for tunnels, installed in the Dartford Tunnel, for high quality voice announcements in a confined space. It uses over 200 special loudspeakers mounted in the ceilings to achieve sound levels over 100 dB. Low profile speakers afforded the same height clearances as luminaires. A very narrow sound opening is claimed to avoid reverberation problems

Another aspect of the OrbiPark SafeTunnel package is the SafeSignal system of variable visual guidance and communications developed by Andrej Cufer for AKA-PCB of Slovenia. This can be used to indicate safe escape direction (variable according to the position of the fire), alerts and alarms, speed restriction by stroboscopic indication of speed or simple indication of the sides of the tunnel or carriageway. T&T

Obituary

Zdenek Dan Eisenstein PhD., DSc., PEng.

Dr. Z. D. Eisenstein received his Undergraduate and Graduate Geotechnical education at the Czech Technical University in Prague between 1959 and 1965. Following postdoctoral work in London, U.K., he accepted an academic position at the University of Alberta in Edmonton, Canada, in 1969, becoming a Full Professor in 1974 and a Professor Emeritus in 2001. From 1972 to 1983, Dr Eisenstein completed four Visiting Professorships in Brazil (2x), South Africa and Germany. In 1990 he became an Honorary Professor at Pontificia Universidade Catolica, Rio de Janeiro, Brazil and in 1991 he received an Honorary Doctorate from The Czech Technical University.

Dr. Eisenstein's prime research and professional interest was soft ground tunnelling, especially in urban environments. On this and other topics he has published over 160 papers and has conducted over 100 lectures worldwide. Awards include honorary doctorates from Universities in Prague and Rio de Janeiro and no less than 7 further achievement prizes in the field of Tunnelling and Geotechnical Engineering.

Dr. Eisenstein was an expert advisor and consultant on dams, foundations, deep excavations and tunnels for over 150 projects across the globe. Some of the tunnelling projects included: the Channel Tunnel, the Westerschelde tunnel in Holland, the Rio Subterraneo tunnel in Buenos Aires, the City Link tunnels in Melbourne, the Edmonton LRT tunnels, the feasibility studies for the Gibraltar Straits tunnel and the Canada Line Subway Tunnels, in Vancouver. Most recently, he was the Chairperson of the Tunnel Advisory Panel for the Los Angeles Metropolitan Transportation Authority, a member of the Peer Review Panel for the Toronto Transit Commission and an advisor for the New York MTA.

Dr. Eisenstein was an active member of the ITA. He was elected Member of the Executive Council in 1987, First Vice President in 1989 and served as the President from 1992 – 1995.

Dr. Eisenstein is survived by his wife, Jana and their two daughters and sons-in-law: Alice and Dave Langston, and Jana and Paul Levett. He also leaves behind him his 5 adoring grandsons.

Letters to the Editor

Sir,

With reference to your feature article "Shotcrete technology – innovation and investment" pp35-39 March 2009.

While in general a reasonable good overview I am very disappointed that your author in his section "Standards and Education" page 38 – 39 he made no mention of the current Euro-codes that cover the testing of sprayed concrete and the fibre types that are available in the market place.

These documents have been available since April 2005 through into 2006. It is most important with the potential workload that these codes / standards are known and more importantly used so that client's consultants and all concerned are using the very latest data that will enable these projects to move forward with confidence to successful conclusions.

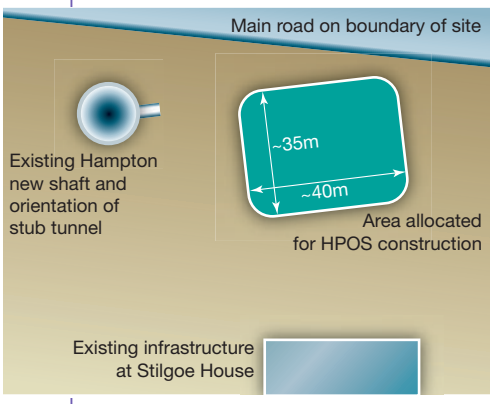
John Greenhalgh, Bekaert Ltd

The Hampton Pump Out Shaft solution

In this Harding Prize runner up paper, David Naylor, project manager for Mott MacDonald, describes the design process for the Hampton Pump Out Shaft project and how the construction was successfully completed with the use of appropriate construction methods and careful planning

The Hampton Pump Out Shaft Project aims to increase the efficiency and reliability of supply from Hampton Advanced Water Treatment Works (AWTW). This involves the construction of a new pump-out shaft and connection tunnels to the existing operational network. The new Hampton Pump-Out Shaft (HPOS) will deliver potable water from either the Hampton WTW to the existing High Pressure and Low Pressure networks and, during planned outage of the WTW, source water directly from the Thames Water Ring Main (TWRM).

The major civil works associated with HPOS include the construction of the shaft itself (i.d of 15m, excavation depth of 40m) and the construction of two tunnels connecting HPOS to the existing works and the TWRM. The works are situated within the Hampton Advanced Water Treatment Works; therefore careful consideration of the construction methodology had to be used throughout so as not to interfere with this operational site and to work safely in a confined environment. This combined with the industrial made ground and buried structures at the site and other site difficulties made construction a challenge. However, the thoughtful choice of construction methodology and thorough pre-construction planning and design have overcome these difficulties and have demonstrated what can be successfully achieved in urban underground construction projects in challenging locations.



Left: **Fig 1 - Site location plan**

Project organisation

The work on the Hampton Pump Out Shaft began with the outline design completed by Mott MacDonald in partnership with Thames Water designers led by Lead Design Engineer Tanveer Ahmed in 2006/7. Following this work with an outline design that highlighted the potential risks and constraints for this project, the scheme was tendered for the construction phase. Thames Water selected Costain Ltd as the contractor to deliver the main civils works, who in turn employed Mott MacDonald as the detailed designer for the project. For Mott MacDonald, the author acted as the project manager for the design package from early into the project commencement.

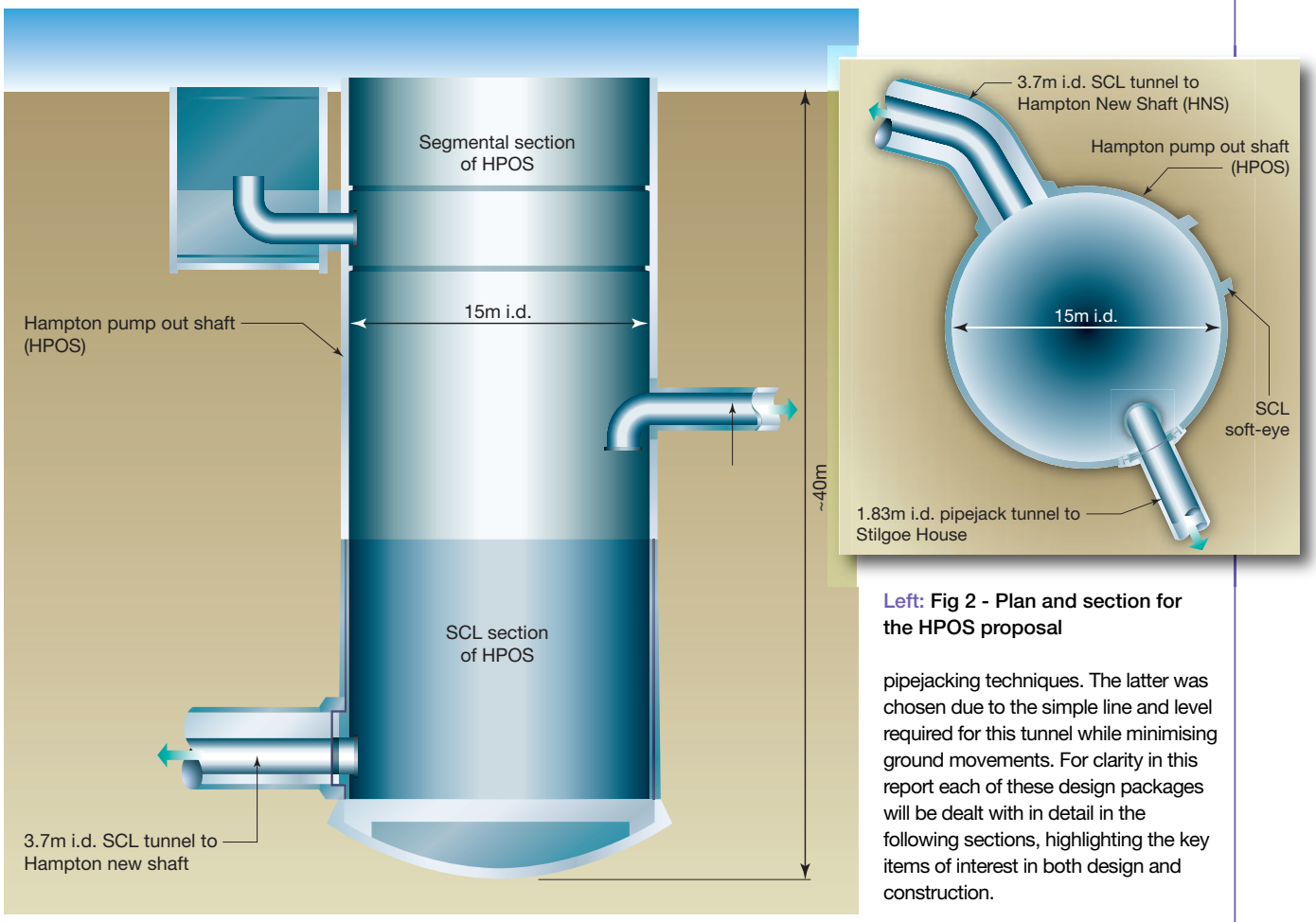
The detailed design for the project began in the latter half of 2007 with construction work beginning at the start of 2008. Construction is currently predicted to finish on programme by February 2009.

