OCTOBER 2009

tunnels & tunnelling INTERNATIONAL

FOCUS ON AISA

Reports from South Korea's immersed tube and mixed ground on China's metro

GROUND CONSOLIDATION

T&TI looks at how contractors are combining ground improvement technologies

SINGAPORE: FINAL BREAKTHROUGH ON THE CIRCLE LINE.

The extension of Singapore's subway network is one of the most ambitious tunnel projects in Southeast Asia. With its 29 stations, the new Circle Line will connect all the existing subway lines which converge on centre of the city in a radial pattern. With a total length of 33.3 kilometers, the Circle Line will be one of the longest, completely automated subway lines in the world when it goes into operation in 2011.

The companies commissioned with the construction chose Herrenknecht tunnelling technology for more than 70 percent of the routes. Eleven tunnel boring machines in all drilled through almost 24 kilometers of extremely demanding geological conditions consisting of loam and layers of sandstone and granite with varying degrees of weathering. The nine EPB Shields with diameters of 6.58 and 6.6 meters, already completed their tunnel sections, with lengths of up to 3.4 kilometers, in 2008. The last of the two Mixshields (Ø 6.6m) faced the challenge of excavating the Circle Line's the most demanding section, the western curve, and reached its target on August 17, 2009.

Congratulations to the client, the Land Transport Authority, and the tunnelling teams on passing this important milestone successfully.

SINGAPORE | SINGAPORE

PROJECT DATA	CONTRACTOR
9x EPB Shields, **2x Mixshields** Diameter: 6,580–6,600mm Installed power: 945–2,000kW Tunnel length: total of 23,777m Geology: loam, alluvium, sand, boulders, sandstone, weathered sandstone, granite and weathered granite	S-212, S-214, S-262, S-263: Woh Hup STEC NCC JV S-305, S-306, S-307, S-308: Woh Hup STEC Alpine Mayreder JV S-310, S-311, S-312: SembCorp Engineers and Constructors

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HERRENKNECHT Tunnelling Systems

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Signing off

Well here it is my tunnelling friends, my last ever rant as editor of *T&TI*. After 10 years on the magazine, I've decided to call it a day and try something new. I can honestly say, the early years of working on T&TI were some of the best of my life. I've been lucky enough to visit places I would never have dreamed of going, and meet the sort of people I didn't even believe existed.

I remember (partially) my first experience of 'Gan bei' or in other words attempted grievous bodily harm by rice wine, in the back streets of Shanghai. It was, you must understand, a matter of honour.

One and a half hours of drinking what looked, and tasted, like nuclear waste and we were in serious trouble. By then my name had escaped me, as had a large slice of my self-respect. I looked down at my laminate name tag to jog my memory and forgot an earlier very childish joke by which I had been registered at the conference as Ivor Biggun, worse still, my boss David, was now sporting the name Phil McCavity.

The rest of the story is for another day…but needless to say, the bits I do remember still make me laugh. Whether it's been the randomness of Bangkok, the edgy backstreets of cities like New Orleans or Durban, Iceland's beautifully rugged interior, trying not to be sick eating fermented herring under the northern lights off Sweden's dramatic coastline, all of the trips have one thing in common. And that's the people, the tunnelling people. There must be something about this industry that attracts folk cut from the same cloth, and I don't think it's the money!

If you want to promote this industry to the young, I reckon these are two of your major ace cards. Great people, and the opportunity for worldwide travel and adventure - what more could you want (apart from better pay and no more twelve hour shifts)?

Anyway, space prevents me from rambling on further, but I'd really like to take the opportunity to genuinely thank everybody who's helped and supported us here at *T&TI* over the last decade. But all things must change, *T&TI* is now owned by a new company, Progressive Media, and I wish them a future.

I know you will welcome the new editor of *T&TI* with the same warmth you did me, and help him or her, take *T&TI* from strength to strength and into the next decade.

All the best to you all, and I'll doubtless see you again soon.

Tris Thomas

COMPANIES IN THIS ISSUE

Investigation into Cairo collapse launched

An investigation is underway into the causeof the partial tunnel collapse on Cairo Metro Line 3 project, which trapped a TBM and opened a sinkhole in a densely populated area of the city early last month. Investigators need to gain access to the TBM operators' cabin to recover data from the final hours of the machine's operation.

Cairo Governor Abdel-Azim Wazir and Cairo Metro owner the National Authority for Tunnels (NAT) have established a committee to investigate the possible cause of the collapse. Neither office was available for comment as T&TI went to press.

The tunnel was being bored by a 9.4m diameter Herrenknecht Mixshield TBM when the disaster struck. The collapse caused a sinkhole 15-20m diameter and 20m deep. The TBM was boring through soft ground comprising an upper 8m layer of mixed fill on base deposits of very soft, highly permeable sand and sandy-clay soils, all under a high groundwater table.

The sinkhole was filled by 1000m^3 of concrete but the weight of the concrete on the soft ground caused a second ground collapse the following Sunday night.

The sinkhole is located in one of the oldest parts of the city but no injuries and no structural damage to buildings in the area was reported. However, eighty families in 10 buildings were evacuated while safety inspections were carried out.

The TBM was operated by a French-Egyptian construction consortium joint venture led by Vinci and including Bouygues along with Egyptian partners Arabco and Orascom.

A Vinci spokesperson told T&TI, "Subsidence occurred on 3 September at the construction site of Line 3 of the Cairo metro (phase 1) in Al-Geish Street in the Bab El-She'riya district."

She added, "The situation on the surface is under control and the families that were evacuated following the subsidence have returned to their homes.

"The sinkhole on the surface has been filled in but the road has not yet been opened up to traffic because consolidation works are being carried out from the surface.

"The methods and measures to be implemented in order to be able to reach the tunnel boring machine and the damaged area of the tunnel are being studied and validated.

"An investigation into the reasons for the subsidence is under way. "

Nozzelmen to be certified

The European Federation of National Associations Representing Concrete last month launched a Nozzelman Certification Scheme to set a standard for the industry. In a statement the ENFRAC Sprayed Concrete Technical Committee said industry guideline and European standards had helped improve the quality of sprayed concrete and certifying the Nozzleman would be a further step forward.

The certification scheme is not a training course and will only offer certification to Nozzlemen who have already gained the necessary experience and can demonstrate their technical knowledge and practical ability.

The scheme is currently limited to wet, robotic sprayed concrete and has been developed primarily for the European market, although it will have a wider application.

The scheme will operate through National Examiners who will assess Nozzlemen for their theoretical and practical skills at their workplace. The first stage of the scheme is to identify and accredit suitable Examiners through the attendance of an EFNARC Assessment course, which is being run by CUC - International Centre for Geotechnics & Underground Construction on behalf of EFNARC at the Hagerbach Test Gallery, Switzerland.

The Examiner Assessment course costs of CHF3400 (US$3,372). As *T&TI* went to press the first examiner course had already taken place, but a second course has been provisionally arranged for 11-13 November 2009.

Shis tunnel holes through

Teams excavating the Shis highway road tunnel in Sharjah successfully holed through on the westbound bore this month creating the UAE's longest rock tunnel. Drill and blasting work on the eastbound bore is expected to breakthrough next month.

The 1.3km twin bore tunnel is part of the 9km two-lane dual carriageway linking the port of Khor Fakkan on the East Coast of Sharjah Emirate to Diftah in the central region.

Passing through some of the highest and steepest ranges of the Hajar Mountains, the road needed to cut 260m below the peak.

The rock the teams blasted through is one of the hardest rocks in the region, predominantly highly fractured inter-bedded gabbros - an igneous rock. The 1270m bore was completed in 826 days, including holidays, with an average rate of excavation of 2.6m a day. The record rate for a single months draw was 69m in one direction achieved in November last year.

The approx 7.0m radius tunnel heading varies according to the rock type and has a 2m deep bench of excavated profile, making a cross sectional area of some 100m^2 and ensures a clear traffic envelope of 9.3 by 5.5m.

The tunnel was bored using the NATM method, stabilising the tunnel with rock bolts and shotcrete before being lined with a waterproof membrane and permanent concrete inner shell.

The thickness of the shotcrete was based on the Q-System of rock mass classification. The project experienced class 2,3,4 and 6 rock type giving a minimum shotcrete thickness of 50mm in class 2 rock and lattice girders embedded in 280mm thick shotcrete in class 6 rock found in the initial drive.

Halcrow, as consultant to the Government of Sharjah, Directorate of Public Works, was responsible for the design and supervision of the tunnel construction.

The first blast was on 28 June 2007 on the westbound bore and blasting launched on the eastbound bore on 27 August 2007.

Excavation rate averaged 2.6m a day

Egypt searches for Gaza tunnels

U.S. Army Corps of Engineers has deployed a sonar system for detecting tunnels under the Egyptian border with Gaza, according to local media citing Egyptian government sources. The sonar system is being tested and is expected to become operational later this year.

A spokesman for the U.S. Army declined to comment on the reports. Middle East Newsline, quoting Egyptian security sources, claimed the Egyptian Military and Interior Ministry installed the sonar with U.S. Army help. U.S. delegates toured the border last month.

The tunnels are often between 6 and 20m underground where the sand is hard enough to tunnel through. The 500-600m tunnels take some 5-6 weeks to excavate with tunnelling rates at about 15m a day. The tunnels rarely have any form of support, which has often led to collapses.

Emergency services in Gaza last month announced a 19-year-old was killed in a tunnel collapsed. More than a hundred Palestinians are believed to have been killed in the tunnels either through Israeli air strikes or collapses.

Big Dig resin supplier pleads guilty

US firm Powers Fasteners last month pleaded guilty to federal charges relating to its failure to give proper disclosure of its product's abilities in its design manual. The epoxy resin supplied by the firm to Boston's Big Dig tunnel failed to support the tunnel ceiling leading to a collapse that killed one motorist.

The prosecution alleged that company's design manual claimed the fast acting epoxy resin had the same strength as the standard setting resin despite Powers knowing from tests that it did not.

Acting United States Attorney Michael K. Loucks and the investigating team last month charged Powers "in a one count Information with making a false statement in connection with the construction of the I-90 Connector Tunnel on the Central Artery/Tunnel project, a federally approved highway construction project."

A statement by the The United States Attorney's Office for the District of Massachusetts said, "The Information alleges that the general contractor, Modern Continental Corporation, responsible for constructing the I-90 tunnel ceiling, utilized a Powers Fasteners epoxy product, Power Fast Epoxy, to secure the drop ceiling to the roof of the tunnel using anchor bolts epoxied into drilled holes.

"Powers… sold two versions of the epoxy product, a Fast and Standard Set… It is alleged that Powers was aware, through testing it had commissioned pursuant to then existing industry testing standards, that the fast set version did not perform as well as the standard set version under sustained loads, and in fact, was not suitable for long-term overhead loads like the tunnel ceiling.

"Allegedly, despite this knowledge, Powers failed to disclose these facts in its published Design Manual in 1999."

Several anchor bolts ultimately failed, and on July 10, 2006, several ceiling panels collapsed on a vehicle, killing a motorist. The National Transportation Safety Board ruled the cause of the failure was the use of the Fast Set epoxy.

Powers entered into a plea agreement with the United States Attorney's Office agreeing to plead guilty to the charge and be placed on federal probation. The parties have also agreed that Powers pays a $100,000 fine as a penalty, taking into consideration the company's $16 million settlement and deferred prosecution agreement with the Commonwealth of Massachusetts, as well as its payment of a $6 million civil settlement to the estate of the victim.

F1 tunnel nears end

Final preparations are being made to the Yas Island tunnel in Abu Dhabi ahead of it's Formula 1 debut next month. Contractor Advanced Specialist Treatment Engineering is applying a spray-on waterproof membrane to seal the sides of the tunnel when the water is allowed back into the cut.

In total approximately 49,000m^2 of the Integritank system will be used on the 1.2km long, 40m wide tunnel. Time pressure on the project meant the coating could not be laid in a single session but according to Stirling Lloyd the "the advanced methylmethacrylate (MMA) based resin used in the system produces a strong bond both to the substrate, and to itself, even when applied in stages with no compromise in quality."

Construction of the cast in-situ cut-and-cover tunnel began in October 2008 while Stirling Lloyd contractor Advanced Specialist Treatment Engineering arrived on site in the November to begin the application of the waterproofing. The coating was scheduled for completion as *T&TI* went to press.

Abu Dhabi's Yas Island tunnel makes its debut in November

Push for railway tunnel under Copenhagen

Copenhagen City Councillors reviewing a planned railway link between the Danish capital and the inland city of Ringsted have called for a 2km tunnel under the Valby district to avoid disruption to the recreational area. The Danish public transport authority Trafikstyrelsen expects the go-ahead for its 7.7bn Kroner (US$ 1.5bn) scheme this Autumn but Social Democrat spokesperson Anne Vang told local press a tunnel must be part of the project.

'It's great that they want to invest in modernising public transit, but I can't understand why they don't want to make the necessary investments to prevent a housing area from being destroyed,' Vang said.

Trafikstyrelsen construction manager Martin Munk Hansen told *T&TI* a tunnel would be cut and cover and cost about 350M Kroner (US$69M). He explained it would not have any major effect on the socioeconomic results. Hansen declined to comment on the likelihood of the tunnel going ahead saying, "This is a political decision."

The new line, which is favoured by Trafikstyrelsen over a 2.9bn Kroner (US$600M) upgrade to the existing network, will be completed in 2018 if approval is given. Funding for the new line was approved by parliament in January.

Rockfall troubles for Niagara, Glendoe

Construction work at the Niagara Tunnel, in Canada, and operations at the Glendoe hydro scheme, in Scotland, have both suffered due to rockfalls in built parts of their hydro tunnels.

Investigations and repairs are underway at the Niagara Tunnel after a small rock fall at temporary lining in a section excavated earlier by the 14.4m diameter Robbins TBM, "Big Becky".

The rockfall happened more than 3km into the tunnel, which will be 10.2km long and more than half of which has been bored. No-one was injured in the incident, which brought down lining and rock. The section of tunnel had previously suffered overbreak.

Repairs are underway, and with the design-build contractor Strabag having brought forward a six-week planned maintenance work for the tunnelling equipment it hoped the programme impacts will be minimised. Work is continuing on installation of the permanent lining.

The project is being developed by Ontario Power Generation (OPG) to expand output from the Sir Adam Beck Complex. Tunnelling progress suffered from poor ground problems earlier in the Queenston shale, leading the client and contractor to negotiate a realigment of the tunnel and completion schedule.

At Glendoe, investigations have revealed the rockfall found near the top of the power tunnel, in August, to be 'very substantial' and the plant will stay shut down 'well into 2010 at the earliest'.

No details have been given on the cause of the tunnel failure. Neither has the owner, Scottish and Southern Energy (SSE) given any quantification of the hole at the top of the headrace, which links a reservoir to the underground powerhouse.

Repairs have not yet started as planning work continues on how best to fix the top end of the 6.2km long headrace tube. The plant only started operations less than a year ago, and there has been no equipment damage caused by the failed tunnel.

Tunnelling work was completed by the beginning of 2008. The headrace was bored by a 5m diameter unshielded TBM (a Robbins original build, refurbished by Herrenknecht), the geology comprising schist and quartzite with minor faults. Lining support consisted of bolts, steel ribs, mesh and shotcrete.

The project has a total of 16km of tunnels, apart from the powerhouse bid, and most of the network was excavated by drill and blast. It's not clear if the damaged zone was built in the TBM drive or any connecting stretch done by drill and blast.

Tunnel work to launch for Israel's longest tunnel

Work is set to start next month on Israel's longest tunnel, an 11.5km rail tunnel for a high speed connection between Jerusalem and the Israeli capital Tel Aviv. The work starts a little over a month after the Israeli National Planning and Building Commission rejected an alternative rail route proposed by environmental organizations.

The twin bore, single rail tunnel forms part of section C of the A1 line, between Shaar Hagai at the entrance to the Judean Mountains and Emek Arazim on the western edge of Jerusalem. A second twin bore tunnel 1.2km in length is also needed to pass through the mountain range and will be linked to the long bore by a bridge.

Client for the project Israel Railways awarded excavation of the tunnels and construction of the bridge to a joint venture of Israeli firm Shapir Civil & Marine Engineering and Austrian firm Alpine Mayreder. The project will cost some ILS1.6bn (US$426M).

The new Tel Aviv-Jerusalem high speed line will include nine tunnels in total with a combined length of 14 km. The first tunnel on section C, named the Hachoresh tunnel, will be built in softer ground than the 11.5km tunnel, named the Hachamisa tunnel. Both tunnels will be 9.2m in diameter.

The first 300 metres on the west side of each bore of the 1.2km Hachoresh tunnel will be built using the cut-and-cover method and completed using drill and blast. The Hachamisa tunnel will be driven from west to east using a double shield hard rock TBM for some three quarters of its length and from east to west by drill and blast for the remainder.

Construction is expected to take some 44 months to complete.

Giants under Yangtze complete drive

Herrenknecht last month announced the successful completion of tunnelling under the Yangtze River in China for the Nanjing-Shanghai road link. Two mixshield giants, each with a diameter of 14.39m, completed the breakthroughs of both bores earlier this year, the first in May and the second in August.