Site geology and constraints

The author and key representatives from the contractor evaluated the following main site specific constraints to define the most suitable construction methodology:

Confined Site Footprint - The HPOS was required to connect into the existing infrastructure in the Hampton New Shaft and Stilgoe House. Consequently the shaft would have to be situated in the small area of land situated close to these pieces of infrastructure (see figure 1). This area had the further obstacle of the busy main road to the north of the site area, with a major gas main present. Any disturbance of this road and utility would not be permitted throughout the construction. In addition, due to the size of the 12 No. Pumps that would be present in the fully operational pump-out shaft, the shaft would have to be at least 15m wide internally with all portals for the connection tunnels 90 degrees apart. Due to the orientation of Stilgoe House and Hampton New Shaft this consequently meant one of the connection tunnels would include a bend of small radius (fig 1).

Made Ground and underground obstructions - Preliminary geological work on the proposed site area indicated that the majority of the shaft and tunnel construction would be in stiff London Clay. However this clay was overlaid by approximately 6m of made ground. This made ground was predicted to include the historical remains from previous operations at Hampton Treatment Works. In particular a Victorian engine house with major foundations was previously situated in the vicinity of the proposed HPOS location, and so the possibility of encountering brickwork within the first metres of shaft sinking was seen as high. Consequently, the construction method chosen for the shaft would have to take this into account, while also considering the ideal construction conditions once within the London Clay. **Site Operations -.** All proposals for the construction could not interfere with the operation of Hampton AWTW. Across the proposed working site lay several water mains which were to remain operational throughout the work, and so all construction proposals must not damage the mains in any way. As a result, settlement predictions and impact assessments would be vital in ensuring that the construction of the HPOS and associated works would not interrupt the operation of the AWTW.



Left: Fig 2 - Plan and section for the HPOS proposal

Construction methodology

Initial site investigations indicated the potential for water just below ground, which led to the consideration of the use of a cofferdam on site to control any water present. Any cofferdam however would be difficult to construct with major obstructions in the ground. Therefore Costain decided a trial shaft would be prudent to confirm the construction methodology for the initial part of the shaft. This quickly confirmed the presence of brickwork and concrete structures in the HPOS location and proved that the quantity of water present could be controlled by local pumps. Thus it was proposed to use traditional precast segment construction by underpinning until within the London Clay. For this, 375mm thick, 1m deep segments were proposed for a depth of approximately 22.5m.

Preliminary design work undertaken by Mott MacDonald indicated that once beyond 22.5m below ground level, the required segment size would have to be larger to accommodate the increased permanent ground loading. This issue and consideration of other project constraints led to the change of construction methodology for the second part of the shaft.

At the base of the shaft, an opening for the connection to the Hampton New Shaft was required in addition to a stub tunnel or soft-eye required for possible future Thames Water extension work. To form these openings in the shaft lining would be time-consuming with precast segments, with large steel sections required if using jamb-and-lintel frames. Any initiative to minimise manual and mechanical operations at the base of the shaft would be beneficial for health and safety reasons. Additionally, with the required curvature, constructing the HPOS to Hampton New Shaft tunnel with a Sprayed Concrete Lining (SCL) had already been discussed. Therefore it was proposed that SCL be used to construct the second half of the HPOS, the low level portals and soft-eye, offering a simpler, safer and more durable solution for forming breakouts (fig 2).

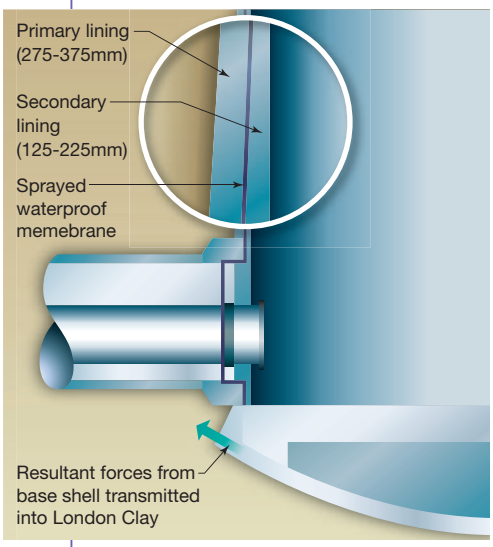
The detailed design proposal is as shown in Figure 2. 375mm thick precast concrete lining for the initial 22.5m followed by a composite SCL lining for the lower half of the HPOS. For the low level tunnel, SCL would again be used and the high level connection tunnel would be constructed using pipejacking techniques. The latter was chosen due to the simple line and level required for this tunnel while minimising ground movements. For clarity in this report each of these design packages will be dealt with in detail in the following sections, highlighting the key items of interest in both design and construction.

Section of Hampton Shaft

For the initial section of the HPOS, 23 No. 375mm thick, 1m deep segments were used using underpinning techniques. The segments were designed to a 150 year design life to withstand the full ground and hydrostatic loading, with a worst case scenario of water level being at ground level. All handling and storage loads were also considered. Water-tightness would be maintained by EPDM gaskets running on the perimeter of each segment. Operational loadings within the shaft were required to be checked, with intermediate floors within the finished shaft being supported by two rings of segments with reinforced corbels.

From early on in the underpinning procedure it was clear that the choice of proceeding with underpinning was prudent due to the amount of solid material found within the initial advances of the shaft. Large amounts of solid brickwork were found which would have caused large difficulties for any other form of construction.

Once past these obstructions, the sinking of the initial segmental part of the HPOS proceeded without difficulty. Construction then moved onto the SCL section before the



Above: SCL robot in operation during first SCL section of the HPOS
Left: Fig 3 - Final design proposal for SCL section of the HPOS

portals in the precast section of the shaft were constructed. These were designed to accommodate pipework of some 1800mm diameter and as such opening of 3m in height were formed using universal sections in typical jamb and lintel arrangements.

SCL section of HPOS

During the initial discussions between designer and contractor on the approach for the SCL section of the shaft, it was decided that the SCL would be applied using a robotic manipulator machine. This allows more control over the thickness of the sprayed concrete applied with less rebound (thereby saving material costs), allows the operator to be away from the face of the excavation and removes all risk of HAVS from manual handling. Additionally, it was decided that the same machine would be used both for the HPOS-HNS connection tunnel and the 15m ID shaft. Therefore a machine was required that was relatively small but had a large reach for spraying concrete to complete the shaft. Following research into these requirements, it was decided that the MEYCO Oruga would be the ideal choice. It was the ideal size, had a flexible spraying envelope and had a good track record on other jobs.

With the decision on the machine for the SCL established, the next decision was for the sequencing of the operations. The aim would be to strike a balance between advancing at a rate that is structurally safe and stable while trying to minimise construction time and number of operations. Using previous project experience and some ground modelling, it was decided to advance at 1m at a time and then spray in quarter sections of the shaft.

To waterproof the shaft a composite lining was proposed based on a primary and secondary sprayed concrete lining with a sprayed waterproof membrane between them. This membrane would be BASF's Masterseal 345, that had been used successfully for a variety of tunnel projects and could be simply applied to the shaft's primary lining using the same machine and personnel used for the sprayed concrete.

For the sprayed concrete mix, a proposal was required that could be used in all weather conditions, produce the required long term strength while providing adequate early-age strength for safety considerations, and also be flexible enough to be used for the shaft, shaft portals and the low level tunnel. Referring to the Austrian Sprayed Concrete Guidelines, it was appropriate to base the early age strength on the "J2" curve which is specified for when "sprayed concrete is to be placed in thick layers (including overhead) at a high delivery rate". This would certainly be true for Hampton particularly in the case of the low level connection tunnel and adhering to the guidelines would provide the long term strength and workability that would be required for the second part of the HPOS.

To aid the workability of the mix and for crack control structural fibres would be added. For the permanent design case of the shaft, these fibres would not be considered and the structure would be designed as if it were plain concrete. This decision was made as it is currently debated the extent that fibres would aid the tensile strength of concrete, and current design standards do not account for any benefit with their addition. The designer specified mixes with both polypropylene and steel fibres so that a cost analysis could be accomplished by the contractor. This was an important task as the availability of both types of fibre are highly variable, and so by specifying both it allowed the contractor the choice to vary the type of fibre dependent on market availability of fibres. As it transpired, polypropylene fibres were more available and cheaper than their steel equivalents and so were used throughout the construction.

With the decisions on the construction methodology agreed, the detailed design began to look at what would be required to construct a shaft that would meet the requirements for the design life. The shaft was analysed by performing a finite element analysis that fully models the construction sequence, from each advance to the final long term condition, with all of the resultant changes in ground conditions. This was performed by creating an axi-symetric 2D FLAC model, with each construction advance modelled and the model run to equilibrium. Using this model, the required thickness of both the primary and secondary lining could be easily found. The long term loading situation was modelled with the full ground loading applied on the primary lining. The long-term hydrostatic load was taken as being applied at the waterproof membrane and so was loading the secondary lining. This is a conservative assumption as any composite effect of the both linings acting together would be beneficial.