Nanjing, the central city of the province of Jiangsu, is an important transportation hub on the axis leading inland from Shanghai. In order to channel the rapidly growing traffic load, a six-lane road tunnel, with three lanes in each direction, is being built beneath the River Yangtze.

The two tubes of the "Nanjing Yangtze River Tunnel" are 2,985 meters and 2,990 meters long, respectively. The drive required two of the largest TBMs in the world.

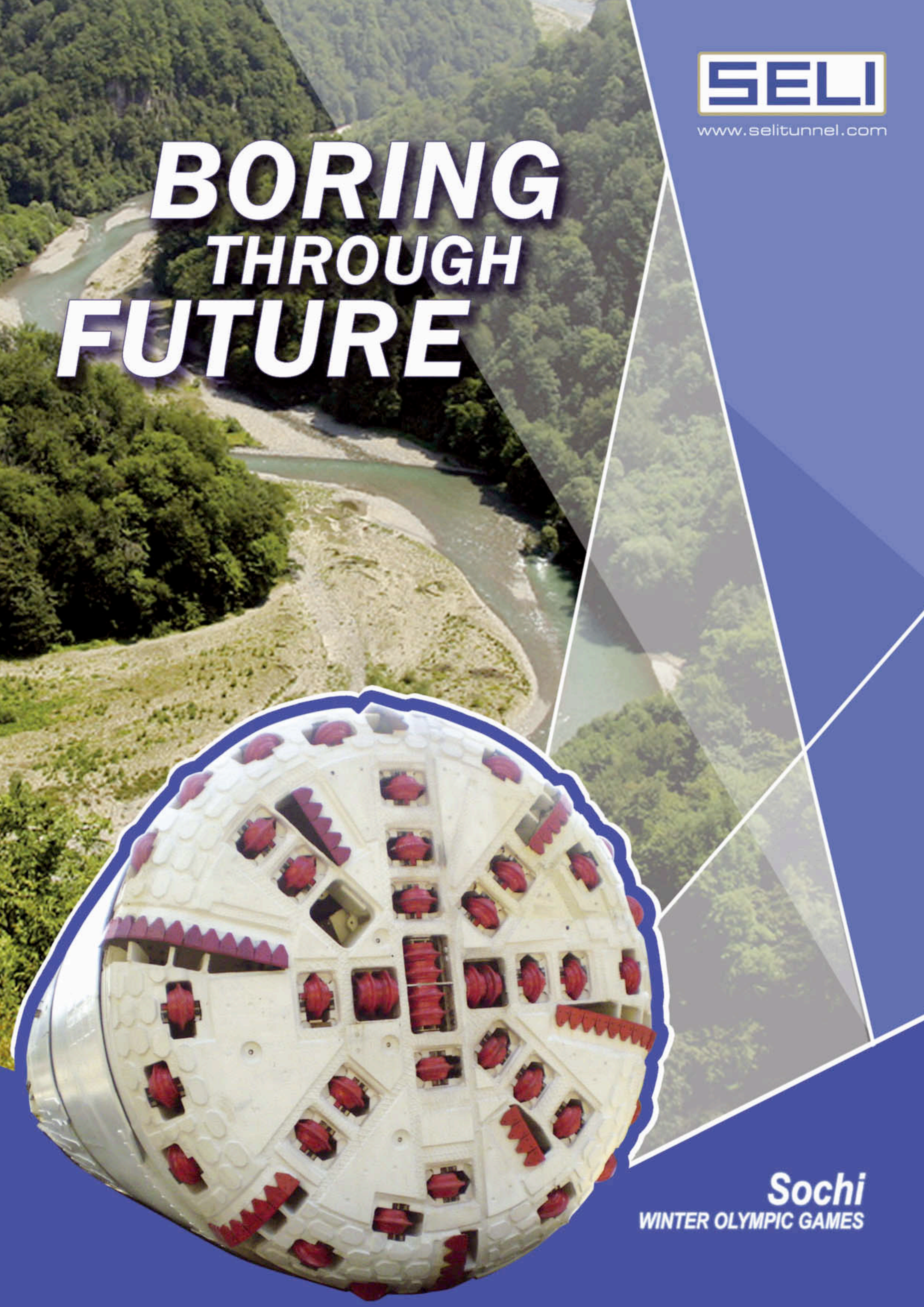
After the start of tunnelling in January 2008 (S-349 Mixshield) and May 2008 (S-350 Mixshield) respectively, these two machines tunnelled through very challenging terrain. Water pressures of up to 7.5 bar had to be supported with supreme reliability at the tunnel face. With an overburden of sometimes only 30 meters to the riverbed, these giants made their way through highly water-bearing gravel and silt layers.

Left: Terrain under the Yangtze was challenging

The Herrenknecht S-350 achieved breakthrough at the target shaft on the left-hand route on May 20, 2009, the S-349 reached its final tunnelling destination on August 22, 2009. The best weekly performance was achieved at the end of July 2009 - 146 meters of newly produced tunnel.

Alois Eisendle, Herrenknecht AG's senior on-site representative for the Nanjing project, was awarded the "May Honorary Labor Medal" by the Federation of Trade Unions of Jiangsu Province for his work on the tunnel.

The project was managed by Nanjing Changjiang Tunnel Project Co. and China Railway 14th Bureau Group Co.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Gotthard TBMs finish northern end

The second breakthrough on the Erstfeld to Amsteg stretch of the Gotthard tunnel was achieved last month, completing TBM excavation at the northern end of the tunnel. Herrenknecht gripper TBM Gabi 2, which has a diameter of 9.58m, completed the breakthrough of the western tube of the Gotthard Base Tunnel on September 16, 2009.

It took just 18 months to excavate the 7.2km stretch, reaching Amsteg six months ahead of schedule. Gabi 1 completed the eastern tube excavation earlier this year (T&TI, July 2009, p6).

The axis at destination only deviated 4mm horizontally and 8mm vertically from the target at the breakthrough point. The average daily tunnelling performance through hard rock and mountain overburdens of up to 1,000 meters was some 18m. The best daily performance by Gabi 2 was 56m of excavated and secured tunnel. Herrenknecht claim this is a world record for a TBM of it's size.

Excavation work in the world's longest railway tunnel has now been completed on the northern side of the Gotthard Range and 91 percent of the whole tunnel has been excavated. Around 137km of the Gotthard tunnel system, which has an overall length of 151.8km, has been finished.

The main breakthrough between Sedrun and Faido is due to take place at the end of 2010 / beginning of 2011. The commercial operation of scheduled train services is planned to start at the end of 2017.

Breakthrough at Amsteg six months early

Greenlight for Port of Miami

Construction of the Port of Miami Tunnel is set to begin by May next year following the delayed financial close on the public-private partnership (PPP) project in Florida.

The project will involved a coastal excavation by TBM to build a 1,190m long twin-tube tunnel. The 12.5m diameter tunnels will be bored up to 36.6m below the water level, and the project to improve traffic access to the port is due for completion in April 2014.

The deal was signed by the concessionaire Miami Access Tunnel (MAT) a JV of Bouygues with bank Babcock & Brown and the Florida Department of Transportation (FDoT), Miami-Dade County and the City of Miami. The authorities also had federal input to the procurement process.

MAT will design, build, finance, operate and maintain the tunnel under a 35-year concession in return for milestone payments during construction and annual availability payments over the 30-year operational phase.

FDoT said the design and construction budget is US$607M. Construction is scheduled to take 48 months from the start of work on site. The maximum availability payment is US$32.5M per year.

The contract was awarded in February 2008, bids having been opened in 2007, but the project met financing difficulties before the end of last year following the impact of global economic crisis. MAT had difficulties in raising the equity required for the scheme and FDoT could not close the deal. Negotiations then ran for months, until a new commercial deal was agreed by the middle of the year (*T&TI*, June, p6).

MAT obtained a new equity partner, Meridiam Infrastructure Finance, to join French construction group Bouygues. Meridiam will contribute the majority of the equity to the concessionaire.

Call for second Oresund crossing

Danish researchers have called for a second fixed link between Denmark and Sweden as they claimed the Oresund crossing is insufficient. Technical University of Denmark Professor Otto Anker Nielsen said that a tunnel between Swedish city of Helsingborg and the northern Danish city of Helsingor would ease stress on the Oresund Bridge and tunnel link.

His study argued for the new tunnel based on traffic forecasts, which show the existing bridge between Malmo and Copenhagen would reach capacity by 2018. Traffic forecasts also suggested that more than 500 trains would be crossing the channel every day in 2018.

The traffic pattern report was commissioned by IBU-Öresund, a cooperative infrastructure development project between communities in both Sweden and Denmark, and includes four different proposals for tunnels ranging in price from 11 billion to 19bn kronor (US$142 – 270M).

The least expensive proposal is for a tunnel only large enough for passenger trains, while the priciest suggestion includes funds for a both a cargo and passenger rail line, as well as an additional third stretch from Helsingborg to the Danish town of Snekkersten, and then on to Helsingör.

The third stretch would have a cargo rail track, as well as a track for a high speed passenger train with direct connections to Copenhagen.

"The H-H connection is profitable from both an operational and societal perspective and is therefore clearly the best solution," said Nielsen, who is a traffic patterns professor at the school's Center for Traffic and Transport.

Reactions to the call were split. The tunnel proposals were received well by regional politicians in southern Sweden. "Another crossing is needed. In the future even more will be transported by rail so that makes initiatives like this a must," said Jerker Swanstein, chair of Region Skane's governing board.

He hoped that a tunnel connecting Helsingborg and Helsingör will be completed sometime between 2020 and 2025, but admits there is still work to be done to convince both the Swedish and Danish governments to invest in the project.

However, Danish Transport Minister Lars Barfoed denied that the proposed changes were necessary or feasible. He argued, "We have neither the capacity, the money nor the need for projects of that size". He did acknowledge that a bridge replacing the existing ferry operation may be an option in the future. "Right now though, the existing Oresund Bridge is enough to handle the traffic crossing over the Oresund."

Robbins set for Chengdu metro

Left: Assembly of the 6.26 diameter EPBM underway

A Robbins TBM is being assembled near Chengdu in Sichuan province, China, to be launched shortly on the first of two planned drives on Line 2 of the city's expanding metro network.

The 6.26m diameter EPBM was ordered at the beginning of the year, along with technical support, by China Railway Construction Corp (CRCC) for its work on Lot 18 of the metro line.

CRCC is to drive two 1.35km long tunnels through weathered strata comprising a mixture of highly permeable pebbles, sand and clay. The stones are expected to average 20mm-80mm, increasing up to 120mm. The shield is fitted with a shaft-type screw conveyor of 800mm. Spoil removal will be by battery-powered rolling stock.

Along the alignment the TBM is to come within 25m of residential buildings, and use active articulation on curves with minimum radius down to 400m to help prevent segment damage at rings.

In total, some 17.6km, or approximately one third, of the 50.6km long Line 2 is to be built underground.

Separately, Lovat has earlier supplied a few EPBMs to China Railway Tunnel Group (CRTG) for its work on Line 2.

Delhi metro breakthru'

A JV of Alpine, Hindustan Construction Co (HCC) and Samsung holed through at the end of last month to finally complete the difficult excavation by TBM on part of the Airport Express Link being built to help expand Delhi's metro system.

The job involves excavation of 3.7km of line through a congested urban area, and calls for construction of two stations – New Delhi and Shivaji Stadium – each of which are 242m long.

The stations are 2.3km apart and the twin tubes linking them were bored by two EPBMs, launched just under a year ago.

Delhi Metro Rail Corp (DMRC) awarded the Euro139.3M (US$205M) contract two years ago to the JV.

Phase 2 of the metro expansion will add 125km to the network, including 35km underground, in time for the city hosting the Commonwealth Games in 2010. The Airport Express Link will be 22.7km long with a total of 15.7km built underground. The tunnelling work on Phase 2 has been characterised by numerous relatively short drives and 14 TBMs have been employed.

Separately, in August, Alpine and HCC completed the last of the NATM work on the Phase 2 expansion. The work was undertaken on a 2.85km long section between Talkotara Garden and Buddha Jayanti Park.

The client said the tunnel – which includes a 180m long cut-and-cover section – is the longest built using NATM in an Indian city. Geology comprised weathered quartzite and schists although soft ground was met in parts. The tunnel was excavated at 17m-27m depth.

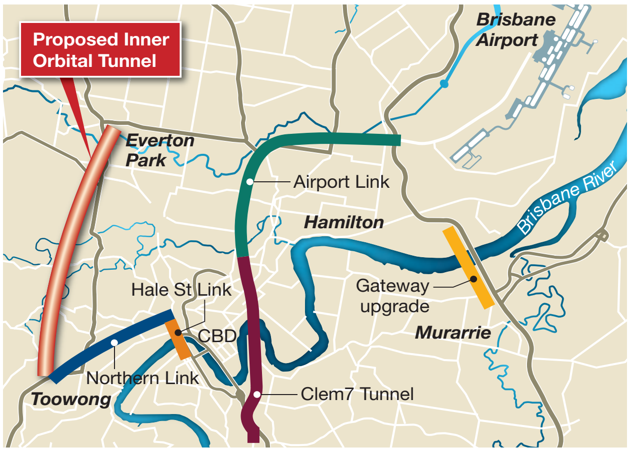
Another tunnel planned for Brisbane

Australia's Queensland government has proposed a fourth major road tunnel in Brisbane to ease congestion in the Western suburbs. A transport strategy published last month by the state government showed a bypass could be built to link the Centenary Highway underground from Toowong to Everton Park, where existing roads lead to the Bruce Highway.

If the tunnel goes ahead it will deliver a orbital ring road system to the city by linking the Ipswich Motorway to the Bruce Highway.

The tunnel is part of Western Brisbane Transport Strategy, which outlines the State government's plans for roads and public transport in the western suburbs until 2026.

Queensland Transport Minister Rachel Nolan said that no funding had been set aside for the tunnel but



a strip of land between Toowong and Everton Park would be reserved from other development.

Earlier proposals suggested a bypass be constructed on the outskirt of the suburbs to ease congestion but projections found the the bypass would not be enough to ease traffic on other roads.

Call for better project management

A senior industry director last month warned firms that careful planning of a project is crucial to successful delivery, claiming that failures in project management were the greatest cause of schedule and budget overruns.

Gary Crossley, managing director of international construction services at Navigant Consulting, told delegate of September's T&TI conference in London, "For a project to be delivered on time - it must be constructable and it must be planned properly."

Crossley claimed that project management failures were responsible for deadline and cost overruns on the Boston Central Artery tunnel project which ran 100% over budget, the Channel Tunnel which ran 80% over budget, the Danish Great Belt Link Tunnels which ran 54% over budget and London Underground's Jubilee Line Project which ran 67% over budget.

He added that a significant number of overruns were the result of non-engineering related issues. A 2001 international study by Reilly & Thompson found that many owners reported that significant cost and programme overruns for at least 30% and probably more than 50% of major underground and tunnelling projects were suggestive of deficient management or lack of adequate oversight.

Crossley cited Heathrow Terminal 5 as a good example of a project that ran to budget and schedule credited the success to BAA's in house risk management. BAA's approach was to identify the sources of risk, and then arrange for its own resources to manage or mitigate them.

Warning delegates of their responsibilities Crossley said, "The process of determining the constructability of a project and then planning its construction are fundamental aspects of successful project delivery."

Prequalification call for Seattle tunnel

A prequalification call has been issued for companies to be shortlisted to design and build the bored tunnel on Seattle's waterfront replacing the earthquake damaged Alaskan Way viaduct and seawall.

Deadline for submissions to Washington State Department of Transportation (WSDOT) is 16 November. The department aims to shortlist up to four parties for design and build of the tunnel by the end of the year.

The tunnel is to have a 2.77km long single bore section, excavated by TBM, and cut and cover stretches at either end. The TBM will drive a tunnel of approximately 16.45m diameter through till for construction of an approximately 15.85m i.d. tube that will be fitted out with a doubled-decked structure.

The final Request for Proposals (RfP) will be issued by early next March and the winning bidder chosen before the end of 2010. Each of the shortlisted parties that bid but lose will receive a US$2M "stipend" from the state agency.

Construction is due to start in 2011 and tunnel excavation completed by November 2013 for the project to open by in late 2015. The estimated cost of this contract is approximately US$1bn.

The entire project to replace the seismically-damaged viaduct and open up the waterfront area is estimated at US$4.24bn with funding coming from the state, county and city authorities as well as the Port of Seattle.

They chose the single-bore scheme as a late option at the beginning of this year.

Bids for new Caldecott tube

Tutor Saliba submitted the lowest of four bids opened late last month for the contract to build a new tube for the Caldecott road tunnel on SR-24 in California.

The contractor submitted a tender of US$214.8M, which was ahead of the nearest offer of US$260.2M, from the Barnard Flatiron JV, and also proposed the shortest construction period – 1105 days. The rival bidder proposed a build period of 1248 days.

Both companies bid below the Engineer's Estimate of almost US$275M given by the client, California's Department of Transportation (Caltrans). The state agency recently secured US$90M in funding for the project from California Transportation Commission.

Tenders were also submitted to Caltrans by Kiewit Traylor JV and Caldecott Constructors. The offers were for US$308.3M (and 1370 days) and US$445.3M (and 1550 days), respectively.