Following several runs of the model, the thickness of the linings required in both the short and long-term cases was as shown in the below figure. The shaft was finished with a curved base shell opposed to a standard flat base slab. This was easily achieved

using SCL and had design benefits compared with a flat base slab. The traditional flat base slab would deform in bending leading to potentially large amounts of concrete and rebar used in the faces of the slab. With the curved base shell, the concrete would be loading in compression and any equivalent 'hoop-force' from the shell would be acting directly against the firm surrounding London Clay. Once the shell was completed, it would be backfilled with concrete to create the flat slab surface required for the final fit out of the shaft (fig 3).

The final item of design with the shaft was the design of the low level tunnel portal for the SCL tunnel to the Hampton New Shaft and the soft-eye for future Thames Water works. It was important with these sections to minimise any reinforcement requirements, and so it was proposed for both structures to create a structural circular ring in the SCL primary lining to transmit any shaft lining loads once the portal was broken through. The ring required a minimal amount of reinforcement to take any tensile loading that would be acting in the ring section. This was accounted for by using steel mesh, which could be easily handled by the staff working in the bottom of the shaft and saved lifting heavy steel sections into the bottom of the shaft. Both of which provided a health and safety benefit compared to using jamb and lintel frames or shear dowels to create portals and could be constructed swiftly as part of the SCL primary lining advance.

With the author regularly in contact with the contractor and offering input as required as the construction progressed, this section of the shaft progressed well and without difficulty. Using these particular portal details saved significant time, compared to the alternatives that would be required in a precast shaft. Through this partnership and open-and-honest approach between designer and contractor the shaft was completed successfully, and the construction could move onto the connection tunnels.

HPOS to Hampton New Shaft

The connection tunnel from the HPOS to the Hampton New Shaft was designed and constructed using a similar method to the SCL section of the HPOS. An 1800NB steel pipeline connection was required with a series of two bends equalling an overall change of 80 degrees to connect into the correct position of each shaft. For the tunnel, Costain proposed a bespoke mechanical excavator which eliminated Hand-Arm-Vibration-Syndrome risks associated with hand-mining. Using the working envelope of the proposed excavator, the author's design team worked to minimise the excavated size whilst maintaining a safe working environment in the tunnel. This led to a 3.7 ID circular cross-section which was chosen to allow sufficient space for the installation of the pipework while providing a shape that could be easily constructed.

The tunnel was analysed using a FLAC model which modelled each step of the construction. It was proposed to proceed with 1m advances and this was allowed for in the analysis with suitable tolerances for the lining thickness and shape control. This lead to the choice of a 200mm lining which would act as a permanent lining to install the required pipework. The void between the steel pipe and the SCL was filled by the use of foam concrete.

The model, in addition to providing the values of compression and bending moment in the lining, provided estimates of expected ground movement. In conjunction with calculations on the allowable movement that the lining would be structurally able to withstand, this enabled a monitoring arrangement and trigger levels to be set by the designer to inform the contractor the limits of convergence and absolute movement. Arrays were set up across the circumference at four positions and movement read using a tape extensometer. This was done more frequently at the start of the drive to ascertain the likely ground movement for the remainder of the drive.

With the mechanical excavator and SCL machine both able to operate within the small confined space of the tunnel, and trained operatives with an eye for detail, the tunnel was able to be constructed to an accurate thickness and shape. Thanks to a sensibly designed construction sequence and good operators on site, the tunnel could be constructed swiftly, accurately and with the minimum of fuss.

Pipejack HPOS to Stilgoe House

The final main piece of construction required for the project was the pipejack tunnel going from the HPOS to Stilgoe House. The main obstacle for this piece of work was the water mains that surrounded the HPOS location with particular cast iron water mains located in the area that the pipejack tunnel would be located. As a result a thorough and detailed settlement assessment was required to be performed by the designer to predict the impact that the construction would have.

The assessment was undertaken using the typical Gaussian curve model of ground settlement that has been used for a variety of major excavations in London Clay. The settlement assessment included all of the construction elements, from the initial HPOS construction to the two connection tunnels. Modelling of the construction stages was important as the predicted movement could be compared to what was observed as the construction was ongoing. This was particularly important as the methodology of calculating the ground movement was based upon previously observed results, but the available data on ground movement for large diameter shaft sinking is minimal compared to tunnel construction. As a result it was possible that the predicted shaft settlement would be quite conservative.

From the initial predictions it was seen that the predicted ground movement would be quite large (ground movement of the scale of 40mm), and so the assessment was continued looking into the impact that such movement would have on the infrastructure. This considered not just the total ground movement but the differential movement and the micro-strain that the pipes would experience and also the joint rotation/pull-out. This suggested that although the maximum ground movement would be reasonably large, the small differential movement meant that the pipes would be within safe values according to recent guidelines but still at relatively high risk. It was decided following consultation between Mott MacDonald, Costain and Thames Water to lower the alignment of the pipejack from the proposed phase 1 design to minimise the settlement and to proceed with a detailed monitoring arrangement on site. This would be used to review the predicted movement against that actually occurring on

Below: Pipejack machine breakthrough into the HBOS

site as construction progressed.

By the time the pipejack began the primary lining for the HPOS had been constructed and the monitoring regime had shown that the movement induced from the shaft construction had been much less than predicted. This was due to the lack of previous recorded data for shaft sinking as mentioned, and the ground conditions at depth being better than anticipated and the good construction of the shaft.

The 40m long 1.83m ID pipejack tunnel was constructed from a small 6m ID temporary shaft to a depth of some 15m, with a back shunt for the jacking rig. The tunnel to the HPOS portal was created using a Lovat TBM. The tunnel was then installed with pipework and the annulus fully grouted up. While the construction method for this tunnel may be simpler in nature than the SCL counterpart, the importance of developing a system to create minimal ground movement was just as important as the complex nature of the composite sprayed concrete lining of the HPOS.

Conclusion

The secondary lining and waterproofing of the HPOS is now being undertaken, with the project due for completion at the end of February on programme. This project took on a variety of obstacles and challenges and through good design with the application of appropriate construction techniques throughout and construction with an eye for detail; all of these obstacles were overcome without difficulties. Such difficulties are not uncommon for underground construction in urban environments in London. Hampton Pump Out Shaft has shown that they can be easily overcome by using a variety of construction approaches with close and open working between designer and contractor throughout.

This scheme particularly benefitted from the use of sprayed concrete and the state-of the-art SCL design allowing the simple, safe and swift construction of a deep shaft with multiple openings. The successful use of a permanent composite SCL lining with the use of a simple to apply waterproof membrane should be noted and recommended for similar new projects where appropriate. Through the acceptance of the use of this new technology in the construction, Thames Water have been rewarded with a final shaft that all involved can be proud of. T&T

ACKNOWLEDGEMENTS

The author would like to thank all the staff that worked on this project, all of whom with their collaborative and open working approach enabled the project to be a success. Of particular note, the author would like to personally thank:

All of the Mott MacDonald design team that worked on this project but especially Chris Bambridge and Ross Dimmock for their support and guidance throughout this project and who along with David Gutteridge and Guna Rajadurai provided welcome advice for this paper;

Richard Stewart, Paul Guider, Jose Farinha and Paul Challinor from Costain for their common sense approach and eye for detail throughout the construction;

The tunnels team from Halcrow who provided a comprehensive and thorough CAT III check for this project and;

Tanveer Ahmed, Mark Morrison, Amit Chakraborti, Dan Reader from Thames Water for their support of this submission and useful advice and guidance.

Vejdekke's mobile factory

Deep beneath AlbaNova at Roslagstull in Stockholm, Vejdekke is constructing something that at present most closely resembles an underground cathedral with a height of 11m from floor to ceiling. Once everything is finished in six years' time, and a million cubic metres of blasted rock have been removed, there will be more than 4km of road tunnel in the Norra Länken (northern link) motorway here. The tunnel driving itself is expected to be completed next year.

A number of special machines are being used to carry out the work. In addition to traditional giant dumpers and loaders, there are also special rock scaling machines here, which are used to prize away loose rock fragments remaining after blasting. Once the rock has been cleaned, holes are drilled and are injected with cement to fill out any cracks and hold the surface layer together.

"The rock in Stockholm is good. It consists mainly of solid granite, so access to it is quite easy," says site manager Peter Antonsen.

The closeness of the holes for injection is determined after a geologist has surveyed the rock. A computer then draws the drilling patterns, and the injector vehicle is driven in once the holes have been drilled. This is actually a complete factory on wheels. The entire device and the vehicle hydraulics are electrically driven because the supply of clean air inside the tunnels is limited in spite of the powerful ventilation system. The "factory unit" consumes 45kWh.

Two injector vehicles are in use in the Norra Länken project. One of these has just been taken into service and is a 4-axle Mercedes Actros 4141 equipped with a HIAB XS 166 E-4 HiPro.

"We have another crane on the older vehicle, but when we needed an additional crane, the manufacturer of that model was unable to meet the new MEWP requirements that now apply across the EU to cranes equipped with aerial work platforms," explains Peter Antonsen.

"So we decided on a Hiab instead, and the actual model was

determined by its reach. A quite small electric pump takes care of the control hydraulics."

"We use it only as a personnel hoist."

The injector, which is connected via a hose to the on-board "cement factory", is manoeuvred manually into position in relation to the sleeves on the drill holes in the rock wall that are to be secured.

"The vehicle contains two mixers, four stirrers and four pumps, which discharge the cement mixture at a pressure of 50 bar," says Peter Antonsen.

The operator himself moves the working platform with his radio-controlled operating device. The work progresses rapidly, and in a normal working day between ten and twenty tonnes of cement mixture are injected into the rock – between 70 and 100 litres into every hole, each of which is 25m deep. The entire rig, including the crane and the injection equipment, cost almost US$933,300, including the factory part.

Hiab
Web: www.hiab.com

Queen's award

Excalibur Screwbolts receives a Royal seal of approval with The Queen's Award for Enterprise in the Innovation Category.

Managing Director Charles Bickford, the inventor behind Excalibur Screwbolts, proudly stepped up to receive the award from The Lord Lieutenant of Essex, Lord John Petre of Ingatestone.

The revolutionary Screwbolt concept is the twin helix thread designed around a drill bit. Excalibur Screwbolts, a one-piece anchor, fix directly into the toughest substrate, such as concrete, without the need for additional fixings, plugs or resins.

Traditional fixing methods have required the use of through-bolts, expansion anchors, sleeves and resins but these were often more labour intensive and less flexible.

Excalibur Screwbolts
Web:
www.excaliburscrewbolts.co.uk

TOP thermoplastic roller

The new TOP roller has a lower weight with respect to a steel roller (about 50%), which means a lower power consumption during operation of the belt conveyor and therefore reduction of power requirements on the plant, easier mounting/maintenance operations, and guaranteeing a safer intervention, especially in application where roller mounting or replacement might be critical.

Furthermore the low level of abrasion and corrosion of this roller (wear resistant) guarantees a longer life of the roller and a lower maintenance of the whole plant.

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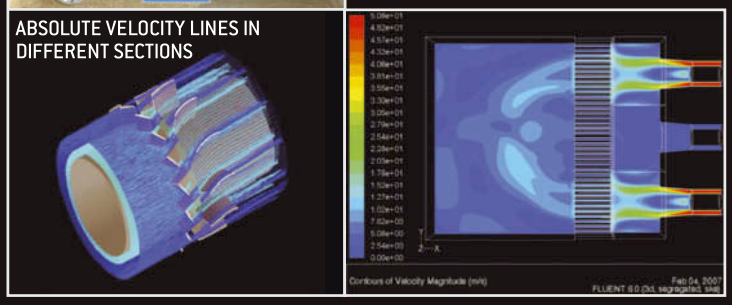

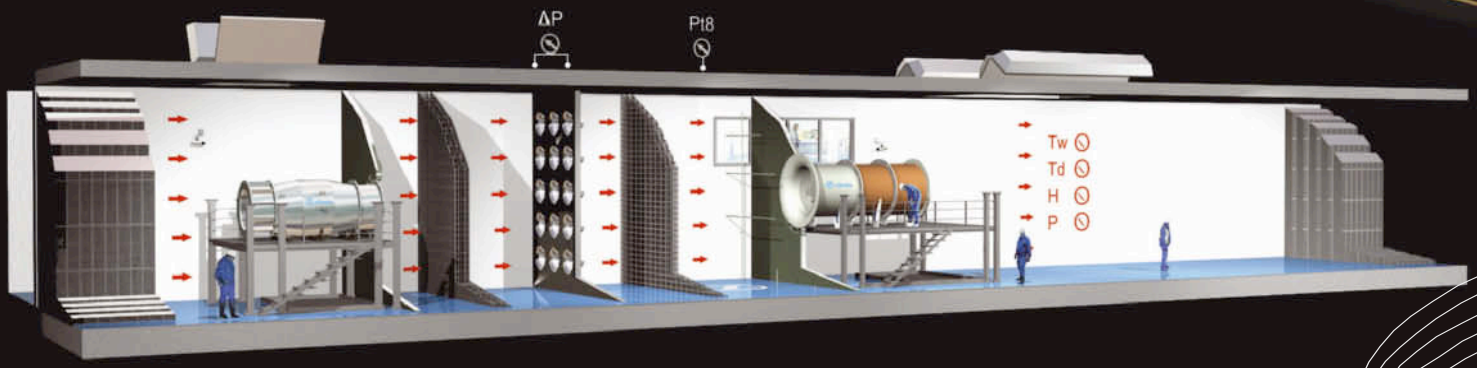

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Disputes in tunnel projects – Part 2

Following on from last month's article, Dr Nigel Legge and Garry Crossley of Navigant Consulting, and Caroline Pope from Berwin Leighton Paisner conclude the March 2009 British Tunnelling Society presentation, illustrating the role ground conditions, the use of provisional sums, and early use, play whilst considering project risk issues

Ground Conditions

In the speaker's experience, when tunnelling projects overrun, a major element of this is blamed on ground conditions, even if the problems in the ground are being used to mask other causes of delay.

Unless the Contractor is taking the full ground risk, each of the standard forms of contract use a version of "reasonably foreseeable" as the test to define the level of ground risk the Contractor agrees to take.

Nevertheless, the question of what was reasonably foreseeable by an experienced Contractor is not readily answerable, and can sprout many arguments and disputes.

Firstly, the argument can be avoided by placing the full ground risk on the Contractor.

The difficulty with this approach is that purchasers only want to pay for what happens, rather than pay a premium for a contingency which may not happen. The foreseeability test is aimed at encouraging the Contractor to price for realistically probable ground conditions. But equally, Contractors complain that despite this pragmatic approach to allocating risk, Purchasers are reluctant to accept the reality of the test (and the resulting additional costs incurred) in practice when unforeseen ground conditions are encountered.

Secondly, if the ground risk is to be shared, the foreseeability test can be refined as in clause 60 of the NEC. Under the NEC, the Contractor is entitled to a compensation event, if an experienced Contractor would have "judged the physical conditions to have such a small chance of occurring that it would have been unreasonable for him to have allowed for them". This does give some clarity around the test particularly as it links to price – the Purchaser cannot have expected the Contractor to have priced for a certain occurrence, if its chances of occurring were so small.

Thirdly, a way, which is being increasingly used to try to limit arguments, is to use geotechnical baseline reports. The intention of these reports is to be used to provide a contractual benchmark as to what is foreseeable. The idea is that the Contractor can claim compensation for matters where

QUESTIONS AND ANSWERS

Question 1

One of the introductory slides showed that the number of disputes is increasing, does this suggest that the Alternative Dispute Resolution system is not functioning properly?

(C Pope) Not necessarily: A large number of cases have been going to the courts to enforce adjudication decisions, which may explain the figures. A reason could be that ADR has not been effective at the early stages, before cases are started in the courts, as although pre action protocol occurs whereby information about the case is discussed before claim form is issued, sometimes parties can become entrenched within that period.

(G Crossley) International perspective - DRB/DAB are mandatory on World Bank projects, though provisions are not included in contracts of large UK infrastructure projects. DRB/DAB is a good way of minimising potential disputes during, and in some instances after, a project has finished (according to speaker's experience in Asia).

Question 2 - Mike McConnell

Is there any evidence that the new suite of NEC contracts are better than the older ICE set of contracts?

(C Pope) NEC is one of the most widely used contracts in the UK. The NEC contract is not intended to be "kept in the bottom draw", but there remains some confusion due to the amendments made by parties. Speaker's experience is that she has rarely seen an un-amended NEC contract. Lawyers tend not to like the contract because it is written in the present tense, though Engineers (especially on site) favour it, due to roles & responsibilities being clarified more easily. Another advantage is its flexibility

Question 3 - John Scholey; Jacobs

Should problems arising in projects be viewed as an under plan of resources, as opposed to an overrun of schedule? How much is fear a factor prior to implementation stage, and how much does this influence allocation of resources (JS suggests this is a significant human factor)?

(G Crossley) Little interface between project planners and the Designers and Engineers during the planning stage is usually a cause of delay in so far as the programme does not properly reflect how the Designers and Engineers have planned to construct the project, with this being seen in Boston's Big Dig where contractors would return to the project manager during bidding stage saying that the works were unbuildable in the programmed time, due to the works being technically complex.

(John Scholey) Planning is generally carried out with unbridled optimism. I was surprised by the quote that large organisations appear to have 'no collective memory whatsoever'

(Dr N Legge) Turnover of staff in large organisations can lead to a loss of collective experience. I am aware of organisations attempting to implement knowledge management procedures to counter this, but I am not aware of how effective these have been.

Rapporteur: Harnaik Mann

Table 1

	Problem	Possible Solution through Drafting of Contract
1	The delays were caused by the Purchaser's late instruction of the M&E provisional sum	Making it clear how much information the Purchaser needs to provide when specifying the provisional sums. Need to determine whether it is an outline or detailed specification, sufficient to be used by the contractor in obtaining sub contract tenders
2	Despite being defined provisional sums, in fact the scope was not sufficiently defined at tender to allow the Contractor to properly assess how much time it should programme for the works, even though it had taken to risk for this in its contract programme.	Clarify what involvement the Purchaser is to have in the package contractor selection in the contract
3	"Interference" in the selection process	The Purchaser needs to consider carefully how much time it needs to review the technical documentation it receives in approval/design review processes. Ensure turnaround times prescribed in the contract reflect the complexity of the works and are realistic for the organization reviewing the documentation
4	The Purchaser using the approval process to further design out O&M costs	Often contracts are drafted on the assumption that the Purchaser will seek clarifications and will get an adequate response, without providing for what is to happen if it continues to be inadequate. Drafting an evergreen clause can cater for this

the Purchaser has either not set a baseline in the geotechnical baseline report, or where a baseline is set, but actual conditions differ from those stated. While there is still scope to argue about whether or not the conditions are more adverse than in the baseline report, it does at least provide a benchmark on which an assessment can be made.