The extension of Caldecott Tunnel calls for construction of a two-lane, fourth tube that will be 1,033m long, 12.58m wide and have seven cross passages linking to the third bore.

Caldecott Tunnel is in Berkeley Hills, and geology along the alignment comprises sedimentary formations with sections of crushed rock and fault zones.

Seelisberg tunnel refurb starts

Planning and design work for the refurbishment of the Seelisberg road tunnel, in Switzerland, is underway after the contract award to a JV led by Poyry.

The major Swiss road tunnel is a 9.28km long, twin-tube structure located near Lucerne, and is to be completely refurbished under a nine year planning and construction period, ending in 2018.

Poyry is leading a JV to undertake planning and design work to 2014, including preparing materials for and managing the construction procurement phase. The JV may also undertake site supervision during the works.

The contract for the planning and design services was awarded by the federal roads agency (Astra/Fedro), which aims to have continuous availability and operations of the tunnel for a further 15-20 years .

Seelisberg Tunnel, which has both horseshoe and circular cross-sections, was brought into service at the end of 1980. Each tube carries two lanes of traffic.

Crossrail secures finance worth £1bn

Transport for London (TfL) has struck a £1bn (US$1.59bn) loan deal to help fund the Crossrail project, agreed the loan with the European Investment Bank (EIB). The loan funds are to be drawn down over six years.

In total, TfL and Greater London Authority (GLA) are funding £7.7bn (US$12.2bn), or almost half, of the £15.9bn (US$25.3bn) project.

Crossrail calls for construction of 41.5km of tunnels in twin-tubes through the heart of the city.

Early construction work is already underway with major work commencing next year and tunnelling in late 2011.

First rail services are due to start in 2017. For the excavation phase, Crossrail has signed a Memorandum of Understanding with the Port of London Authority to enable more than 5M tonnes of spoil to be transported by river en route to various fill sites.

The strategy to transport excavated material will help reduce potential congestion and environmental emissions compared to road.

However some road transportation will still be required to remove the waste material. Some spoil will be removed along the river.

Material from eastern tunnelling sites is to be taken directly by river to Wallasea Island in Essex and two sites in Kent.

While Crossrail continues to examine the potential for using the Grand Union Canal to transport excavated material from the western tunnelling sites, the present plan focuses on removing the spoil by rail to Kent with some also being taken by river to Essex.

Sydney Metro bids called

The Government of New South Wales has called for bids from a shortlist of three JVs to build the first stage of Sydney Metro, which involves a package of tunnels and station works.

Tenders have been requested from:

- Line 1, comprising McConnell Dowell, Abigroup and Obayashi
- Metro Primo, which is made up of Leighton Contractors and Seli,
- Thiess/John Holland

The package of work on the metro includes construction of a 7km twin-tube section between Central and Rozelle. The package also includes construction of five intermediate stations at Town Hall Square, Martin Place, Barangaroo-Wynyard, Pyrmont and White Bay.

Bids are due before the end of this year for contract awarded in 2010. Train services on the stage 1 section of the metro are due to start in 2015.

In June, five consortia had submitted detailed expressions of interest for the project, which is being developed by Sydney Metro, a state government agency.

In August, two parties were dropped to leave a shortlist of three JVs. The two parties that did not make the shortlist are:

- BM2, which includes Brookfield Multiplex Constructions, MacMahon and Bouygues,
- Dragados

The Environmental Assessment for the stage 1 metro route was issued last month for comment.

Geotechnical investigations are continuing and are also underway for the West route, which is stage 2 of the expansion scheme and runs from Central to Westmead. A project planning application for the West metro route, backed by a preliminary environmental assessment, has been submitted to the Government.

BB to buy PB

UK-based contractor Balfour Beatty (BB) is to buy Parsons Brinckerhoff (PB) this month, in a strategic move to boost its services range and strengthen its presence in the US. The deal had not been completed as *T&TI* went to press.

Both firms are active throughout the infrastructure sector, including tunnels. Their projects range from Hindhead, the London tube and Hong Kong sewers to California high-speed rail, Brisbane Airport Link and Singapore Downtown Line.

The takeover is valued at US$626M and is to be mostly financed by a fully underwritten 3-for-7 rights issue of 205.5M BB shares, priced at £1.80 (US$2.90) each.

Conditions to be met for the deal are completion of the rights issue and shareholder approval, including at least 75% of PB's capital stock. Approval of PB shareholders will be sought on 21 October at a general meeting.

The deal may also see the contractor paying up to US$18M more depending on certain, unspecified contingencies.

The right issue is underwritten by JP Morgan, RBS Hoare Govett and Citigroup.

Cavico wins in Vietnam

Cavico has won contracts to build tunnels on the Dakdrinh and Thuong Kon Tum hydropower projects in Vietnam.

A JV of Cavico, Song Da and General Construction and Infrastructure Development Co (GCID) is to build a 7.5km long by 4.5m wide tunnel for the Dakdrinh project as part of a US$16M construction package. The contract was awarded by Dakdrinh Hydropower Company Joint Stock Co.

Cavico also won two contracts – for excavation and insitu concrete lining – at an access tunnel in the Thuong Kon Tun project. Works on the 1.8km tunnel total US$12M. The client is Vinh Son-Song Hinh Hydropower Joint Stock Co.

More Singapore metro awards

Alpine Bau has won another contract on the Singapore metro that calls for construction of two new sections of twin tube tunnels on Downtown Line 2.

Singapore's Land Transport Authority (LTA) also awarded two further contracts on Line 2 last month to GS Engineering & Construction and Shanghai Tunnel Engineering, respectively.

Alpine has a contract to build a total of 4km of mostly bored tunnel in sections C917 and C918. The package of work is valued at a total of S$671M (US$479M) and also includes construction of three stations.

Contract C917 involves excavation of a 1.8km long section with twin tubes and two stations –Sixth Avenue and King Albert Park. The package is valued at S$321M (US$229M) and construction is to start in mid-2010.

Contract C918 calls for construction of a 2.2km long section of Line 2, comprising 920m and 560m long stretches of twin tube, respectively, and a 445m long cut-and-cover tunnel. The section of contract is valued at S$350M (US$250M) and includes construction of Duchess station. Construction is to commence in early 2010.

The concrete segment lined tunnels will be 6.6m diameter with two TBMs on C917 and three shields on C918, two slurry machines for the 920m long section and an EPBM for the 560m stretch.

LTA awarded a contract valued at S$431M (US$308M) to GS Engineering & Construction to build tunnels and two stations, Hillview and Cashew, on contract C913.

Shanghai Tunnel Engineering was awarded C920, which includes tunnels and Newton station for S$356M (US$254M).

Earlier this year other contract awards on Line 2 included SKEC Singapore branch and McConnell Dowell getting C915 and C916 for S$225M (US$161M) and S$340M (US$243M), respectively (*T&TI*, June, p13).

In July, C919 was awarded to Sembawang Engineers and Constructors. The contract value is S$378M (US$270M) and involves construction of tunnels and two stations at Botanic Gardens and Stevens.

June saw two contract awards – C912 for S$452M (US$323M) and C921 for S$803M (US$574M) to Ssang Yong Engineering & Construction, respectively.

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Precast units are used extensively on the project

Deep seated

South Korea is constructing the deepest immersed tube roadway attempted at a depth of 48m. Adrian Greeman takes a look

A pair of remote-controlled underwater jacking frames, an exceptionally deep level jack-up barge with pinpoint GPS aggregate placing , and a mini-submarine marine access vehicle, are among the innovative tools being used on the complex and difficult Busan-Geoje fixed link project currently under construction in South Korea.

The developments are a step forward for modern immersed tube tunnel techniques such as those used for the spectacular Oresund crossing between Denmark and Sweden in recent years. They build on that international experience to allow completion of an even more difficult project. Casting of the tunnel elements is also more complex, as undersea conditions are more difficult.

Korean contractor Daewoo Engineering & Construction, leading a seven firm consortium, has also developed new precast placing and positioning techniques for two cable stay bridges that make up the remainder of the 8.2km long crossing, again building on the Storebælt and Oresund experience in Europe. Work on the bridge sections is well underway and currently the whole six year long project is 79% complete, with a target completion for the end of 2010.

The immersed tube is perhaps the most challenging part of the project and has taken much of the attention of the contractor, designers and technical advisers.

After a slow start it is now going well. First of eighteen huge tunnel elements was placed early in early 2008 and after the planned summer months stoppage of immersion operations for the 2009 typhoon season, works recommenced in October with immersion of element E13, the deepest of the project, placed at a depth of 48m. The remaing 5 elements are now being taken from the dry dock to the temporary mooring area in readiness for transportation and immersion during the coming months with immersion completion planned for March 2010.

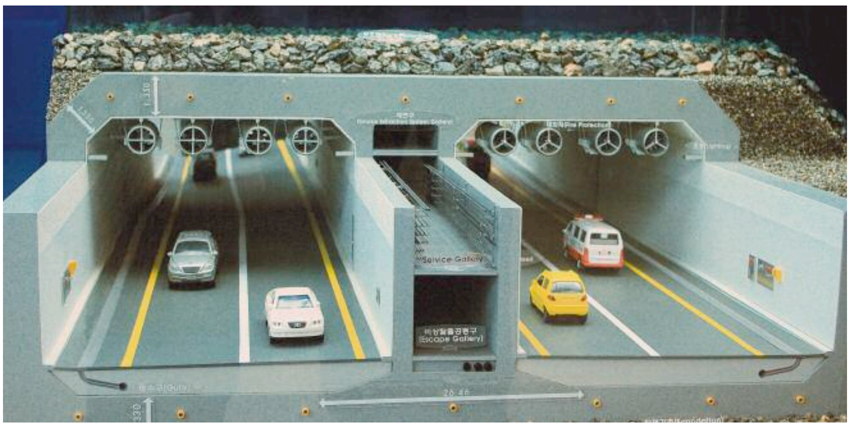
The current progress has given South Korean contractor Daewoo new confidence that it will complete on time a project which is not only one of the largest schemes in the country but among the world's biggest schemes with a $1.8bn cost.

The dual two lane motorway connection, being built in public-private partnership by concessionaire, GK Fixed Link Corporation, will provide a vital motorway link from the busy Busan city, South Korea's second largest with a 3.6 million population, to important shipbuilding yards on the large islands off the southern Korean coast.

The connection also fills a crucial gap in the overall road transport network for the whole Korean peninsula, and will boost tourism in Geoje, a highly scenic island whose southern half is a national park.

The immersed tube tunnel especially, is unprecedentedly complex, both significantly long at 3.7km total length and currently the deepest concrete roadway yet to be built by this technique, in up to 48m of water. This is more than twice the depth of the Oresund, and raises new challenges.

At such depth, water pressures are greater on tunnel walls, seabed preparation more difficult and immersion operations more extended. To add to difficulties the coastal site is also exposed to open ocean currents and to weather systems that include typhoon storms two or three times in most summers, with waves to match the howling winds which can lift and smash



Right: The immersed tube section is 3.7km of the 8.2km crossing
Far right: Bridge connections and rock bores are needed to complete the link

boats, topple and twist harbour cranes and wreck houses.

Such a challenging project is a first in Korea and for Daewoo. Though the company is South Korea's largest contractor and already well-experienced in international work, in the Middle East particularly, it sees the project as an opportunity to step up further into a new league of technical skill and world level contracting capacity.

"People said to me 'surely you should walk before you can run' by doing a smaller immersed tunnel project" says Im-Sik Koo, a civil engineer with 30 years experience and project director for the overall scheme. "But we are proud to be taking this on and overcoming the challenges that it confronts us with."

"It will give us many opportunities around the world on similar projects and other work," he says. Eventually, in a longer term future, he believes it will also open up technical possibilities for even grander schemes, including very long undersea links to China and even to Japan.

To get a head start the company studied and absorbed the lessons of existing schemes, most of all the Oresund project but also others in Hong Kong, Japan, and Europe, through seminars and visits. It has also tapped into the skills built up previously, employing the Oresund bridge designer, Denmark's consultant Cowi, for the overall project design and bringing in some highly experienced Dutch subcontractors for dredging and immersion work. UK consultant Halcrow was employed in JV with TEC of the Netherlands for technical advice and oversight on both the bridge erection and the tunnel elements. Halcrow and TEC also worked on the Oresund project where particularly large scale pre-cast works were used.

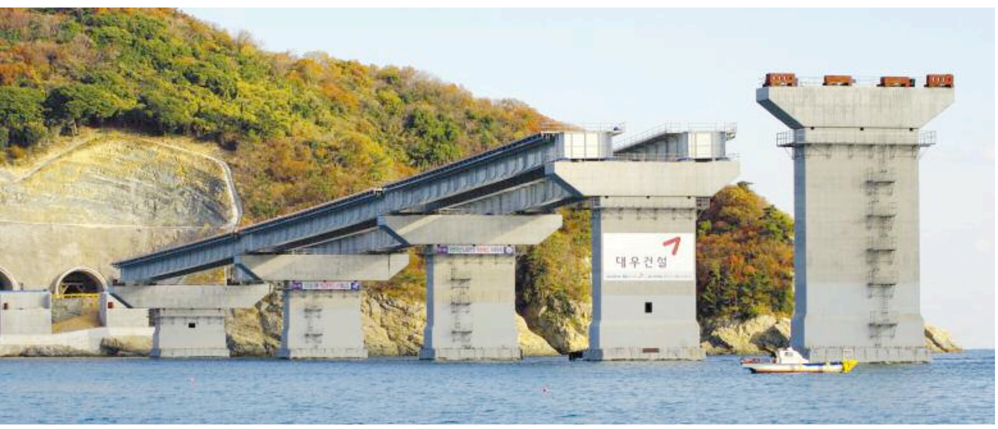
Precast is even more central to the Busan project, for both bridge piers, pylon bases and decks, and obviously for the tunnel, where the casting, and then placing, of the elements is the main feature.

A total of eighteen tunnel elements 180m long are being used for the undersea section, certainly the longest and, at 48,000t each, among the largest units made anywhere. Each is 9.97m high and most are 26.46m wide, providing space for a two lane road in either direction separated by a central service passageway. Two of the elements are 28.40m wide; the extra width provides for an additional truck climbing lane as road gradient increases to join the first of the two bridges.

The tunnel is completed at either end with 170m long portal and approach sections built by cut and cover, one at the start point on the small island of Gaduk, just offshore from Busan city, and one on a tiny rocky outcrop island conveniently located halfway to the crossing's destination, Geoje. Bridge connections complete the overall fixed link via one more small island; there are also short sections of bored rock tunnel on these two small intermediate islands.

All three channels of the crossing will all be used for ship passage, but the tunnel is needed to allow the largest vessels and most frequent use. Plenty of ships need access, firstly from the constant output of the big shipbuilding yards in the area, with mid-size and large vessels in and out to open sea all day for trials and deliveries. There are also movements in and out to Busan, Korea's second largest city which is currently expanding its container facilities with an ongoing Busan New Port development.

An immersed tube was selected because of the channel's depth. The same steeply sloping hillsides which characterise Korea's dramatic landscape, plunge on at the coast to create clear deep water channels between the flooded island peaks. That is good for shipbuilding, and for local fish farming industries, but means bored tunnels would have to go very deep, which would require very long approaches.



The tunnel elements will sit in the seabed in an excavated trench formed by Dutch dredging giant Van Oord, using one of its large trailing suction hopper dredging vessels. That allows much shallower construction than a rock tunnel.

While the trench was being prepared however the focus of work has been on the casting and fitting out the tunnel elements. These are made in a drydock facility created for the project at Anjeong, nearly 40 km across the wide bay formed by Geoje island and the curving mainland coast. Alongside ship yards and fuel landing facilities, an L shaped dock was excavated, 475m long and 11.5m deep, capable of holding four of the big tunnel elements at one time initially. This will then be further enlarged to allow five units to be made at once, to speed up the schedule once the second batch had been made.

Getting the casting work right is the key to the immersed tunnel integrity says Hyun Chil Lim, Daewoo's General Manager responsible for all pre-casting works.

Don Fraser, Halcrow advisor to the project particularly for concreting and pre-casting works explains further. "This is massive civil engineering with large amounts of concrete to be poured, some 18,000m3 in each element, with all the problems that can cause such as heat cracking and shrinkage. But it is also the detail that matters very much; the little things such as joints, waterproofing of form tie holes, accuracy of embedded anchor plates for both permanent and temporary works."

All these are critical because the tunnel design relies on the concrete structure for its watertightness. An alternative of cladding elements in steel, used frequently in Japan was ruled out by the design philosophy.

Using concrete means that the elements can be built up in separate segments, eight along the length of each element. That makes concreting work easier as it can be done one eighth at a time. But it is primarily intended to give the tunnel elements some flexibility along their length.

Each segment is match cast tight against its neighbours but is physically separate, which means that it can move relative to the others. Once the element is in position on the seabed it can behave like a eight segment "worm" to cope with possible seismic vibrations shifting the seabed, for shrinkage of the concrete, settlement and other effects, which would otherwise crack the units.

Such adjustment is small and to prevent movements going too far the segments are locked together with shear keys, restraining such flexibility to a tiny amount.