However it remains the case that often these Baseline Reports tend to be largely factual, as opposed to interpretive, yet it is in the area of how the factual report is interpreted that so many arguments arise.

Use of Provisional Sums

There is a tendency to concentrate on issues arising out of the front end tunnelling activities in the ground. However, the Pie chart (see figure 2 in last month's issue), shows this focus overlooks the fact that many disputes arise from matters that are unrelated to civil engineering activities. As a result, potential pitfalls may arise.

Given the long lead times for major infrastructure projects, the civil engineering aspects of the projects tend to be well defined and subject to early detailed design.

However, the same can not always be said for major M&E elements. Because M&E plant has an important effect on the scheme's O&M cost, the Purchaser wants input into its selection and design. Nonetheless, often this plant is not scoped sufficiently at tender for the Contractor to be able to take the price risk for it. Hence, significant elements of the plant are included as defined or undefined provisional sums to be instructed later, once the Purchaser has clarified its requirements.

Also, even when instructed, the purchaser usually still wants to maintain some control over its procurement and design development. So, although responsibility is transferred to the Contractor, the Purchaser wants to remain involved, exposing itself to arguments about interference. Table 1 outlines problems and solutions regarding the use of provisional sums.

Early Use

Another area where disputes occur are where projects are in delay, putting the Purchaser at risk of being in breach of third party interface agreements or other statutory duties, with the risk of prosecutions or fines unless the scheme can be used before completion. This lead to arguments about:

- How the Purchaser's use of the scheme impacted on the commissioning
- Whether the use of the scheme in this way caused delay
- Whether early use was always going to be needed for commissioning, even if not specified in the Contractors Proposals
- Whether the Purchaser had prejudiced its rights to claim liquidated damages

Requiring the Contractor to allow early use of the scheme will constitute a contract variation, introducing a new constraint on carrying out the works, entitling him to additional time and costs, if it is not provided for in the contract. But does it also mean that the Purchaser loses his entitlement to claim liquidated damages from the date of the instruction?

The former would not prejudice the Purchaser's requirement to claim liquidated damages from the date of instruction, but the latter would constitute the Purchaser having beneficial use of the scheme, such as to prevent it claiming liquidated damages from that date until formal take over.

If specific statutory or third party requirements are known at contract award, these should be recognised in the contract and the liquidated damages clause refined to cater for this situation. This would allow the Purchaser to use the scheme if it needs to do so, minimising the risk of totally losing its entitlement to liquidated damages.

Conclusions

Whilst disputes may not be eliminated, the risks of them occurring may be minimised through effective project planning, not only at the outset of the project, but continuously through its duration. Furthermore, thoughtful drafting of contracts and clear communication to the parties involved is essential to assist in the delivery of large underground infrastructure projects with the minimal number of contractual disputes arising. T&T

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Fire risk on a tunnel boring machine

AM Thyer, Health and Safety Laboratory, and P Key, McConnell Dowell Constructors, try to unravel the serious issue of fire risk on TBMs

This paper presents the findings of a quantitative assessment of the risk of fire on a large TBM used by the Copenhagen Metro Construction Group (COMET, a consortium formed by Tarmac, Bachy, Astaldi, Ilbau, SAE & NCC) to drive the Copenhagen Metro. The methodology follows a similar strategy used by HSL for other TBMs, using fire science to develop an understanding of fire size and severity, and feeds this into a risk assessment to develop an understanding of risks to workers. This risk estimation process was made possible through drawing an analogy between a TBM and a large hydraulically-driven coal shearer, for which good failure rate data was available.

The output of the exercise was used to demonstrate to the Danish authorities that extensive and suitable precautions had been taken against fire, as they required independent confirmation of fire safety following a major fire on a similar TBM used to drive the Storbelt tunnel.

The aim of the project

The first phase of construction of the Copenhagen Metro involved boring two parallel tunnels with a combined length of about 16km under the centre of the city, of which about 14km was to be bored using the two TBMs. Due to the number of access shafts and stations, the maximum length of blind heading from which workers would be required to escape in an emergency was approximately 600m.

The TBMs in question were earth pressure balanced machines, 5.71m in diameter, with eight separate gantries amounting to a total length of 80m. They ran with a crew of ten and had an open construction with plant generally being located on one side of the machine and a relatively clear walkway on the other. Electrical power was delivered via a 11kVA cable to a reel on the rear of the machine. Much of this power was used to operate pumps for hydraulic systems, which moved large inventories of hydraulic fluids in pipelines up to 10cm in diameter, at pressures up to 300bar. In addition to the 9000 l of hydraulic fluid on board, a large diesel generator was present.

Above: **Interior of the TBM, hydraulic pumps and overhead oil storage tank**

Table 1: Fire-related test data for hydraulic fluids

Fluid	Flash point /ºC	Fire point /ºC	Auto-ignition temperature/ºC
Typical mineral oil	166	180	320
Channel Tunnel TBMs mineral oil	230	-	400
Typical triaryphosphate hydraulic fluid	246	365	580
Typical polyol ester hydraulic fluid	280	310	415
Comet TBM polyol ester fluid	280	325	480

Test data for the hydraulic fluid

A comparison of the fire properties for the hydraulic fluid used on the TBM with data for common alternative fluids in Table 1. An assessment of the fire hazards of hydraulic fluids was published by Jagger et al[1]

Leak types and assumptions

The following leak types and consequences were identified.

From this, it can be seen that drips were assumed to result in the formation of a small pool at the point of release, and that large leaks would give rise to either large pools or streams of liquid within the TBM. Depending on their size and duration, pressurised releases would give either

atomised jets of droplets or pools of liquid.

Ignition probability is discussed later, but was assumed to be higher for atomised jets than liquid pools.

Failure frequencies and TBM item quantities

As failure rate data for TBMs was not available, the approach adopted was to make a comparison with a machine used underground in similar operations, in this case a coal shearer. Data on failure rates for coal shears is reproduced in Table 2.

Table 2: Failure rates for hydraulic components on coal shearer

Component	Failure rate per item-hour
Hoses	28×10^{-6}
Hose couplings	11×10^{-6}
Control valve	2×10^{-6}
Steel pipe (inc. couplings)	2.9×10^{-6}
Oil seals	2.8×10^{-6}

It is recognised that a coal shearer differs from a TBM as it is constructed differently and operates in a different manner. In TBMs pipework is contained within the body of the machine and is largely protected, whereas a coal shearer works backwards and forwards across the face, exposing parts of the hydraulic system to damage by scuffing and trapping in moving parts of the machine. It is therefore likely that failure rates for coal shearers may be slightly higher than those for TBMs. It was, however, established that the hydraulic systems were built to similar standards, and that operating pressures were similar.

Given the different numbers of items on TBMs and shearers the failure rates require correction by the appropriate ratio for:

$$\frac{\text{Number of items on Shearer}}{\text{Number of items on TBM}}$$

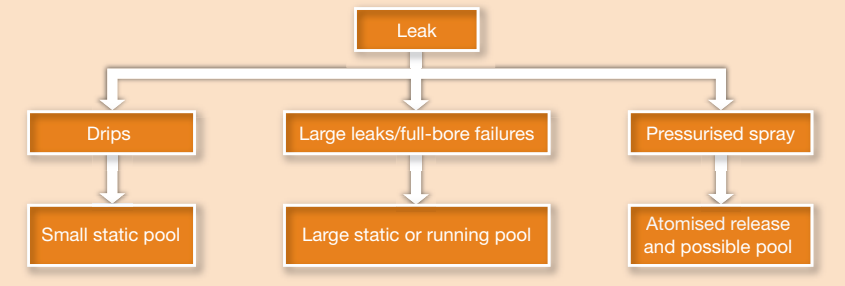
Information on the numbers of each item was sought from COMET and Joy Mining Machines Ltd, whose help is gratefully acknowledged (Table 3). This led to the derivation of the following ratios. Correction is also required to allow for operating time:

$$\frac{\text{\% time TBM is operational}}{\text{\% of time shearer is operational}} \quad \frac{\text{i.e. 71 \%}}{14\%} \quad \text{or 5:1}$$

The 71% figure was based on a five-day week with a 24 hour working period.

Additional factors also needed to be applied in three cases to correct for the mean lengths of hoses and pipes on TBMs and coal shearers.

Applying these factors gave the following failure rates (Table 4).



Above: **Fig 1 – Leak types and consequences**

Table 4: Derived failure rates for hydraulic equipment on a TBM

Component	Failure rate x 10^6 per hour	
Hoses	228	(A)
Hose couplings	101	(B)
Control valve	71.4	(C)
Steel pipe (inc. couplings)	21.7	(D)

These failure types can be partitioned according to the following scheme and were assumed to apply equally to hoses, pipes and couplings.

Leak type	Percentage
Small (2mm) hole	60 %
Medium (5mm) hole	35 %
Large (full bore)	5%

Half of the small and medium releases were assumed to be drips from a low pressure or unpressurised system, and half sprays from a 2mm diameter hole.

For releases from valves and seals, 90% were assumed to be drips, and 10% to be sprays from a 2mm hole.