But there could be movement enough to let in water, and to prevent this happening, substantial and robust waterstops are required at the joints between the segments, embedded in the concrete. Because of the depth of the tunnel there will be a double layer of seals, for the first time on any immersed tunnel. An outer "standard" rubber water stop with epoxy injection will be complemented on the inner face of the tunnel by a steel plate and rubber "Omega" seal.

Fitting these and ensuring their integrity is one of the key tasks during the overall concreting works. In turn the double seal affects the complexity of the concreting, most of all because the shear keys cannot extend the full wall width of 1.33m but must be narrower, in the centre.

However, first of all comes the build-up for the big concrete pour, some 2200m3 for a single segment. The segments, unusually, are formed in one pass, a decision which reduces the potential for seawater leakage problems from concrete construction joints, which could generate restraint cracking.

"No matter how carefully it is done, if you pour one level of concrete for the base, and then the walls later perhaps, the concrete in the first section will already be behaving differently, starting to shrink as it cools and cures. That will lead to cracking so to avoid this either a carefully controlled cast in pipe cooling system is used or the full cross section is done as a single casting as we are doing" explains Fraser.

Segment formwork, and the heavy reinforcement within it, is therefore built up over some weeks for an eventual 24 hour pouring operation. First a plywood base is laid down on a painstakingly grooved concrete foundation, which will allow water flow under the unit when the drydock is flooded. Working platforms go around the sides and base and half the wall reinforcement is setup. Inner formwork units, devised by specialist company Doka, are moved into position on a traveller frame and the rebar finished, with ties through to the outer forms at the top.

During this work comes much of the important detail that Fraser is politely insistent the crews get precisely right. Exact positioning of various cast-in anchor points is required, for both permanent and temporary works for example. Most important perhaps are cast in anchors for two steel beams at the top of the primary end segment, which will be used during immersion positioning; for fixing temporary water ballast tanks used during float out; for detachable brackets which support the steel bulkheads which seal the units during the floatout; and most critically for the steel mounting for the Gina gasket at one end of the unit, and the facing plate at the other end of the element against which the next element's Gina will press.

"The Gina is a compressible seal for the immersion joint between two elements," explains Bo Hyun Yang, Daewoo general manager in charge of immersion work.

Famously named after the rounded figure of Italian actress Gina Lollobrigida, the gasket seal must touch precisely around the perimeter and onto the facing plate during immersion to allow dewatering. It must be set with millimetre accuracy.

Pouring of the concrete is also critical. A special mix for the elements was developed at Daewoo's large construction research campus outside Seoul and then tested and modified at site. "We finally devised a mix that, while not totally self-compacting has very good flow properties which takes some of burden off the vibrator guys if they miss a little" says Fraser.

Getting concrete compaction right was a major struggle during the casting of the first batch of four tunnel elements. "There was a fairly long learning curve" says Fraser. Some surface defects were apparent in trials and the first units though "nothing that was not repairable," he says.

Concrete quality is now "second to none" he says. Work crews have learned how to get inside the walls while the concrete is rising to vibrate it well, and a high strength grouting top up system has been developed to ensure the difficult male shear key projections are completely concreted, in between the waterstops.

A well choreographed pouring operation has developed for fast work on segments concluding with a plastic covering for the concrete faces inside which steam is injected. "It is not steam curing as such but temperature balancing to make sure the gradient between high internal curing temperature, up to 65°C and ambient which can be very cold, is never more than 20°C" explains Fraser. Heat detectors in the concrete monitor what happens.

This measure ensures there is no thermal cracking, which could cause another possible leakage path.

Segments have been cast in an alternating pattern, which eases the difficulties and allows easier fixing of joints later. Once cast, the rubber for the Omega seals has to be installed inside and other finishing done. The Gina gasket must be installed too, another precise operation.

The second batch of casting has seen elements produced in just eight months against 17 for the first difficult batch. The current operation is going better than that, with exemplary quality. With the yard enlarged to allow five elements to be made at a time and with hard work, the casting is on track for the placing operations.

Several units are currently available for placing, moored to the seabed a little way out from the yard where they are taken by tugs when the yard is flooded and the finished units floated up and carefully inched through the dock gate. From here they are eventually taken on an overnight

Each segment is poured in a single casting using 2200m³ journey, 37km to the site by subcontractor Mergor of the Netherlands.

But before immersion the new seabed trench floor has been under preparation. That involves, firstly, ground improvement works on the marine clay of the seabed, from which the trench was excavated. A 30m deep layer lies over gravels and then hard rock granodorite and andesites.

Because of differential settlement risks the main section of the tunnel has been treated with cement deep mixing (CDM), injecting and mixing cement into the soft clay ground in a pattern of columns. "A 'floating layer' is created" says Bong-Hyun Cho, the Daewoo deputy general manager for planning and engineering.

For the end elements, which rise from the seabed to land, there was rock excavation required for the foundation. For two rising elements on the transition island of Jungju there were sand columns installed in the clay, to release pore water pressure and accelerate settlement. Heavy rock surcharge was left in place for 18 months, eventually forcing nearly 3m of settlement.

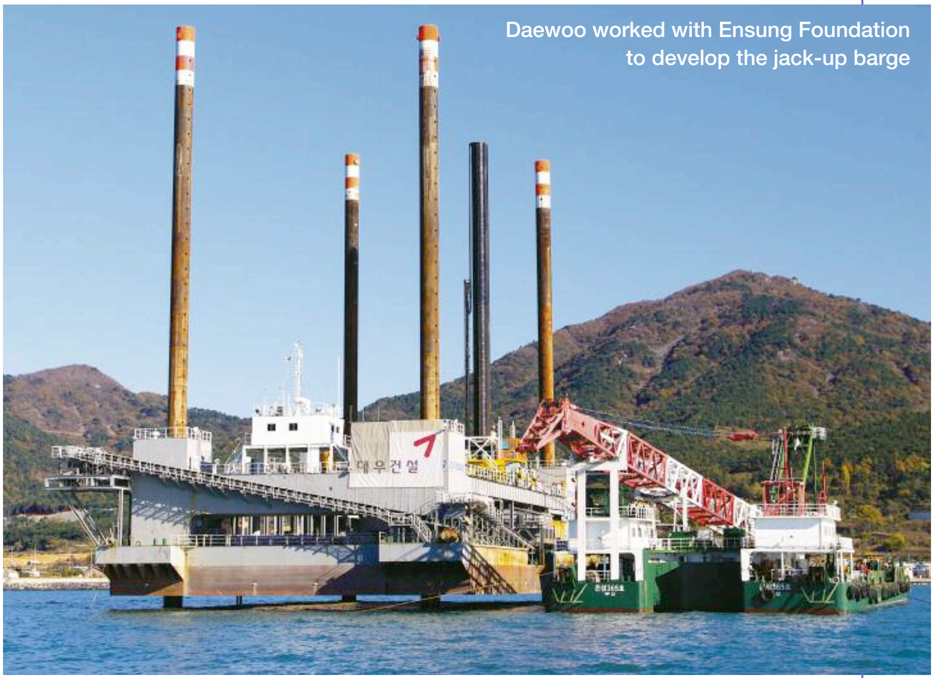
The additional measures were needed because these rising sections of the tunnel sit partially exposed as the tunnel rises from the seabed and require extra rock protection against potential ship collision. The protection is a substantial extra load on the foundation.

Once the ground was prepared a gravel layer is needed in the trench base on which the elements will sit, a system similar to that used on Oresund. It is an alternative to grouting the elements which adds significantly to the immersion time.

The bed needs to be highly accurately placed, a significant challenge in depths of water up to 48m. Daewoo worked with subcontractor Eunsung Foundation to develop a jack-up barge capable of working in such water. A key element is a large diameter vertical tremmie tube to place a 1.6m wide gravel "trail" on the seabed which is built up into a maze like pattern, forming the foundation. The tremmie is precisely positioned and also has a fine control hopper release at the end, adjustable by small hydraulic jacks. Positioning is controlled by total station sightings on the tremmie for the near-shore coastal elements, and by a specially developed high accuracy GPS system for the rest.

"When we had run successful trials for the barge I was able to sleep again at night" says Cho. "The foundation bed is critical for the success of the placements."

Once everything is prepared, the



Daewoo worked with Ensung Foundation to develop the jack-up barge

elements can be positioned. This is done only during the winter season when weather conditions are calm. Even then detailed weather observations from locally installed wave height buoys and a specialist weather service based in Ireland, are needed to ensure a five day calm window for the operation.

"We need less than 0.4m wave height to move and immerse the elements," says Cho.

Once the conditions are right, two special frames are fitted to the next element close to the back and the front. This is the so-called EPS or external positioning system, specially developed for the project. Each has vertical and horizontal jacks on its "feet" and is stressed by cable to the element.

Over these go two pontoons which are connected by winch cables to the elements and EPS frames. The whole assembly is then tugged 37km to site overnight, ready to go with immersion in the morning.

A series of lateral and longitudinal anchor cables to the element and its immersion pontoons allow fine position control of the element as it is made ready. The entire "sinking" is then controlled by pumping ballast water in six 1000m3 temporary tanks fitted inside the element, to alter the buoyancy.

"We add just 2% to its overall weight initially" says Cho. Nine winches on the pontoons then control the slow descent of the element to sit close to its final position. Divers hook up 150t jacks which pull the new unit close. Using guide beams on the element's top and corresponding guide receivers on the existing unit, helps position it.

It is here that the EPS system comes into place too, with its 200t horizontal jacks able to move the unit end for fine tuning. Its vertical jacks also lift the unit slightly to reduce friction on the seabed.

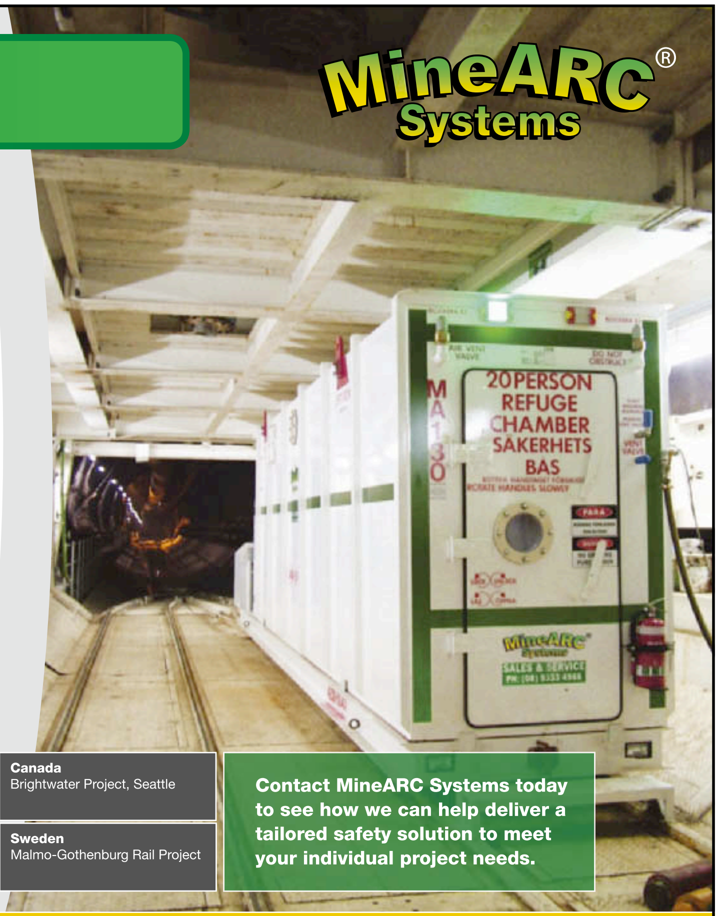
"We use an EPS here because of the depth and the possibility of sea current movement from the open ocean" explains Cho.

Once the Gina is lined up within plus or minus 10mm tolerances, and touches the end plate of the existing section, a new chamber is formed by the now joined spaces in front of the elements' bulkheads. This can be dewatered, and as it is pumped out, reducing internal pressure, the sea pressure forces the new element against the old, compressing the Gina by almost 50%.

To ensure total watertightness an inner Omega seal is also fitted across this joint, once the unit is firmly in position.

More ballast water settles the element tight and then a "locking fill" can be deposited around it filling about half the trench height. Above this there is then a backfill and over that goes a rockfill layer which protects the now buried tunnel against impact should a ship sink over the tunnel line, for example.

These fills add to the load on the tunnel but to ensure that it is weighted down an additional 3000m3 of concrete is poured in the tunnel floor to build up the road bed, adding more than 7000t load to the element. Ballast tanks are then removed, the bulkhead dismantled for reuse and tunnel fit out work proceeds. T&T



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A mixed response to Guangzhou

EPB TBMs measure up to mixed geology in Guangzhou. Desiree Willis reports

China's cities on the Pearl River Delta sit atop one of the most complex geological formations in the world. Ground is layered with silt, sand, highly weathered granite, and hard rock with significant ground water. In addition, the region's soft soils are typically back-fill, as many of the cities, including Guangzhou, were built upon once-submerged flood plains. As one official aptly put, "We like to call it our geological museum."

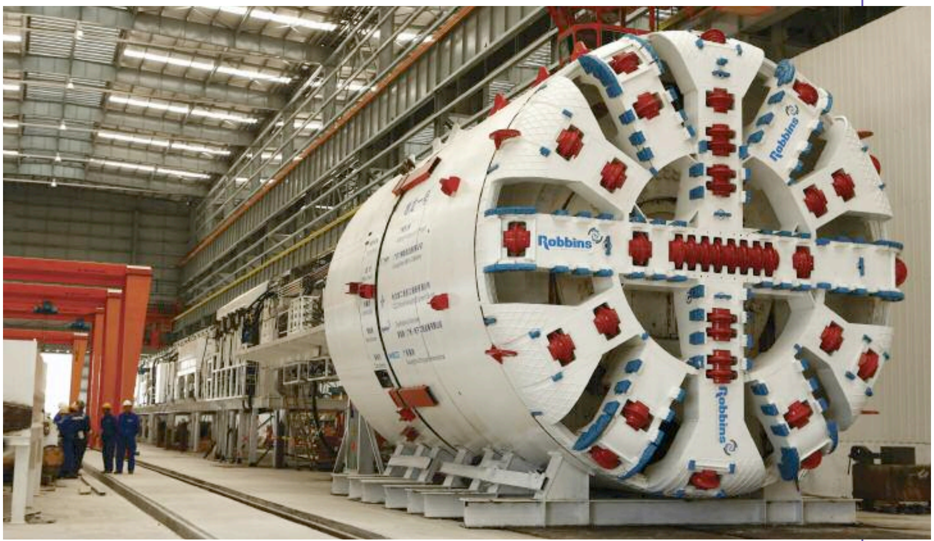
A new metro project between the cities of Guangzhou and Foshan has required extensive testing of the conditions in advance of TBM tunnelling. Two EPBs, manufactured by The Robbins Company, are boring parallel 2.6 km long tunnels with high advance rates despite the tough conditions. The rates achieved by the machines point to distinct variables influencing the project outcome, including effective ground control and machine design.

China Embraces Light Rail

Since 2006, China has invested nearly USD $200 billion in rail infrastructure—a plan that promises to be one of the largest national railway expansions since that undertaken by the U.S. in the 19th century. The government hopes to stimulate the economy and speed efficiency of passenger and freight travel throughout the country by adding 17,000 km of new lines. Metros are planned or are underway in dozens of cities, including Zhengzhou, Xi'an, Chengdu, and Chongqing.

Guangzhou's metro extension is part of the wide-ranging Pearl River Delta Inter-city Rapid Rail Project, a network that will connect key cities within the delta, including Shenzhen and Dongguan, by 2015.

The 32.2 km long Guang-Fo line is China's first ever inter-city rail line, and will cut travel times between the cities of Guangzhou and Foshan to about 50 minutes by 2012. The project's parallel rail tunnels and 21 stations were awarded in 12 separate lots by owner Guangzhou Metro Company. Tunnelling is currently under way using 16 TBMs. A tight project schedule calls for the completion of the first section in Foshan, running from KuigiLu to Xilang station, before the start of the Asian Games in November 2010.



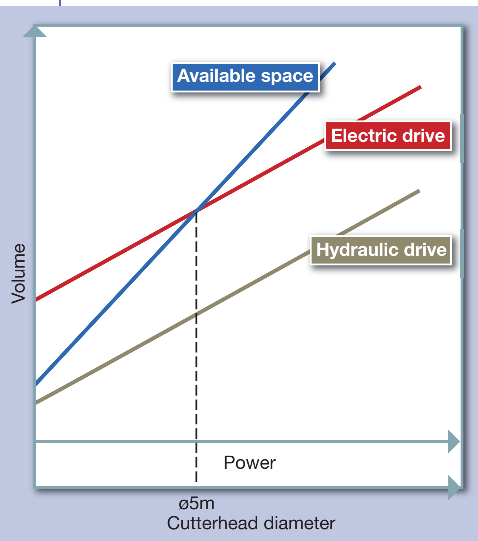
Above: **The two Robbins EPBs boring Lot 12 of the Guangzhou Metro are more than a month ahead of schedule.**
Right: **Cutterhead design for the Robbins EPBs had to take into account hard rock, clay-like ground and coarse sand.**

Lot 12, running between Jushu, Xilang, and Hedong stations, was awarded in 2007 to the China Communication Construction Corp., 2nd Navigation Engineering Bureau Ltd. (CCCC). The contractor selected two 6.3 m diameter Robbins EPBs for the parallel 2.6 km long rail tunnels. "There are many advantages to using TBMs in the project conditions—these include safety, faster advance rates, minimal effect on surface traffic, and simpler construction management," said Mr. Ju Yicheng, Vice Chief Project Engineer for CCCC.

Cutterhead Design

Proper cutterhead design is critical for the variable ground present in EPB tunnels. Geology on the metro's Lot 12 consists of a complex layered profile, ranging from highly weathered to slightly weathered granite, coarse sand, and silt at pressures up to 4 bar. About 70% of the tunnelling is through a mixed face, with the alignment above the spring line in soft soils and the bottom half of the tunnel in rock of at least 50 MPa UCS. The remaining 30% consists of flowing sand with high water content. The resulting cutterhead design had to address the sticky clay-like consistency of highly weathered rock, as well as the soft soils and harder rock conditions.

The Guangzhou machines have been designed with spoke-type cutterheads and a large opening ratio of 37%, allowing for a smooth flow of muck into the mixing chamber. Both carbide bits and 432 mm



Above: **Figure 1. Generalized Illustration of the Power to Volume Ratio. More efficient electric drives can only be used on machines over approx. 5 m in diameter, as the available space on smaller machines allows for hydraulic motors only.**

(17”) hard rock single disc cutters are used to combat both the clay-like and rocky conditions expected. In soft ground, the knife-edge bits scrape away at soils, while the disc cutters break away rock at the face by creating a crush zone through which fractures propagate.

Cutterhead rotation is kept low (around 1.5 rpm at maximum), in stark contrast to the higher speeds (around 3.0 rpm maximum) used in hard rock TBM tunnelling. In hard rock, high rpm results in fast advance, while in soft ground high rotational speed often results in ground disturbance and surface settlement of non-self-supporting geology. In soft ground, the same result of high advance rates can instead be achieved by increasing the cutterhead torque, which increases the instantaneous rate of penetration.

Each EPB cutterhead is driven by ten variable frequency drive (VFD) electric motors, for a total cutterhead power of 900 kW. Ultimately, the type of motor used depends on the so-called power to volume ratio. Smaller diameter machines, less than about 5 m, must use hydraulic motors to achieve high power, in order to take up less space on the machine. Though less bulky, availability tends to be less for hydraulic systems—about 75%, compared to more than 90% average availability for electric drives.

Mixing the Muck

Four independent foam injection points on the cutterhead are used to further consolidate the flow of muck. The independent systems also prevent clogging of multiple ports on one side of the cutterhead, which is often the case when common lines are used. Clogged ports can lead to uneven wear of the cutterhead and cutter tools.

The type of additive used is based on a standardized curve comparing geology and particle distribution. Ground with less than 30% fines, or particles less than 0.2 mm in diameter, is difficult to fluidize. In this type of non-cohesive ground, bentonite is used for consolidation. Foam is being used on the Guangzhou tunnels, in part because it is less costly and because it reduces the required cutterhead torque. Though the ground is good quality and does not need an additive such as bentonite, neglecting to inject foam can still lead to increased thrust and required power, as well as higher cutter consumption. If water pressure is high and small particles are present, a polymer can be injected in addition to the foam to increase cohesiveness of the material.

Muck and additives are further mixed within the cutterhead in the mixing chamber. Two mixing bars fixed to the inside of the cutterhead and to the pressure bulkhead homogenize the muck as much as possible before it exits via an 800 mm diameter shaft-type screw conveyor. Shaft-type conveyors are typically used in ground where large boulders are not predicted, and where there is potential for significant water inflows. In ground where boulders are expected, a ribbon-type screw conveyor is installed, which allows for boulder removal through an opening down the center of the conveyor.

Articulation through Curves

Choice of machine articulation can be a major variable affecting project speed. Much of the transit twists beneath the city, with curve radii as small as 200 m. Active articulation is used in curves, which engages articulation cylinders between the front and rear shields to steer the machine independently of the thrust cylinders. The process allows the thrust cylinders to react evenly against all sides of the segment ring during a TBM stroke in a curve.

Segment deformation, a common cause of project delays, occurs when the passive articulation system is used in curves. Passive articulation does not utilize articulation cylinders independent of thrust cylinders, so the machine reacts against sides of the segments unevenly in curves.

Geological Challenges and Surface Settlement

The two Robbins EPBs began boring in January and February 2009, and were launched from the cut and cover site of Jushu station in southern Guangzhou. Surface settlement is a concern throughout the tunnel route, which travels beneath rivers, research sites, roadways, and vulnerable building foundations. To

Below left: **Image 5: Ground settlement precautions were taken at the Pearl River Fisheries Research Institute, though no problems were detected.**
Below right: **The Robbins EPBs are utilizing active articulation to avoid segment deformation in tunnel curves.**

Above: **The first 6.3 m diameter Robbins EPB broke through into the Xilang Station site in August 2009.**

mitigate the risk of subsidence, back-fill grout is used to fill the annulus between the 300 mm thick, pre-cast concrete segment rings and the surrounding soil. The backfill grout is injected where the completed rings exit the tail shield. The volume and the pressure of the backfill grout injection are continuously monitored and controlled to eliminate the risk of surface subsidence.

High-risk areas include the 80 m wide, 4 m deep Huadi River between Jushu and Xilang stations, a significant waterway dividing the city. Ground beneath the river consists of layers of fine silt and sand with highly weathered granite below. The machine passed through the section, expected to have water pressures up to 3 bar, with few problems. "While the underground water was quite significant, we carried out effective measures including increased polymer injection. This worked very well," said Mr. Yicheng.

Near the waterway is another area for concern—the Pearl River Fisheries Research Institute, with numerous sensitive ponds. The ponds are used for research into high-yield fish farming, and were monitored for signs of disturbance as the TBMs passed some 10 to15 m below. Other than a few small bubbles visible at the surface, no ground settlement was detected.

Monitoring is present throughout the tunnel route, as there are dozens of building foundations that the tunnel passes under. "We stabilized a number of the building sites using pile foundation underpinning. We've also controlled settlement using surface stabilization and mucking volume control to decrease the chance of voids," said Mr. Yicheng.

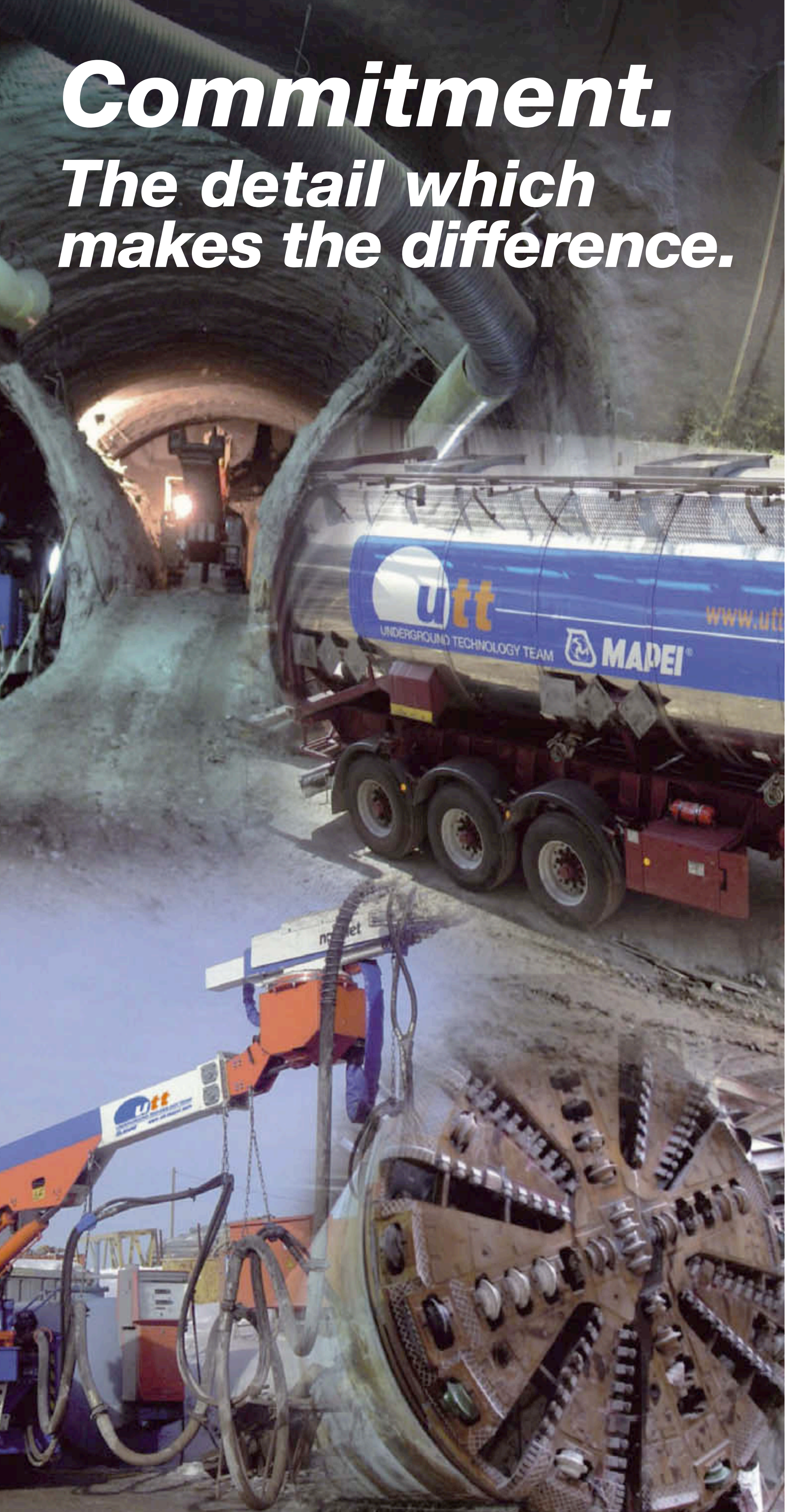
Record-Setting Excavation

After seven months of tunnelling, the machines have achieved more than 16 project records including a best month of 377 m—higher than any of the 16 TBMs that have worked or are working on the Guang-Fo Metro Project. Prior to the final breakthrough, the machines must emerge into the cut and cover site of Xilang station, where they are inspected before embarking on their last 664 m long section to Hedong station.

Both 6.3 m (20.5 ft) diameter machines are more than a month early on their project schedules, with the first machine completing its initial breakthrough into Xilang station on August 15, 2009. The TBM excavated its first section of tunnel with few problems and minimal cutterhead wear. The second machine is on track for its first breakthrough in September 2009.

The two EPBs have operated at an average 95% availability, in expected ground conditions requiring few cutter changes. As of August 2009, 66 disc cutters had been changed on the first machine and 46 on the second, while no carbide bits had been changed on either of the TBMs.

Mr. Yicheng of CCCC attributed the fast advance to two main factors. "We are quite satisfied with the excavation speed of these machines. We believe the high rates are a combination of fewer equipment failures and efficient project management." T&T



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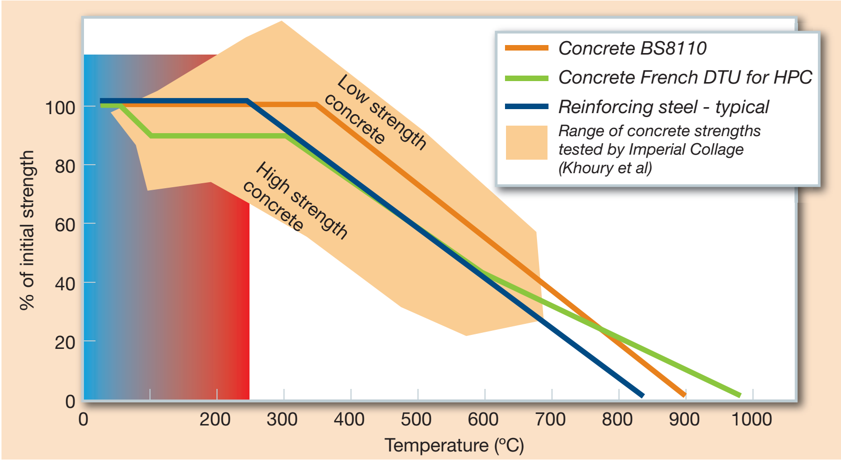
Passive resistance

Claire Verani of MEYCO Global Underground Construction examines the use of passive fire protection

The new EU directives and up-coming legislation decree that all the major existing road tunnels need to be upgraded to the latest safety requirements over the coming years. As a consequence, higher demands will be placed upon fire protection systems required to fulfil not only fire protection and fire life safety requirements but also provide the most economical and durable solution for the given risks in the tunnel. Owners and designers must endeavour to choose the optimum solutions for the given circumstances.

High durability concretes have become a prerequisite to increase the design life of structures. In order to achieve these high durability requirements, concrete is designed to have low permeability and hence poor performance in case of a fire with higher probability of spalling. This was evident in the dramatic Channel Tunnel fire in November 1996, which resulted in almost complete loss in concrete section.

There are many ways to protect a structure from the negative effects of heat, however thermal barriers emerge as the most robust and apropriate solution to protect against both the mechanism of spalling and that of strength loss caused by the exposure of concrete structures to elevated temperatures.



Above: **Fig 2 - Loss of resistance and structural capacity**

Right: **Fig 1 - Concrete panels showing the spalling mechanism**

Table 1: Number of victims of tunnel fires

Tunnel	Casualities
1978 Velsen (The Netherlands), 770m road tunnel	5 deaths and 5 injured
1979 Nihonzaka (Japan), 2km one tube road tunnel	9 deaths
1982 Caldecott (USA), 1km road tunnel	7 deaths and 2 injured
1983 Pecorile (near Genova, Italy), 600m road tunnel	8 deaths and 22 injured
1989 Brenner (Austria), 412m two tubes road tunnel	2 deaths and 5 injured
1995 Pfänder (Austria), 6.8km single tube road tunnel	3 deaths due to car crash itself
1995 Baku (Azerbaijan), train tunnel	Very serious human consequences
1996 Channel tunnel (UK-France), train tunnel	Several injured (intoxication)
1996 Isola delle Femmine (Italy), 148m road tunnel	5 deaths and 10 injured
1999 Monte-Blanc (France-Italy), 11.6km single tube road tunnel	39 deaths and 25 fireman sent to hospital
1999 Tauern (Austria), 6km single-tube road tunnel	12 fatalities (7 deaths due to car crash)
2000 Kaprun (Austria), Kitzsteinhornbahn	155 fatalities
2001 Gleinalm (Austria), 8.8km single-tube road tunnel	5 deaths due to car crash
2002 St. Gotthard (Switzerland), 12.6km bi-directional road tunnel	11 deaths due to HGV collision with fire

Fire damage

Over recent years, a number of notable tunnel fires in Europe (table 1) have led to the tragic loss in human life. In addition to this immensely ill-fated consequence, it is worth considering the structural damage that may occur following a fire in a tunnel environment, that can also cause, even if indirectly, severe danger to users.

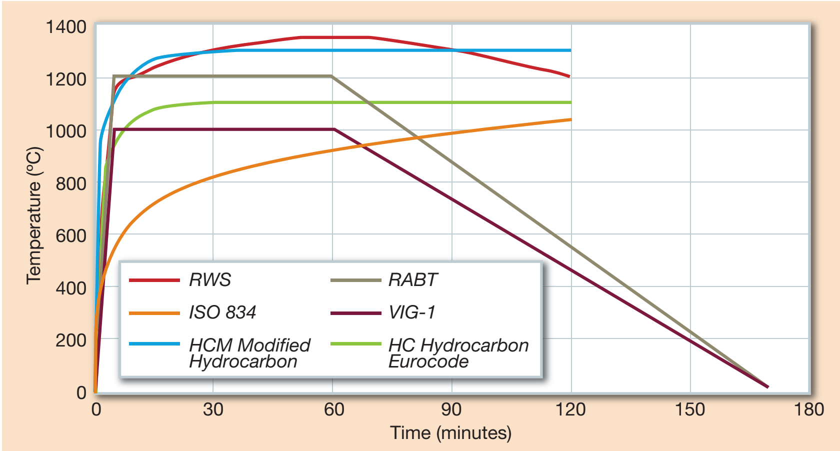
Structural damage to tunnels implicates repair work at elevated costs as well as extended periods of loss in service. Mont Blanc, for example, cost the operator some €203M (US$304) in lost revenue and some €189M (US$284) in repairs.

Numerous bodies have begun to investigate tunnel user safety and methods of protecting the structure from fire. Active fire protection systems, which include water sprinklers, water mists and foam deluge systems, act directly on the fire and smoke element to reduce their effects before the situation escalates out of control. Passive fire protection systems, on the other hand, comprise all solutions aimed at protecting the tunnel structure from the fire.

When concrete tunnel linings are exposed to fire, the following structural issues need to be considered:

- concrete typically undergoes explosive spalling, and will continue to do so until there is no concrete left, or the fire diminishes;
- concrete loses structural strength at elevated temperatures; and
- steel reinforcement loses tensile strength at high temperatures.