The resulting overall frequencies are therefore:

Drips: F(Drip) = (A+B+D) x (0.6x0.5) + (C+E) x 0.9 = 3.29×10^{-4}

2 mm spray: F(2mm) = (A+B+D) x (0.6x0.5) + (C+E) x 0.1 = 1.31×10^{-4}

5 mm spray: F(5mm) = (A+B+D) x 0.35 x 0.5 = 0.72×10^{-4}

5 mm non-spray: F(Non-spray) = (A+B+D) x 0.35 x 0.5 = 0.72×10^{-4}

Full bore: F(Full bore) = (A+B+D) x 0.05 = 0.21×10^{-4}

Event probabilities and fire frequencies

The properties of the oil (flash point 280°C, AIT 480°C) indicate that it would not ignite readily, particularly if the release were a pool. A spray or mist is easier to ignite, and could give rise to low energy explosions if droplet clouds were to develop. The individual events identified and the probabilities assumed are shown in Figure 2 on the next page.

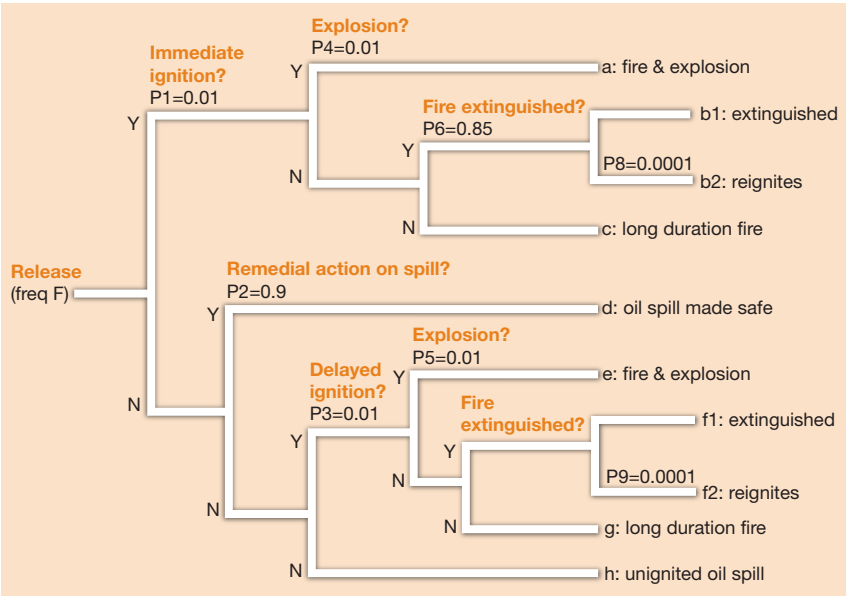
The relative likelihood of the events described depends on the probabilities P1 to P9, which will be related to the size and type of the oil release, and the environment into which it is released.

Fire frequencies

Using the values P1 to P9, together with an appropriate release frequency gives the fire and explosion frequencies are shown in Table 5 on the next page.

Table 3: Estimated numbers of items on TBM and coal shearer

Item	TBM	Coal shearer	Ratio of number of items on shearer to TBM
Hoses	123	66	1.9
Hose couplings	246	136	1.8
Control valve	91	13	7
Steel pipe (inc. couplings)	24	0	3.5
Oil seals	42	26	1.6



Left: **Fig 2 - Event tree for probable fire and explosion scenarios for a 2mm^2 spray release**

Table 5: Fire and explosion frequencies

	Scenario	Frequency of fire	Frequency of explosion
1	Drip pool	F(D) x 5.5 x 10^{-5}	None
2	2mm spray	F(2mm) x 0.0016	F(2) x 1.1 x 10^{-4}
3	5mm spray	F(5mm) x 0.0016	F(5) x 1.1 x 10^{-4}
4	5mm non-spray	F(N) x 0.00011	None
5	Full bore	F(F) x 0.00011	None

Table 6: Fire and explosion frequencies

Fire size	Frequency of fire	
3m^2 pool	F(D) x 5.5 x 10^{-5}	= 1.81 x 10^{-8}
2mm hole (0.35-0.44kg.s^{-1} release)	F(2mm) x 0.0016	= 2.10 x 10^{-7}
5mm hole (2.3-2.8kg.s^{-1} release)	F(2mm) x 1.1 x 10^{-4} + F(5mm) x (1.1 x 10^{-4}+ 0.0016) + F(N) x 1.1 x 10^{-1} + F(F) x 1.1 x 10^{-4}	= 1.48 x 10^{-7}

Due to number of factors such as the properties of the fluid, release conditions not truly being conducive to the formation of an explosion and, the finite ventilation rate for the tunnel limiting fire size, scenarios 3, 4, and 5 can be considered to give rise to similar consequences. The table therefore simplifies to Table 6.

Consequence assessment

The potential consequences of a fire on the TBM were calculated on the assumption that releases could be ignited, leading to a range of fire sizes and durations. A typical pressurised spray fire is shown to the right.

The hazards from these fires were considered to be injury from the heat generated and exposure to toxic combustion products.

Heat injuries can arise from direct contact with the fire, exposure to thermal radiation, or proximity to hot smoke.

As well as heating effects, exposure to smoke will also deliver doses of CO, CO_2 or other toxic gases to those in the vicinity. In order to estimate the extent of these hazards relevant details, such as the tunnel dimensions, the heat of combustion of the fluid and its density were input into a simple computer programme written specifically to calculate the hazards of fires in blind tunnels.

The programme estimates the smoke temperature and velocity at various points down the tunnel and determines the degree of mixing or dilution of the smoke. It also calculates the thermal dose and toxic exposure to CO/CO_2 received by a person in the tunnel, given an assumed location for the individual, a reaction time and an escape velocity.

The mitigating effects of a water spray barrier on the TBM were estimated using a separate programme with modified fire parameters.

Effects on tunnel occupants

The consequence model was applied to each of the identified fire scenarios, for both the typical 200 bar operating pressure, and the maximum system pressure of 300 bar. The results are summarised in Table 7. In all runs the time taken for personnel to react was assumed to be 10 seconds and the escape velocity to be 1m.s^{-1}[2]. This latter figure may seem low, however, in the event of the tunnel being filled with smoke it is

Right: **Burning hydraulic fluid spray release**

probably a reasonable assumption as the primary guiding sense will be touch.

For comparison, the mitigating effects of a water spray barrier on the TBM were also calculated for the same fire sizes. As would be expected, velocity and temperature reductions generated by the water spray led to reductions in both thermal dose and exposure to CO/CO_2. Close to the fire, the model predicted increases in the time before incapacitation through smoke inhalation ranging from a few percent to 140%. Similar reductions were predicted in thermal dose received by escaping personnel, with reductions for a 2.8 $kg.s^{-1}$ spray release being in the order of 40 - 110%.

Comparison with risk criteria

The results of a risk assessment are usually presented in terms of individual and societal risk, which have been defined by the Institution of Chemical Engineers as:

Individual Risk (IR): The frequency at which an individual may be expected to sustain a given level of harm from the realisation of specific hazards: and,

Societal Risk (SR): The relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards.

The risk of people receiving a significant thermal dose or toxic exposure as a result of a fire on the TBM can be estimated by combining the frequencies of fires occurring with the consequence estimates. In this study, the significant thermal dose was taken as $1000(kW.m^{-2})^{4/3}$, which equates to a 1% chance of death, and a significant toxic exposure as 180s.

For an initial position, 10m from the fire, calculations indicated that a significant thermal dose would be received for both the 2 and 5mm spray releases, but not for the $3m^2$ pool. The overall risk was therefore the sum of the frequencies for the 2 and 5mm jet fire scenarios given in Table 6.

Risk of significant injury or death at 10m

$= 2.1 \times 10^{-7} + 1.48 \times 10^{-7}$

$= 3.58 \times 10^{-7}$

At 30, 100, 150, and 300m from the fire, only the effects of the 2.3 or 2.8 $kg.s^{-1}$ spray release caused the thermal and toxic dose criteria to be exceeded. The risk at these distances was therefore: 1.48×10^{-7} per hour.

With the spray barriers in use, neither the thermal nor the toxic criteria were exceeded at 500m, so the risk at this distance was zero. Table 8 lists the risk at each of the specified distances.

The risks in this table refer to a 24 hour operation. Assuming a 4-shift system, individual risks can be derived by dividing the values in Table 8 by 4. The maximum individual risk was therefore predicted to be 7.3×10^{-4} per year.

Sensitivity study

The effects of halving the reaction time to 5 seconds was investigated to determine the effect it may have on the chance of escape. Similar changes were also made to the escape velocity, which was doubled to 2 $m.s^{-1}$, (7.2 km hr^{-1}). Halving reaction time was not found to significantly effect the chance of escape. Increasing escape velocity did[2], however, have a beneficial effect as, although the toxic threshold was exceeded, the thermal exposure fell to nearly 5100 $(kW.m^{-2})^{4/3}.s$, indicating that, should a self-rescuer be worn, the individual may have a chance of escape. However, whilst this velocity may seem reasonably achievable in normal circumstances, it may not be so whilst wearing a self-rescuer and in a smoke-logged tunnel.

Table 7: Calculated effects for fire scenarios in tunnel – without water spray barriers

Fire type/fluid release rate		Initial position of person from fire (m)					
		10	30	100	150	300	500
$3m^2$ pool	Thermal dose $(kw.m^{-2})^{4/3}.s$	Escapes	Escapes	Escapes	Escapes	Escapes	Escapes
	Toxic exposure	Escapes	Escapes	Escapes	Escapes	Escapes	Escapes
0.35$kg.s^{-1}$ (200 bar)	Thermal dose	>8000	Escapes	Escapes	Escapes	Escapes	Escapes
	Toxic exposure	Engulfed in flames	Escapes	Escapes	Escapes	Escapes	Escapes
0.44$kg.s^{-1}$ (300 bar)	Thermal dose	>8000	Escapes	Escapes	Escapes	Escapes	Escapes
	Toxic exposure	Engulfed in flames	Escapes	Escapes	Escapes	Escapes	Escapes
2.35$kg.s^{-1}$ (200 bar)	Thermal dose	>8000	>8000	6,328	4,809	581	Escapes
	Toxic exposure	Engulfed in flames	18 s	>87 s	>180 s	>180 s	Escapes
0.44$kg.s^{-1}$ (300 bar)	Thermal dose	>8000	>8000	>8000	>8000	1,497	Escapes
	Toxic exposure	Engulfed in flames	16 s	48 s	145 s	180 s	Escapes

Table 8: Risk values for exposure to fire at specified distances along tunnel (without spray barriers)

	Initial distance from fire (m)					
	10	30	100	150	300	500
Risk per hour	3.58×10^{-7}	1.48×10^{-7}	1.48×10^{-7}	1.48×10^{-7}	1.48×10^{-7}	0
Risk per year (8000 hours)	0.0029	0.0012	0.0012	0.0012	0.0012	0

Conclusions

The information presented in this paper demonstrates a relatively simple method to enable the quantification of the fire risks on a TBM. This, along with a detailed review of fire precautions, allowed the operators to successfully demonstrate that adequate precautions had been taken to ensure safe operation, and also enabled informed decisions to be taken on emergency actions in the event of fire.

It is recognised that there are uncertainties in some of the data used in this study, particularly those numbers used to determine the relative number of items on the TBM and coal shearer, however this should not invalidate the general findings of the study.

Other variables include factors such as the reaction time, which may be longer if personnel initially try to fight the fire, the escape velocity, or the availability of self-rescuers. Should a self-rescuer be worn, the likelihood of escape would increase considerably beyond 150m from the fire. T&T

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Steel fibres or synthetic fibres?

Friends, enemies or potential allies? Like synthetic fibres, steel fibres have their qualities, particularities and faults. France's LCPC's (Laboratoire Centrale des Ponts et Chaussées) Pierre Rossi gives this account

Civil engineering and construction professionals no longer consider fibre reinforced concrete as exotic. This is after over 30 years of technical research and development. This positive assessment is the result of several factors including:

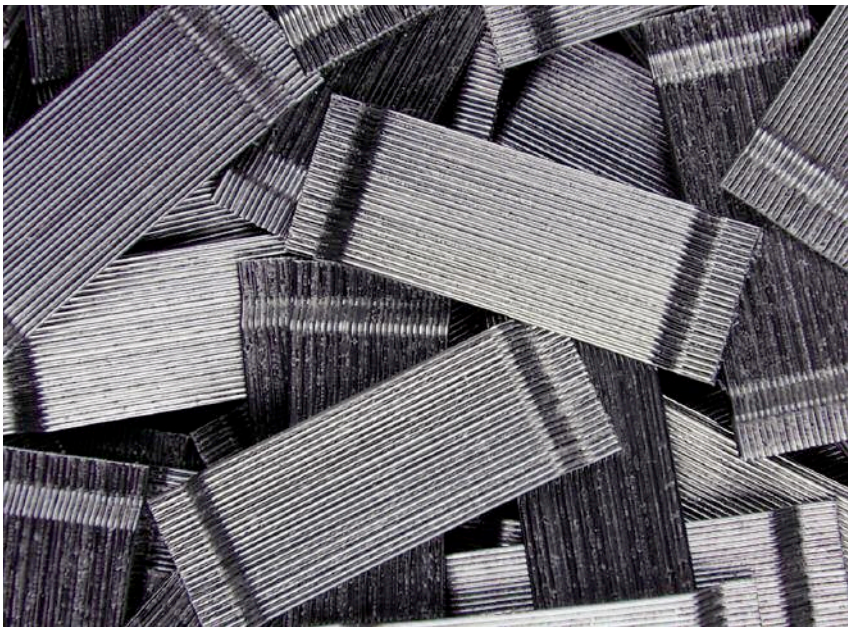
- The benefit of conclusive experience (especially for steel fibre concretes which have been used since the 1970s)
- Very good technical understanding of these materials (formulation, use, physical, chemical and mechanical properties, etc.)
- The existence of national and international recommendations on the sizing of the structures or structural elements made up of these materials (today perfectly validated for steel fibre concretes)

Therefore there are markets in constant growth for these materials today.

Some objective comparisons

There are now two types of fibre available on the markets: steel fibres and synthetic fibres.

When confronted by a pair of whisky connoisseurs we want to make sure they don't turn into alcoholics and drink the whole bottle. Indeed when relying on the scientific or technical literature concerning the comparative performances (attractions?) of the two kinds of fibre, to our dismay we find that the "thirst" often justifies the means. In other words, we find approximations, errors and unfortunately even bad faith (or worse) sprinkled in these learned texts. The objective is not to play to the fibre court but to offer some of the most objective elements possible (at least that is what we hope) so that the users of the famous fibre can come to the market without compromising quality. In order to get to this point we have not chosen to make an exhaustive comparative analysis between the two competitors, but to focus this analysis on two important problem areas where they are clearly differentiated. These two problems are mechanical performance and durability.



Above: **Example of Dramix® steel fibres**

Mechanical performances

Firstly it is useful to remember the two indispensable basic points about fibre reinforced concrete. A fibre reinforced concrete is a composite material made up of a matrix – the concrete, and the reinforcement – the fibre. In a fibre reinforced concrete the fibres spread the strain across the cracks created in the matrix. In other terms the fibres are only useful if there are potential cracks in the material. No cracks, no fibres.

When faced with cracks, one mechanical characteristic of the fibre is paramount. The Young modulus defines the rigidity of the fibre.

Indeed, the higher the Young modulus of the fibre, the better the control of the cracks created in terms of length and opening. These values diminish as the Young's modulus of the fibre increases.

This principle is essential as long as the anchoring of the fibre in the concrete is assured. The cracks in the concrete appear at different times in the life of the material. From the first moments (plastic shrinkage…) up to a very advanced age. As a result these cracks appear at times in the concrete corresponding to structural characteristics (e.g. density) and mechanical characteristics (resistance in compression, Young modulus) which progressively develop.

During the first three hours the resistance of the concrete and its Young modulus are very low: compression resistance lower than 3MPa, traction resistance below 0.3MPa and Young modulus below 5Gpa. These figures are only orders of magnitude.

Above: **Concrete cracks by shrinkage or loads. Adding steel fibres not only works on temperature and shrinkage control, but increases the load bearing capacity**

Above: **Example of synthetic fibres used in protection against fire**

If the concrete cracks during this period, loads to be taken by the fibre and crack openings will be low. After 24 hours and more the mechanical properties of the concrete increase considerably; compression resistance higher than 10MPa, traction resistance above 1MPa and Young modulus above 15Gpa. These are still orders of magnitude.

During this maturation period if the concrete is "pushed" again to crack, the loads taken again by the fibres as well as the openings of the crack will be much more significant.

How will both behave when concrete cracks?

a) Steel fibres, most often in steel have a high Young modulus (200GPz) and a high resistance in traction (between 800 and 2,500Mpa). At a very young age, since small openings in the cracks may appear and because of the poor anchoring of the fibre in the not very compact matrix, these steel fibres are not very effective against the cracks. The matrix does not pull on the fibres perpendicularly to the cracks so the cracks also do not react very much. The more the concrete ages, the more the steel fibres are needed by the cracks. They respond very effectively.

b) The synthetic fibres used on the concrete are mainly polypropylene fibres. They have quite a low Young modulus varying between 3 and 5GPa. They are offered on the market in very small sizes (in length and diameter).

More recently another type of synthetic fibre has appeared on the market: polymer fibre, also called macro-synthetic. It is "offered" for structural applications.

Its size is more significant than polypropylene fibres. These macro-synthetics also have a higher Young modulus than those of polypropylene fibres, it varies between 5 and 10GPa approximately.

Finally, two other types of synthetic fibres are also used in concrete, but on a much lower level. These are PVA fibres and aramid fibres with Young Modulus of 30 and 70GPa respectively. These fibres are now used in very high and ultra high performance fibre reinforced concretes.

c) The following remarks concern polypropylene fibres and macro synthetic fibres.

Because of their low Young Modulus these fibres are very reactive to potential cracks at a very young age, in particular polypropylene microfibres. Indeed, slight displacements on the fibres linked to small openings of the cracks in these fibres generate sufficient loads to combat the propagation of cracks. This effectiveness is increased because certain polypropylene fibres are fibrillated and therefore very well anchored. This is also the case in a not very compact and adherent matrix such as very young concrete.

Conversely as the concrete becomes more mature, synthetic fibres become less significant. Indeed, because of their low Young modulus synthetic fibres must undergo large displacements, corresponding to the large openings of the cracks, to generate appropriate seams in the cracks. Therefore, in aged and cracked structures in concrete with macro-synthetic fibres, cracks are much more open than with steel fibres and the deformation of these structures may be (too) significant.

d) Another point to consider concerns the mechanical aspects. It concerns the problems of creep of the fibres.