The spalling phenomenon causes the violent detachment of fragments of the structure with consequent reduction in section of the



Above: **Fig 3 - Design fire curves**

Right: **Fig 4 - Polypropylene fibres**

lining and thus reduction in resistance and structural capacity (see Figure 1).

The second phenomenon is the loss in structural strength of concrete and reinforcement steel at high temperatures, also illustrated in Figure 2 (adapted from ITA 2004 & Khoury 2005).

As can be seen in Figure 2 maintaining the structural concrete below 300°C (i.e. limiting the maximum temperature in the structure) in the event of hydrocarbon or cellulose fires prevents all negative structural issues from occurring.

In additional to the maximum temperature criteria, the rate of heating is crucial as it has a dramatic effect on the spalling mechanism: the higher the heat release rate (HRR), the higher the generation of water vapour pressure and the thermal expansion of the aggregates. This thermal shock can cause quite spectacular explosive events.

The role of passive fire protection is to protect the structure from these consequences.

Fire load and curves

The event of a fire has very different effects on road/rail tunnels when compared to civil works due to the highly combustible loads entering tunnels, such as Heavy Good Vehicles (HGVs) and freight trains, which can cause a severe fire in case of an accident, meaning a higher fire load, higher maximum temperatures and a faster heating rate.

Some design fire curves used until recently underestimated the real HRR and maximum temperature during fires. During recent real life fires, fire loads greater than 200MW and gas temperatures above 1350°C were registered. As a result of these fires, tests were conducted, guidelines and directives published giving criteria which designers can use for the fire protection of new build or existing tunnels.

UPTUN WG2, for example, recommends that the ISO834 be used if there are no (or only empty) HGVs passing through the tunnel. The maximum HRR can be estimated between 5 and 50MW. In case of HGVs the fire loads can be much higher and will generate a HRR of between 50 and 250MW, depending on the amount of combustible materials it contains thus the HC or the RWS curve is recommended (see Table 2).

The structural response to a tunnel fire depends upon the nature of the fire which can vary considerably from fire to fire. The key feature is the temperature-time curve imposed by the fire at the structure's surface, and especially:

- the heating rate (i.e. the rate of temperature increase) which influences the development of temperature, moisture and pore pressure gradients within the concrete;
- the maximum temperature level which influences the nature of the physiochemical relations in the material and through this its properties;
- the duration of the fire which influences the temperature development into the structure with time; and
- the cooling regime (eg water cooling would have a different influence upon the material and the temperature distribution from "natural" cooling).

To establish the characteristics of the fire protection to apply to a structure, it is necessary to predict foremost the type of fire to which the structure might be subjected.

Numerous fire curves (see Figure 3) exist that simulate, theoretically, the increase in temperature with time, given a fire load.

Assessment methods are constantly being developed to demonstrate the ability of materials and fire protection systems to prevent concrete spalling and steel and metal elements from heating and melting due to rapid heating under fire exposure conditions and to mitigate both structural and economic consequences of fire.

Fire curves used include:

ISO 834 (celluloid) curve: this curve is utilised in the case of fires in buildings (schools, offices, hospitals, hotels, etc.) and simulates a celluloid fire in an environment with adequate ventilation.

Hydrocarbon curve (HC): this curve is applicable in the case of a small size fire, of petrol or combustible liquid, such as a car tank or a gasoline cistern.

Hydrocarbon modified curve (HCM): represents a compromise between the traditional hydrocarbon curve (liquid or gaseous) and real life situation that can take place inside a tunnel. It is more severe respect to the hydrocarbon curve.

RWS (and UNI 11076): This curve is widely recognised throughout Europe as one of the most representative of a tunnel fire.

Many tests have been carried out both real scale – inside disused tunnels – and in laboratories to understand the evolution of fires inside tunnels. It was possible to note that the registered temperatures during a fire are higher than those of a similar fire load in open air or inside a building. Almost all countries that utilise the RWS curve, have decided to limit the thermal programme to two hours, as it is presumed that after this time, rescue services will be able to get close to the source of the fire and begin the fire suppression. Recent large scale fires, particularly that inside the Mont Blanc, have demonstrated that the temperatures inside the tunnel are too high to consent an intervention even after many hours and therefore some countries (Austria and Switzerland) have extended the RWS curve to 180 minutes (3 hours).

Polypropylene fibre modified concrete

In recent years, fibre manufacturers have promoted multi- and monofilament polypropylene fibres (32 to 18 micron diameter fibres – Figure 4) to contractors and design teams, detailing that the addition of 1 to 3kg of fibres added to the concrete mix gives an extremely economical solution to concrete "fire protection".

From testing, fibre modified concrete will exhibit less spalling, and in some cases no spalling whatsoever. One theory is that the melting of fibres at approximately 160°C produces channels for escape of the steam that allows water vapour inherent in the concrete matrix to escape without generating internal pressure, thus inducing high permeability at the critical time required and thereby preventing explosive spalling. Another theory claims that micro-cracking around the fibres contributes to steam reduction.

For specific design fires, the quantity of fibres required will alter accordingly – then larger the design fire, then greater the quantity of fibres required. As an example, for an ISO834 cellulose design fire, approximately 1kg/m3 of fibres are required, whereas for RWS hydrocarbon design fires, the quantity may increase to approximately 3kg/m3 as indicated. Concrete mixes with high fibre contents tend to be difficult to pump and place, and careful mix designs using admixture technology to overcome these problems are required.


Fig 5 - Roughness measured with a laser

Although the fibres offer an anti-spalling system, they do not protect the structural concrete from the detrimental effects of high temperature nor do they protect any structural reinforcement at the heat exposed concrete tunnel lining. Consequently, the use of fibre modified concrete should be considered carefully for use in structurally reinforced concrete tunnel linings.

Thermal barriers

Thermal barriers are designed to be installed (spray applied, cast Insitu or even as prefabricated boards) as a shield to protect the structure from fire at any time.

Thermal barriers typically consist of extremely porous, low density concretes and also contain polypropelene fibres. They are not only used to prevent the spalling of concrete, but also to protect the concrete and the steel reinforcement from the damaging effect of heat on the resistance of such materials.

Historically these have been vermiculite-cement based products applied by hand spraying with the technology being transferred to tunnel applications from the petrochemical industry.

Vermiculite based systems are relatively weak products (2.5MPa compressive strength) and may not offer adequate mechanical properties in the light of increasing client demands for more durable solutions where cyclic loading resistance is required. Vermiculite systems need to be mechanically bonded to the tunnel structure with stainless steel mesh. It is vital for sprayed systems to have adequate durability to resist both physical and chemical attack during the normal service life of the tunnel.

New studies have permitted the development of thermal barriers that do not contain vermiculite and that can be installed, as a fully bonded system, directly onto the substrate without the necessity of mechanical fixing, such as a mesh, or as a mechanically bonded system, in high risk areas or where surface preparation is not possible, or as a combination of the two.

New high durability mortars have recently been developed which exhibit increased fire protection and structural properties allowing a thin and impact resistant solution for fire protection. These products are based on light weight concrete technology giving compressive strength of up to 15 MPa.

Application thicknesses are designed as a function of the fire curve, exposed time of the structure to the fire, and the interface temperature (i.e. temperature that the concrete can reach in that time) and of the cover (distance of the reinforcing steel from the interface). Typical thicknesses can range from 30 to 50mm.

This barrier thickness ensures that in the case of a fire the total integrity of the support avoiding that it may spall or reduce the structure's capacity. Following a fire event, it will not be necessary to repair the concrete structure as it will remain integral.

In the particular circumstance where anchorage system for ventilation of cladding are supported on the structural lining, they would not come away because spalling would not take place.

This fire protection mortar may be:

- sprayed as sprayed concrete, manually or via mechanised robotic application, with or without the necessity of mechanical fixings due to its high adhesive tensile strength property (1-1.5 N/mm2 to concrete)
- cast insitu
- precast in panels

In the first instance, an alkali-free accelerator will be added to the wet mix to ensure rapid hardening and thus achieve rapid bond strength. To avoid using mechanical anchorage systems, it is necessary to prepare the substrate onto which the mortar will be sprayed to ensure sufficient roughness necessary for

Risk to life	Risk to construction	HRR MW	Road, examples vehicles	Rail, examples vehicles	Metro, examples vehicles	At the fire boundary
Risk to life		5	1-2 cars			ISO 834
Risk to life		10	Small van, 2-3 cars, ++	Electric locomotive	Low combustible passengers carriage	ISO 834
Risk to life		20	Big van, public bus, multiple vehicles		Normal combustible passengers carriage	ISO 834
Risk to life		30	Bus, empty HGV	Passenger carriage	Two carriages	ISO 834
Risk to life	Risk to construction	50	Combustibles load on truck	Open freight wagons with lorries	Multiple carriages (more than two)	ISO 834
Risk to life	Risk to construction	70	HGV load with combustibles (approx. 4 tonne)			HC
Risk to life	Risk to construction	100	HGV (average)			HC
Risk to life	Risk to construction	150	Loaded with easy comb. HGV (approx. 10 tons)			RWS
Risk to life	Risk to construction	200 or higher	Limited by oxygen, petrol tanker, multiple HGVs	Limited by oxygen		RWS

Left: Table 2 - Examples of fire load given traffic types and corresponding recommended design fire curve

Table 3: Minimum values and allowed deviation for the laser index system

Segment roughness	Minimum average required	Maximum standard deviation*
R_p	1.16	0.05
Z_2	0.79	0.31
i_a	13.5	1.50


Easy-to-use


Simple


Accurate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bonding. This effect may be obtained in many ways: through hydromilling of the substrate, in order to expose the aggregate, in the case of existing structures with smooth surfaces, or through jet washing of the concrete with a prior treatment of the surface with a bond inhibitor. In practice, before casting the lining, the formwork is treated with products that inhibit the superficial bond of the cement paste so that , following demoulding, high pressure washing will expose the aggregates making the surface appropriate for a fully bonded solution.

The level of necessary roughness, for a safe and complete adherance of the mortar can be easily measured via laser equipment (see Figure 5) connected to a computer.

The laser gun is placed on the prepared surface and, via a calculating system, provides 3 index numbers: Rp, Z2 and Ia. The level of roughness is acceptable when these indexes reach the minimum values as reported in Table 4.

The mortar, if applied as a fully bonded sprayed thermal barrier, ensures continuity in the concrete structure.

This means that possible cracks that may occur in the open structure will be visible on the mortar without however compromising the fire protection, allowing inspection of the structure below. (This would not be possible with a mechanically fixed solution or the board solution).

The main disadvantage with sprayed systems is the resultant sprayed surface finish, as some clients require a high level of reflectance, particularly for highly trafficked road tunnels. Float finishing and over painting is possible, but labour intensive. Rail tunnel surface finish requirements are less onerous in general, and an "as sprayed" finish is acceptable, making the use of sprayed fire protection mortars particularly viable.

The mechanically fixed spray applied and the pre-fabricated board solutions permit protection of the structure without the necessity of hydromilling the existing structure (substrate).

Taylor-made pre-fabricated boards, with design thickness and curvature according to individual project requirements, have an excellent surface finish and are fixed to the structure via stainless steel fixing bolts. The installation method requires more time than a fully bonded sprayed solution.

Pre-fabricated fire protection boards offer a clear advantage for box shaped tunnels where there are no curved tunnel walls or complex geometries e.g. cut and cover and immersed tube tunnels. Furthermore, the surface finish of the board systems is appealing to clients. However, they are not well suited to curved profile tunnels and are generally 1.5 to 2 times more expensive than sprayed systems, which can prove cost prohibitive. Apart from their high cost, vehicle collision damage is often considered a maintenance problem in road tunnels using pre-fabricated board protection systems.

Table 4: Types of fire protection

Risk	Low					High
Tunnel use	Utility	Country tunnels	People tunnels	Metros	High speed rail	Urban road
Geology	Hard rock		Hard rock-urban		Soft ground	Sub-sea/river
Other factors	Local fire department		Low use tunnels		No local fire dept.	Economics
Protection measure	No protection		Fibre modified		Thermal barriers	

Above: Table 4 - required thermal protection by structure

The MEYCO Fire Protection System, MEYCO Fireshield 1350, has recently been applied inside the Bodio section of the Gotthard Base Tunnel (see Feature on page 30).

Conclusion

The amount of European transport tunnels in daily use without any form of fire protection is of concern. Of course, following risk assessments a great majority of these tunnels may not need fire protection, but certainly under the new requirements of the European Directive No.2004/54, and perceived new directives there are many tunnels that will require retrofit fire protection systems to be installed.

Very thin spray applied thermal barriers (less than 45mm) will be required for many of these tunnels if clashes with the operational envelopes are to be prevented. The use of polypropylene fibre modified concrete is not considered an option for many existing tunnels due to the limited operating space. However, consideration may be given to sprayed concrete with polypropylene fibres if the space profile permits a minimum layer thickness of approximately 80mm.

It should also be noted that the general trend in increasing vehicle and train sizes and also increasing the tolerance to the structural lining to avoid clashes (at higher line speeds for example) puts additional pressure on the industry to develop very thin fire protection solutions.

In order to determine which system is appropriate for specific tunnels, consideration of the risk of structural collapse of the tunnel linings, and the effect it will have on 3rd parties is required.

In the case of existing tunnels, passive fire protection, in the form of thermal barriers, applied to the existing structure seems to be the only solution.

A final consideration stems from the fact that nowadays all structures, for durability reasons, will need to be designed with concrete that has lower water/cement ratios (therefore very low porosity).

This, from the fire behavioural side, does not represent a good solution because the structure is very dense and compact and therefore, does not permit the water vapour to release the pressure. In this case, to ensure the durability of the structure from all points, (chemical and thermal attacks), it is necessary to utilize a concrete with low w/c ratio and a thermal barrier.

An example of this application can be found in TBM tunnels: the precasted segmental lining have high densities and therefore low permeability, therefore are very vulnerable to spalling. T&T

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Protecting Gotthard's cut-and-cover

Alessandro Ferrari of Lombardi Engineering Ltd looks at how passive fire protection being used to protect Gotthard's cut-and-cover Bidio Section

At the heart of the new flat transalpine rail route being constructed by the Swiss Federal Railways is the Gotthard Base Tunnel. The tunnel is part of the Swiss AlpTransit project, also known as New Railway Link through the Alps (NRLA).

With its planned length of around 57.1km, and a total of 153.5km of tunnels, shafts and passages, once finished, the Gotthard Base Tunnel will be the longest tunnel in the world.

The tunnel cuts through the Gotthard massif at nearly ground level. The two portals will be near the villages of Erstfeld, Canton Uri (Northern Portal) and Bodio, Canton Ticino (Southern Portal).

The dual purpose of this project is to provide a high speed link for passengers between southern Germany in the north and Italy in the south of continental Europe and to transfer freight traffic from the roads to rail, as required by the 'Alpine Protection Act' of 1994. It represents also an essential step to actively protect the sensitive region of the Alps and to get an important contribution to preserve the environment in general.

The tunnel system mainly consists of two single track tunnel tubes that are interconnected approximately every 325m by cross passages. The horizontal distance between the tube axes varies between 40 and 70m. Furthermore, at the one third and two third points along the tunnel, there are two multi-functional stations with track changes, emergency stations, technical equipment rooms and ventilation systems.

In order to optimise the total construction time, the tunnel was divided into five sections: Bodio, Faido, Sedrun, Amsteg and Erstfeld.

The design consortium of the Bodio, Faido and Sedrun Sections (total length about 38km) is the engineering joint venture Gotthard Base Tunnel South (Lombardi Engineering Ltd/ Amberg Engineering Ltd / Pöyry Infra Ltd.

The Bodio section, at around 15.9km, connects the Southern Portal with the Faido multi-functional station. The two tunnel tubes and 51 cross-passages of this section were excavated between 2000 and 2006. Following the initial cut-and-cover and loose ground sections approximately 400m each in length, the 1.7 km in the eastern tube and 0.8 km in the western tube were excavated by drill and blast. The remaining section up to the boundary with the adjacent Faido section was then driven by the main contractor using two open face TBMs.

General fire protection

It is important to the operator that the tunnel remains in use at all times. Therefore, reasonable effort should be put into allowing continued operation of a tunnel bore in the event of a passenger and freight train fire in the other tunnel bores.

A passenger or freight train fire in the GBT could potentially cause damage to the structure putting tunnel users at risk. This would lead to time-consuming and expensive rehabilitation works to bring the structure to its original state.

For these reasons the following two requirements must be met:

• *Availability during the event* (individual safety): the main and mandatory criterion is to ensure the safety of people and full operation of the tunnel until all users are safe. In order to assure this, the availability of the tunnel has to be maintained as long possible until users are able to reach a safe place. This implies that the affected bore must be structurally safe and adequate for 45 minutes, and the neighbouring bore for 90 minutes.

• *Availability after an event* (cost effectiveness). In the case of a fire on a train reasonable effort should be put into ensuring that the service interruption is minimized. This is a cost optimization problem.

The reopening of the railway line has immediate priority following the rescue of users. In order to ensure this, constructive fire-protection measures have to be taken to exclude major damages or collapse of the neighbouring bore and also to reduce resulting damages, time and costs for the repair of the damaged bore.