The creep of a material describes how it deforms in time even under constant strains. Steel fibres at the levels of strain in concrete do not creep or hardly ever. This is not the case for synthetic fibres. Indeed these creep in a non negligible fashion.

Below: **Creep test - only steel fibres have a creep control and as such strength on age**

Above left: **Example of macro synthetic fibres** Above right: **Steel fibres are increasingly used in arches partially or completely replacing steel armatures. Introducing polypropylene microfibres into the composition of the fibre reinforced concrete reduces the risks of scaling. The combination of steel fibres and polypropylene microfibres is therefore an optimum solution**

This may have negative effects. Indeed, one may encounter a situation where in a given situation the concrete with synthetic fibres responds correctly to the specifications of the structure (mechanical stability, deformation, openings of cracks) and the creep of fibres (between cracks) makes the structure "sway" in a situation which is not acceptable with deformation (good use of the structure) and crack openings which become too significant (durability problems).

Durability

When people talk about the durability of fibre reinforced concrete concretes there are two factors involved: the material and the structure.

a) the first aspect concerns the problem of corrosion of the fibres (material). Regarding synthetic fibres, apart from some aramid fibres, there is no durability problem in the fibre in the concrete.

Regarding steel fibres, corrosion of the fibres may obviously occur. Experience and research conclude:

- Superficial corrosion of the fibres may cause discolouration on the surface of the exposed structures
- Surface corrosion of the fibres does not cause any fault or disturbance in the mechanical operation of the structures using it

This potential corrosion of steel fibres may be minimised in practice by:

- optimising the formulation of the fibre reinforced concrete
- using non steel frameworks or ones with an "internal skin" (synthetic tissue for example)
- using galvanised fibres

b) The second aspect regarding the durability of fibre reinforced concretes concerns the fire resistance of structures. Steel fibres are not a determining factor in the fire resistance of structures. What we can underline is that a structure in fibre reinforced concrete behaves rather better in the presence of fire than a normal reinforced concrete structure (fewer breaks).

Conversely, some synthetic fibres, particularly polypropylene microfibres have a significantly positive impact on this problem. This effectiveness is due to a very simple phenomenon: in the case of a fire, polypropylene fibres disappear (they have reached their fusion point) to leave in place a significant network of fine canalisations (capillaries) shared through the volume of the structure. These canalisations act as expansion vessels for the water vapour generated under pressure by the fire (evaporation of the water present in the concrete).

c) Regarding the durability of the fibre reinforced concrete structures, a last important point concerns maintaining a function required for a given structure over time. Like any covering in fibre reinforced concrete which has to ensure a seal (e.g. in presence of water infiltrations). Because of the creep of synthetic fibres, mentioned above, this function, currently ensured by a concrete structure in synthetic fibres, may not be so some time afterwards. This is a problem for which steel fibre concretes are not concerned.

Finally, in the case of prefabricated portable elements, or structures which may come into direct contact with users, safety problems may arise if these are steel fibre concretes. This phenomenon mainly concerns fibre reinforced concrete concretes the fibres of which have small diameters, that is under or equal to 0.25mm. Indeed one can never guarantee 100% that any steel fibre will not show on the surface of the structure, which may cause injuries.

Technical solutions exist to mitigate this inconvenience, solutions which should not be skipped. The problem of injury caused by the fibres does not occur with synthetic fibres.

What do we need to remember?

Summarising the above, it can be said that:

- Steel fibre concretes do not perform well with regard to young age cracking, but they are very effective for the cracking in concrete structures which have reached maturity
- Polypropylene micro fibre concretes are effective in young age cracking (plastic shrinkage)
- Macro-synthetic concretes are technically less significant than steel fibre concretes (with a problem of keeping certain functions over time) in relatively stressed structures
- Polypropylene microfibres are recommended to improve the fire resistance of concrete structures
- Care is needed regarding portable structures or in contact with the user when they contain micro steel fibres. These micro steel fibres can cause cuts if no technical solution is adopted

To conclude, those who have assessed the respective performances of the two fibres and who have left sectarianism and bad faith at the door, may chose, in some cases to combine the two reinforcements which are not as hostile as you might have thought. T&T

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WEBSITE DIRECTORY

Dates & Events

9-11 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

9 -11 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&TI 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

07-09 OCTOBER
58th Geomechanics Colloquy 2009 Salzburg, Austria
The popular annual 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: Web: http://www.oegg.at/events/geomechanics-colloquy

28-30 OCTOBER
China's 4th International Symposium on Tunnelling, Shanghai, China
Organized by :China Civil Engineering society; Shanghai Society of Civil Engineering; Shanghai Tunnel Engineering Co., Ltd. Contact: Mr Lou Ruyue; Tel: 86-021-54640607; email forum@tunnelling.cn; Fax: 86-021-54641018; web : http://english.stec.net/

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

4-5 NOVEMBER 2009
Nordic Symposium of Rock Grouting - Geotechnical Seminar - Rock Mechanics/Engineerin Seminar, Helsinki, Finland
Sponsored by ITA-AITES. Underground Space Seminar contact: Bjarne Liljestrand; tel: +358 400 362850; email; bjarne.liljestrand@sroy.fi. Rock Mechanics/Engineering Seminar contact: Erik Johansson; tel: +385 50 5112162; email: erik.johansson@sroy.fi. Nordic Symposium of Rock Grouting contact: Ursula Sievänen; email: ursula.sievanen@sroy.fi

18-19 NOVEMBER
12th International Conference of ACUUS, Shenzhen City, China
'Using the Undergound of Cities: for Harmonious and Sustainable Uran Environment' is the theme of this conference. Contact: Dr Guo Dongjun, Ms. Peng Xiaoli, Ms. Sun Xiaoyuan, Dept of Civil Engineering, Nanjing Engineering Institute. Fax: +86 25 84272793; email: ACUUS2009@163.com; web: www.mwwting163.com/kehu/auc/index.html

26-27 NOVEMBER
Austrian Southern Railway Link Conference 2009 Leoben, Austria
This event focusses on Austria's Southern Railway Link, specifically, the design and construction of the 32.8km long Koralm Tunnel and the 27km long Semmering Base Tunnel along the route. November 27 involves a site trip to the currently under construction Koralm Tunnel Lot KAT 1. Contact: Marion Kainrath: email: technologieakademie@unileoben.ac.at: Web: 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 web: http://www.stuva.de/

27-29 DECEMBER
13th International Conference on Structural & Geotechnical Engineering 2009, Cairo, Egypt
This two day event will cover all aspects in the field of structural and geotechnical engineering, organised by the conference secretariat, Ain Shams University Faculty of Engineering, Structural Engineering Department. Contact: Prof. Dr Eman Soliman; tel: +2 02 26839318; email: Info@ICSGE2009.com; web: www.ICSGE2009.com

BRITISH TUNNELLING SOCIETY

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

15 OCT: **Channel Tunnel Repairs**
Following the fire in September 2008 in the Channel Tunnel, all aspects of the swift repair works will be discussed by Christian Maquaire of Eurotunnel. 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; 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 clients, contractors and consultants 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.
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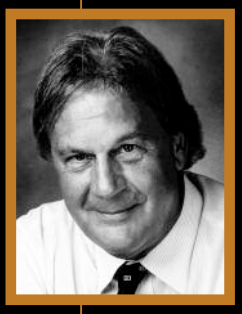

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Subscription price (12 months) mailed anywhere in the world: US$239 / £147 / 220 (UK only £99.00). Claims for missing subscribed copies can only be entertained within three months of publication.

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REPRO/PRINT

Tunnels & Tunnelling International is printed at Stephens & George Print Group, Merthyr Tydfil.

Tunnels & Tunnelling International ISSN number 0041-414X is published monthly for US$226 a year by Progressive Media Markets Ltd, Progressive House, 2 Maidstone Road, Sidcup DA14 5HZ, UK. Periodicals postage paid at Rahway, NJ.

POSTMASTER: send address corrections to Tunnels & Tunnelling International c/o BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001. US agent: BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001.

Tunnels & Tunnelling Conference 2009

in partnership with the **British Tunnelling Society**

Photography by Steve Bates

Tuesday 29th September 2009

The Queen Elizabeth II Conference Centre, Westminster, London SW1P 3EE

CONFIRMED SO FAR

TBM technology up-date - **Dr Martin Herrenknecht**, Chairman of the Board of Management, Herrenknecht AG, Germany

A TBM/NATM synergy? - **Lok Home**, President of The Robbins Company, USA

Advances in Sprayed Concrete Lining technology and practices - **Ross Dimmock and Alun Thomas**, Mott MacDonald, UK

Experiences and research findings on sprayed concrete - **Volker Wetzig**, Research Director, Hagerbach Test Gallery, Switzerland

Avoiding conflicts in Tunnelling - **Michael Stokes/Garry Crossley**, Navigant Consulting

Crossrail 1½ hour Project Special - Presented by **Chris Dulake** and senior members of the Crossrail Team:

- project overview - the last six months and the next
- planned approach on procurement
- design and construction delivery
- TBM requirements
- ground movement and monitoring strategy
- establishing the Academy

Building Barcelona's Line 9 - **Nicola Della Valle**, specialist tunnelling consultant

For content details of each presentation please visit **www.tunnelsandtunnellingconference.com**

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Watch this space for further announcements, but make September 29th a date at the QEII Conference Centre

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