In 2003 the "fire protection" task force was founded by AlpTransit Gotthard AG with the following goals:

• Identification of fire scenarios for "freight train fire" and for "passenger train fire"

• Elaboration of a damage and risk assessment (without protection) for the different fire scenarios

• Assessment and recommendation of protective measures, provided both availability requirements are fulfilled

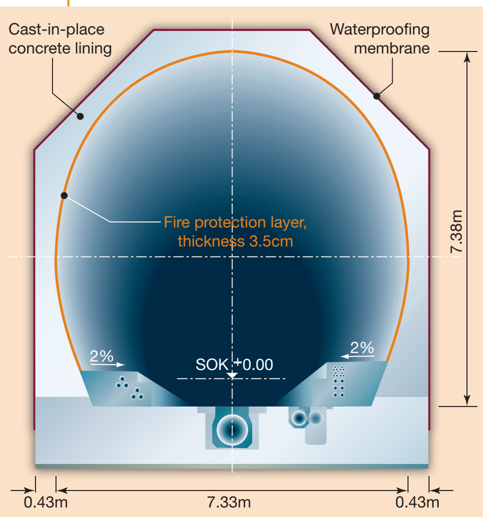
For the evaluation of the design fire scenarios of the tunnel structures, fire sizes of 250MW (freight train) and 40MW (passenger train) were assumed. A computer simulation of freight and passenger trains (with a train length of: 750m, 32 wagons) catching fire inside a tunnel bore was undertaken. In the simulation, each wagon burns for 45 min with the fire source hopping from wagon to wagon every 6 minutes (moving source). The duration of the fire is 4 hours.

Different temperature-time diagrams have been developed around Europe, however a new time-temperature curve was adopted for the Gotthard Base Tunnel, to better consider the particular fire-event scenarios and the effective tunnel design.

The need for fire protection was identified through a damage and risk assessment conducted for the entire length of the tunnel. This meant evaluating, for "individual safety" and "cost effectiveness", the probability and extent of damage and consequences to the safety and to the structure of the tunnel system without any fire protection.

The following passive fire protective measures were identified:

- Addition of polypropylene fibres (especially in unfavorable geological formation) to avoid spalling
- In combination with polypropylene fibres, increased concrete cover, to protect the steel and ensure no reduction in tensile strength with increased temperature
- Sacrificial fire protection layers to insulate the tunnel lining.



Above: **Fig 1 – Cross-section of the cut-and-cover portion Bodio with thermal barrier;**
Right: **Fig 2 – Hydromilling**

Fire protection in Bodio

The cut-and-cover section of Bodio started in 2000 and was completed two years later. It consists of two bores each of 400m in length and one cross-passage, which is situated about 260m from the southern portal.

Following the investigations of the fire protection task force it was decided that to comply with the individual safety criterion a fire protection layer on the existing tunnel lining was necessary on the whole length of the cut-and-cover section of Bodio. This is because in the event of a fire, it could not be excluded that damage or collapse of one bore could cause damage to the other making it impossible to evacuate the tunnel.

Many fire protection systems were analysed and rated for their technical and economical performance. A cement based fire protection layer resulted as the best solution for the cut-and-cover section of Bodio.

The following are requirements for the passive fire protection layer:

- Fire protection of the existing tunnel lining according to the RABT/ZTV standard design fire curve (90 minutes at 1200°C and the following cooling phase of 110 minutes) with respect of the following two conditions: temperature at the interface £ 400°C, temperature at the reinforcement (with a concrete cover of 4cm) 250°C.
- After an event the fire protection layer can be partially or completely replaced
- Good tensile bond strength with the existing concrete lining
- High frost and freeze-thaw resistance
- Dead load resistance and resistance against stresses caused by the train service. The assumed amplitude of air pressure fluctuation is ±10 kN/m2
- Resistance against variations in temperature between -10°C and +40°C and against fluctuations of relative humidity between 20% and 100%
- Resistance against cleaning by high pressurized water
- Resistance against local perforations and against stresses induced by fixation of railway infrastructures
- The thickness of the fire protection layer has to be as thin as possible because of the tight space available
- Service life of 50 years

Bodio solution

Under the prescribed circumstances and requirements the application of a layer of MEYCO Fireshield 1350 mortar was chosen. The product distributor (BASF Construction Chemicals) defined a minimum thickness of 31mm for the mortar to meet the fire protection requirements of the project. The fire protection layer was applied on the concrete lining in both tunnel sections (see Figure 1). To give some tolerance in the layer thickness of ±4mm a standard thickness of 35mm was defined - the

Left: **Fig 3 – Fire protection mortar is applied in one step** effective layer thickness therefore varies between 31mm and 39mm.

A fully bonded solution combined with stainless mesh reinforcement was chosen to ensure the tensile bond strength with the existing layer met the requirements.

The existing surface of the cut and cover section was pre-treated using robotic hydromilling (2'000 bar) of the concrete surface to ensure full bonding of the mortar to the substrate. A minimum depth of roughness of 5mm was prescribed. (see Figure 2).

A stainless fine-meshed mesh reinforcement (with a diameter of 1.5mm each 5cm in both directions) was installed on the structure substrate with a minimum of 5 stainless bolts per m2 to provide additional safety against delamination. Afterwards, the fire protection mortar was applied in one step with a sprayed concrete robot (see Figure 3).

A total area of about 13,500 m2 of fire protection mortar was spray-applied in the Bodio Section of the Gotthard Base Tunnel. Figure 4 shows the detail of the fire protection layer construction.

Right: Fig 4 – Fire protection layer construction;
Right, bottom: Fig 5 – The Fischer spacer used for fixing reinforcement matting

For fixing stainless steel reinforcement matting to the inside walls of the tunnel a new spacer (mesh holder) developed by Fischer has been used in combination with the Fischer Nail Anchor FNA II 6x30/20 A4 (see Figure 5). This new spacer system has been tested according to the RWS fire curve. The coloured markings show the user the necessary minimum thickness of the mortar layer to be sprayed over the matting. T&T

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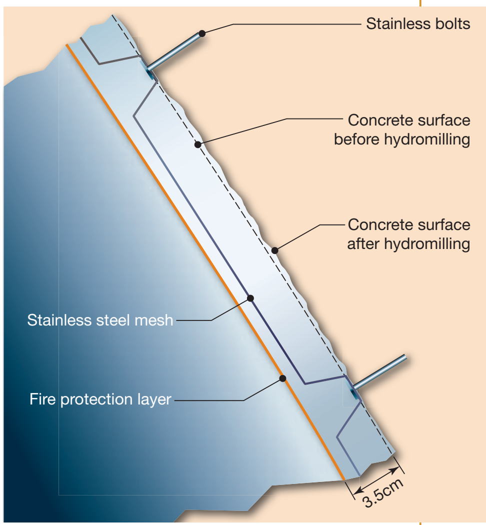


Fibre decider

Designers have a range of options when specifying fibre reinforcement but some are more suited to underground structures than others. Charles Allen of London's Tunnelling Ltd examines the options

The use of steel fibre reinforced concrete (SFRC) for underground applications now has a history of over three decades in sprayed concretes and over two decades in segmental tunnel linings.

As growth of the use of SFRC in sprayed concretes developed in the underground sector, several manufacturers entered the market, presenting designers with an array of steel fibres from which to choose.

Early specifications for steel fibre reinforcement were often very basic and prescriptive, merely asking for a set dosage rate per m^3 of concrete, ignoring factors such as rebound characteristics, tensile strength and aspect ratio.

Over the years, as more knowledge was gained about the behaviour of steel fibres in concrete, performance specifications became more prevalent and new test methods were developed to monitor and measure this. By the end of the 1990's, it was becoming easier for designers to confidently specify steel fibres for use in both sprayed concretes and segmental linings.

However, during the same period, a range of synthetic fibres entered the underground construction market giving designers yet more choice. These included micro and macro-synthetic fibres, which were generally manufactured from polyolefin and polypropylene.

The polypropylene versions were used to improve the performance of concrete in fires by significantly reducing spalling and the polyolefin fibres favoured for structural performance, in competition with steel fibres.

The result is that today we have a fair degree of confusion in the market as to which generic type of fibre a designer should select. Each fibre type has its own characteristics and suitable applications but this piece concentrates on their use for structural purposes in sprayed and pre-cast concrete linings for underground civil engineering structures such as tunnels and caverns.

The main parameters of fibre reinforced concrete (FRC) that are pertinent to tunnel lining design are the bending moment capacity, indirect tensile strength, flexural (and residual flexural) strength and ductility (or toughness) values.

Over the years, many test methods have been developed to measure and determine the performance of FRC. These include beam tests, square and round panel tests and, more recently, the double punch (or Barcelona) test. The common factor in each of these tests is the measurement of the ability of FRC to continue to support and carry load after the concrete matrix has cracked. This is, in effect, the essence of the structural performance of FRC.

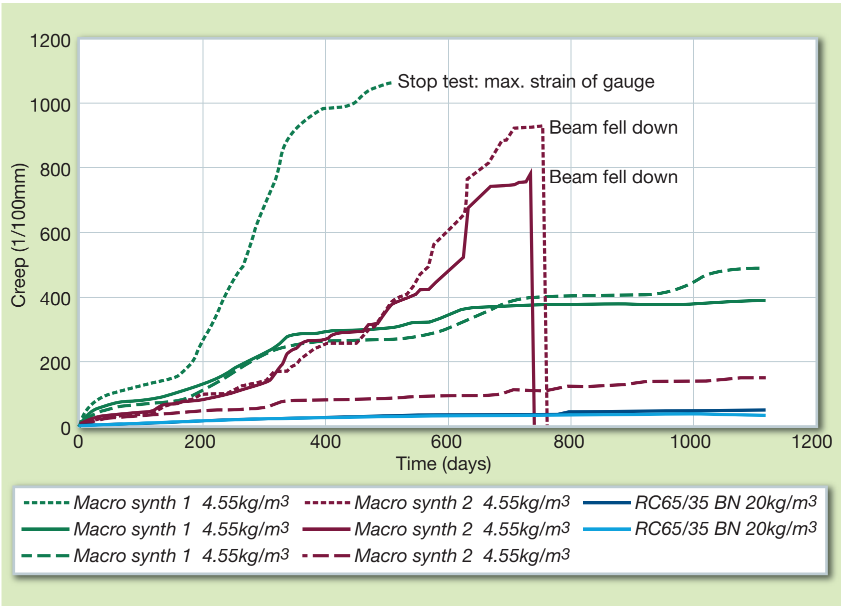
After first crack of the concrete matrix, the tensile forces are redistributed to the fibres bridging the crack. If the FRC continues to carry load as further cracks are propagated and deformation takes place, then it is easy to understand that creep of the fibres is a very important parameter.

Macro-synthetic fibres versus steel fibres

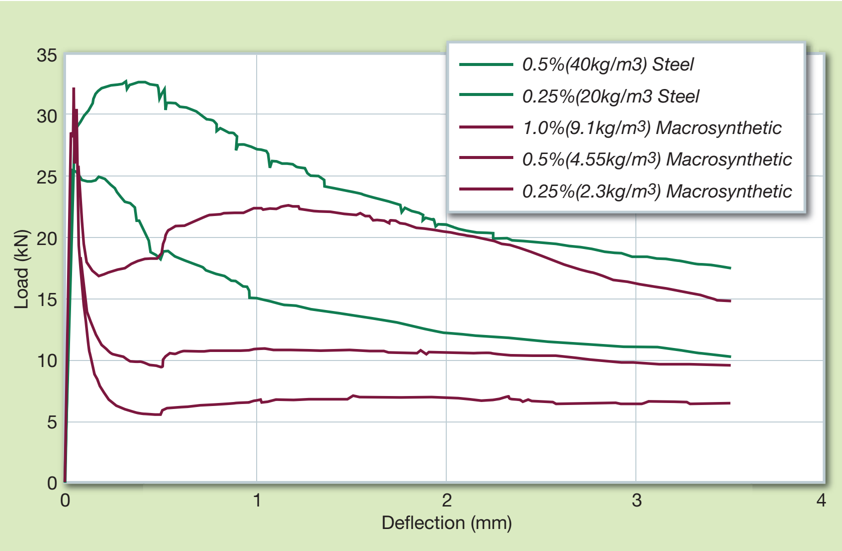
There are a large number of macro-synthetic fibres available in the market, made from a variety of organic polymers and with differing geometries. The elastic modulus of steel is approximately 200 GPa, whereas that of macro-synthetic fibres is generally between 2 and 10 GPa. As well as requiring more strain to achieve a similar level of stress, macro synthetic fibres, like concrete, exhibit an inherently elasto-plastic behaviour under load so it is therefore quite simple to conclude that macro-synthetic fibres will exhibit higher creep characteristics than steel fibres under sustained load.

Due to the significantly lower stiffness of synthetic fibres versus steel, it is inevitable that crack widths in synthetic FRC will be greater than those in steel FRC, given that loads and conditions are equal.

In underground civil engineering structures it is highly desirable to keep lining deflections and, consequently, crack widths to an absolute minimum. In mining support applications, where very high deflections (and crack widths) are acceptable and anticipated, then macro-



Right: **Fig 1 – Long Term Creep (deflection in 1/100 mm) versus time (days) [Lambrechts 2005]**



Left: **Fig 2 – Comparative beam toughness tests [Ratcliffe]**

synthetic fibres can be used and may well have a benefit over steel fibres in sprayed concrete. Such fibres have been used extensively in the deep level mines of Australia and South Africa.

In 2000, Stefan Bernard, the developer of the round panel test for FRC, suggested that "steel would be the material of choice for applications requiring small maximum crack widths, with synthetic fibres becoming more attractive for high levels of deformation".

Admittedly, synthetic fibres may have improved their performance since then, but more recent comparative beam toughness tests for segmental linings by R Ratcliffe of the Australian Tunnelling Society, demonstrate that even high dosages of macro-synthetic fibres have toughness levels at low deflections that are inferior to moderate dosages of steel fibres (Fig 2).

The curves in Fig 2 indicate a strain hardening characteristic of steel fibres at low deflections, whereas the macro-synthetic fibres exhibit strain softening. This means that once the concrete matrix has cracked, tensile loads are redistributed and taken up by steel fibres more quickly than by macro-synthetics, thus providing greater toughness at the level of crack widths required for civil engineering structures. It is only when macro-synthetic fibres are used at very high (often greater than those quoted in manufacturers' literature) dosage rates that strain hardening can be achieved.

Currently, the specified test of choice for sprayed FRC in civil engineering structures is the plate test according to European Standard EN 14487-1, Sprayed Concrete, Definition, Specification and Conformity". The energy absorption value measured for a panel can be adopted when, in the case of ground support, emphasis is placed on the energy which has to be absorbed during the deformation of the ground. This is especially useful for primary sprayed concrete linings.

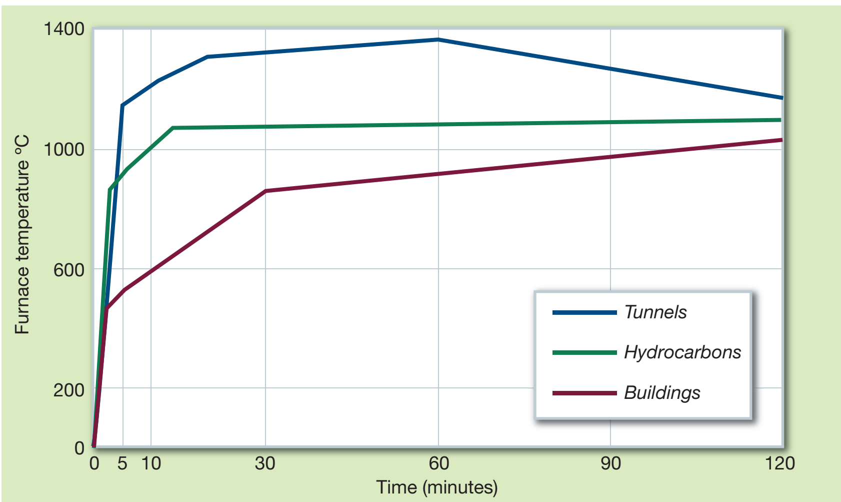
The round determinate panel test, ASTM C1550-08, which measures the residual strength for deflections up to 40mm has been promoted by the macro-synthetic fibre industry. However, selection of the most appropriate central deflection to specify depends upon the intended application for the material. The energy absorbed up to 5mm central deflection is applicable to situations in which the material is required to hold cracks tightly closed at low levels of deformation. Examples include final linings in underground civil structures such as railway tunnels that may be required to remain watertight. The residual strength up to 40mm deflection is, in fact, only applicable to situations where the material is expected to suffer very severe deformation in situ (which means a very wide crack). Generally speaking this test should not be used for civil engineering structures with more than 10mm anticipated deflection.

The round panel test is an isostatic one, it should not be used to make a correlation with the EN hyperstatic square panel test. A hyperstatic test is an indeterminate, multi-crack process test whereas an isostatic test is a determinate process with pre-determined crack patterns. Because of this difference, it is not possible nor makes sense to try to compare the results of theses two tests.

When it comes to waterproofing membrane systems some information from the macro-synthetic fibre industry has intimated a serious concern about the danger of steel fibres producing from sprayed concrete surfaces and puncturing through previously, or subsequently, installed waterproof membranes. However, the practical experience on many sites and test results from independent laboratories confirm clearly that there are no problems with the membrane/protection sheets in combination with steel fibre reinforced sprayed concrete.

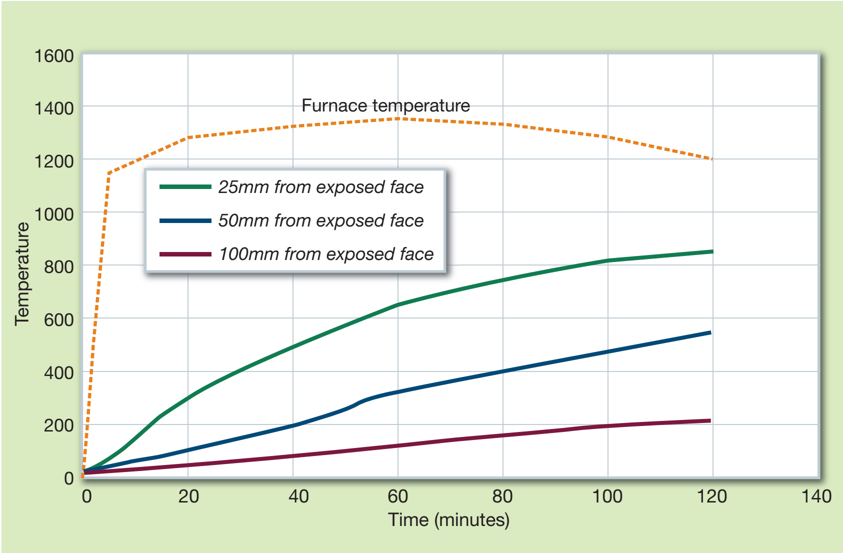
Performance in tunnel fires

In recent years, the occurrence of major fires in tunnels has created a much needed emphasis on safety and the need to mitigate potential structural damage in tunnels. During the design phase of the Channel Tunnel Rail Link (CTRL) London tunnels, extensive fire tests on tunnel



Right: **Fig 3 – Fire temperature curves**

Right: **Fig 4 – Typical temperature profiles with concrete sections subjected to fire**



segments under loaded conditions were conducted by CTRL at the University of Delft in the Northerlands.

The tests proved that the inclusion of 1 kg/m3 of synthetic monofilament fibres to the SFRC matrix significantly reduced the depth of spalling in the segments. This is due to the fact that the fibres melt and provide additional space and routes to their interfacial zones for the vapour pressure in the concrete to dissipate and hence reduce the amount of spalling.

As a consequence of the test results, polypropylene monofilament fibres of 18microns diameter and 12mm length were incorporated in the SFRC segments for the entire length of tunnels in the CTRL project.

More recent developments in monofilament fibre technology and fire test results indicate that fibres with a diameter <20 microns diameter and of 6mm length should be recommended for optimum resistance to spalling in fires. It should be noted here that micro-synthetic fibres do not give any additional structural capacity to concrete. It should also be noted that, contrary to some supplier literature, macro synthetic fibres have no significant effect on spalling.

Fires in tunnels can reach high temperatures of up to 1400˚C as shown in Fig 3. The melting point of synthetic fibres is generally between 150 to 180˚C, which is beneficial in the case of micro-synthetic fibres for spalling resistance.

In the case of macro-synthetic fibres subjected to fire, however, the situation, in terms of their structural load carrying capacity is more alarming and here it is worth quoting directly Clause 5.1.5 of Concrete Society technical report number 65 (2007): "When subjected to fire, macro fibres will soften as the temperature rises and will melt at a temperature of 150-160˚C. They will lose their mechanical properties and will no longer provide any structural capacity. Clearly, therefore, it is important to avoid the use of macro synthetic fibres to provide structural capacity which may be lost in the event of a fire with consequent collapse. Even where used for non-critical purposes, it may be necessary to remove and replace the affected concrete after a fire. In some situations the use of passive fire protection to limit the temperature rise in the concrete may be necessary."

Steel fibres do not start to melt until approximately 1130˚C and consequently, at high temperatures, have more capacity to hold a FRC composite together than macro-synthetic fibres.

Fig 4 (6) shows the typical temperature profiles within concrete sections that are subjected to fire (e.g. sprayed concrete or segmental final linings). From looking at the graph, it is easy to estimate that after approximately one hour exposure to a tunnel fire, synthetic macro-fibres within the first 100mm of concrete will have melted and lost their structural capacity.

Fire resistance tests on SFRC segments have recently been conducted in Europe. They showed that metallic fibres are an improvement over traditional steel reinforced concrete, which, due to the thermal conductivity of the rebar, causes rapid bursting and spalling of the exposed concrete.

Spalling, although unavoidable, is limited in steel fibre concrete when compared to ordinary reinforced concrete.

As with conventionally reinforced concrete segments, the addition of polypropylene monofilament fibres to the composition of the SFRC considerably reduces the risk of spalling.

Therefore a combination of metallic fibres and polypropylene monofilament fibres constitutes an optimum solution for the improved fire resistance of pre-cast, in-situ and sprayed concrete final linings in underground structures.(7)

Summary

Although macro-synthetic fibres may have a place, on occasions, in sprayed concrete support for some mining applications, uncertainty remains over their suitability for application in both sprayed concrete and segmental final linings for civil engineering structures.

The major concerns that designers need to consider when specifying a generic fibre type for final lining applications are anticipated convergence/deflections; long term creep characteristics of the fibre type after cracking of the concrete matrix and performance in fire.

In addition, more practical matters, such as the effect of the fibre type on the plastic properties of the concrete should also be taken into account.

The performance of fibre reinforced concrete increases with the performance of the concrete matrix; the volume of fibres in the mix and the intrinsic performance of the fibre in the matrix (geometry, aspect ratio (l/d), method of anchoring, tensile strength, E modulus etc).

Therefore clear test procedures and performance criteria of the FRC should be specified for each project. T&T

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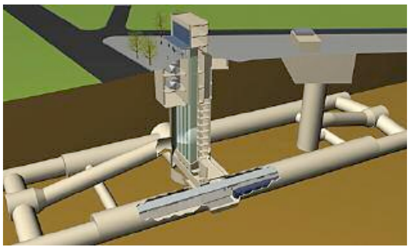
A solid grounding

In order to improve ground conditions for underground structures contractors are increasingly combining technologies for maximum effectiveness. Maurice Jones checks on some of the latest applications



Above: **Schematic of the Beacon Hill Station excavations, Seattle [Photo: Hatch Mott MacDonald**

One of the most significant projects of recent years in terms of ground improvement under difficult conditions has been the Beacon Hill station and tunnels for the Seattle Sound Transit's Link light rail project between central Seattle and Sea-Tac Airport. The project was short-listed for the international category of the British Construction Industry Association Awards this month, and employs what its engineers term a 'tool-box' of ground improvement and support measures to successfully tackle very difficult ground at depth.

The platform level is some 50m below the hill surface and the 46,000m^3 excavation took place in challenging, soft and mixed, glacial and fluvio-glacial deposits, which often required ground improvement.

Methods used included jet grouting and vacuum-assisted deep dewatering wells for general ground improvement, plus a range of sequential excavation method (SEM) toolbox items, some of which can be regarded as ground stabilisation or consolidation. These included barrel vault canopies, grouted pipe and rebar spiling, chemical grouting and, again, vacuum dewatering.

For most projects including Beacon Hill, there is a question of how to balance the expense of site investigation against the value of foreseeing possible expense due to remediation of ground problems and delays to construction. Clearly the greater the variability in ground conditions, such as in the glacial deposits of the Beacon Hill project, the more site investigation is desirable, whether before or during tunnelling.

Even when there is considerable knowledge of ground conditions, there are still differences in philosophy between those who believe the ground should be treated mainly before excavation, generally by grouting, and those who rely mainly on support selection during tunnelling, such as in observational methods.

Above: **Beacon Hill Station's concourse excavation with grouting pipes in the crown.**

Depending on the circumstances both may be run on the same project, and both will be aided by careful planning and supervision but especially during tunnel excavation. This is mainly because timing and sequence become important factors in success or failure, as investigations into major tunnelling collapses have shown.

Such was the uncertainty of the ground conditions for the Seattle Beacon Hill project, combined with pressure on the schedule for completion that additional geotechnical investigations and ground improvement were made from the surface during construction.

The Beacon Hill station and tunnels project is a major example of selecting the most appropriate ground improvement techniques and combining them to reduce risk and accelerate the project programme.

Although open excavation underground, such as at Beacon Hill, is the most likely method to need ground improvement, even closed face TBM tunnelling may benefit from ground stabilisation and consolidation, perhaps to reduce ground pressures on the TBM, to make the ground easier to excavate, or to improve steering characteristics.

Grouting

Grouting is one of the most commonly used solutions and there are a wide variety of methods available, the selection of which can depend on the grain size of the ground to be treated; presence of fractures; flow and pressure of groundwater; support required for underground excavation and adjacent structures; the importance of subsidence reduction and cost.

The simplest means is permeation grouting, also known as cement or slurry grouting. The grout can be a slurry, usually cementitious, or a liquid ('chemical') grout for greater penetration and possible interaction with groundwater. The groundwater-control function of grouting can be aided by groundwater lowering (see below) to reduce the groundwater pressure on the grouted ground and/or to reduce flows and lessen the chances of grout wash-out/leaching.

The most successful applications of slurry grouting include void filling, gravels and openly fractured rock such as caused by blasting overbreak or faulting. The mix ingredients, in addition to cement and water, can include clays, sand, fly ash, lime and any necessary additives such as retardants. The water-cement mix ratio, the injection pressure and particle size will all affect the success and extent of penetration.

As with more advanced grouting methods, instrumentation including computerised control and monitoring can be an important element of a successful operation.

Grouting at higher pressures can be used to produce different effects in the ground being treated, such as prevention of subsidence during excavation by compensating for ground movement caused by the excavation. Injection is between the excavation and overlying structures, or a slab-like structure is created within the ground above the excavation by injecting grout into a defined location, again compensating for possible future ground movement. As such the method can be particularly important in tunnelling under sensitive areas such as urban structures and manufacturing facilities. Since compensation has to be a precise operation, not least in calculating the amount of grout needed to compensate for millimetres of subsidence, careful control is very important. The grouting control system will best be initiated by automatic instrument monitoring of subsidence and other ground movements to keep deformations within specified limits.

Bachy-Soletanche's compensation grouting system integrates several monitoring and control programmes starting with the Enpasol drilling parameters recorder to establish where the grouting holes are, this is then inputted into the Castaur fan grouting design program. This design, together with results of ground monitoring through the Smacs parameters measuring system, are fed into the Sphinx grouting operations monitoring system and Compensation Grouting Numerical Advance Control (COGNAC). The results from these systems are used to control the grouting plant through the Sinnus computerised system.

Above: **Moretrench installation of dewatering wells at Beacon Hill with dual rotary drilling**

Keller group, one of the leading practitioners and developers of grouting systems calls the compensation grouting process Soilfrac.

Jet grouting is one of the most effective means of tackling unconsolidated deposits, especially if waterlogged and so has major applications in tunnelling. In such deposits it can be a more economical, and permanent, alternative to ground freezing and compressed air, and can also compare favourably with traditional grouting and deep slurry trenching and piling. It works by mixing the soft in situ material with jetted in cementitious grout to create 'soilcrete' columns.

Although the process is comparatively quick, a major drawback in urban applications is the surface access required, as the large rigs usually required for jet grouting could present a problem if access is restricted. However, recent development of small, containerised systems that are easily mobilised means that work can start on the day of set-up, with equivalent rapid demobilisation and overall cost savings.

There are three traditional forms of jet-grouting – single-jet, double-jet and triple-jet. Any can be used in any application providing operational parameters are adjusted to the ground conditions. Since the jets erode the soil for mixing with the cementitious mix, cohesionless soils are most suitable, especially with single-jet rigs, since they are easier to erode. In the double-jet system air and fluid are supplied to two different, concentric nozzles to increase erosion and mixing efficiency.

An enhancement of jet grouting developed by the Keller Group over the past eight years is SuperJet. This is a modified double-fluid-jet system with improved tooling and higher energy input to create large-diameter (3-5m) 'soilcrete' elements of mixed ground and grout. Keller Group company Hayward Baker, which has used the process in large projects in the USA, says that it is best applied for bottom seals, such as in cut-and-cover and shaft base layers, or to 'surgical' treatment applications. It may not be necessary to completely seal the base layer if the process is used in conjunction with groundwater control.

In Hayward Baker's first application, for the Brigantine Connector cut-and-cover tunnel in Atlantic City, SuperJet grouting in 4m diameter columns was used to form wales along the base of sheet piles as part of the wall structure, and also to form compression struts to support the wales at 10m centres.

Geotechnical drill-rig specialist Klemm of the Bauer Group produces a variety of rigs for both underground and surface use and including a 74.5kW, 11.1t model, the KR 401-2, especially suited to jet grouting. The jet grouting controller system MBS3 is a programmable recording and control unit for everyday work, but which can be adapted to customer requirements to include a range of diagnosis and setting possibilities.

Groundwater control

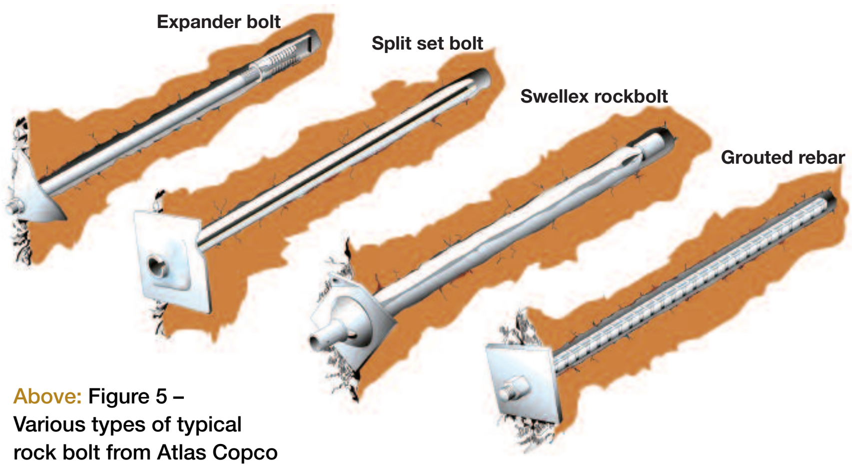
Alongside grouting groundwater control can be critical to ground stabilisation. Apart from limiting the flow of water into excavations, various groundwater control techniques can be used to prevent the movement of fines that would otherwise change the ground's geotechnical characteristics and possibly cause collapses. Groundwater lowering is a relatively simple, temporary alternative to cut-off techniques such as grouting, diaphragm walls, contiguous piling and ground freezing. The first use of wellpointing in North America, by the founder of Moretrench, Thomas Moore in 1925, was undertaken to consolidate fluid sands in a sewer construction trenching operation.

The three basic types of dewatering systems are ejectors, wellpointing and deep wells, selected depending on the ground permeability and drawdown required. Ejectors, or vacuum dewatering, are used mainly in less permeable materials such as fine soils, with drawdown to 50m.

Raked boreholes can be used to reach under surface features such as transport routes. A vacuum is created in the base of the hole by a nozzle and venturi fed by high-pressure water from the surface. This draws in groundwater that is passed to the surface with the feed water. One pumping station can operate around 75 wells.

Wellpointing systems, single- or 2-stage, are for shallower drawdowns (6m for single-stage to 10m for 2-stage) over wide areas. They are also suited to gravels as well as sands and silts. The wellpoints are connected to a common header-main and then to the vacuum pump that can handle up to 50 wellpoints.

Above: Image 4 - A wellhead for deep well dewatering used on the Channel Tunnel Rail Link phase 2



Above: Figure 5 – Various types of typical rock bolt from Atlas Copco

Pumped recharging of the aquifer, behind cut-offs, can be employed to protect structures such as timber piling, which can be adversely affected by the main dewatering system.

Deep-well systems are effective in a wide range of ground conditions and for considerable drawdowns limited only by the hole depth, pump performance and aquifer response. They employ multi-stage submersible pumps in the boreholes. When used to stabilise granular soils the hole is fitted with a liner and filter to support the hole whilst allowing water ingress. The pumps are controlled from a central console on the surface.

Moretrench assisted the Beacon Hill Station project engineers in redesigning and installing a deep-well system to stabilise and drain granular deposits before excavation. Due to the complicated geology surrounding the test shaft, inadequate dewatering of non-cohesive granular soils was discovered despite wellpoints and other drainage methods. Sand lenses could flow under groundwater pressure heads of only a foot. An initial array of 26 base and 12 optional vacuum-assisted deep wells was laid out. Several aquifer pumping tests were performed to evaluate the hydrogeology of granular soils and whether these should be dewatered or grouted (jet grouting or chemical injection). Due to the results of the shaft investigations the array of wells was expanded with another 21 wells around the whole station 'footprint'. Extra exploratory borings also found an unexpected sand lens at the station West Longitudinal Ventilation Adit and a full face of sand on the East Damper Chamber horizon. The new wells were located through high-pressure sand layers, and vacuum applied to each wellhead.

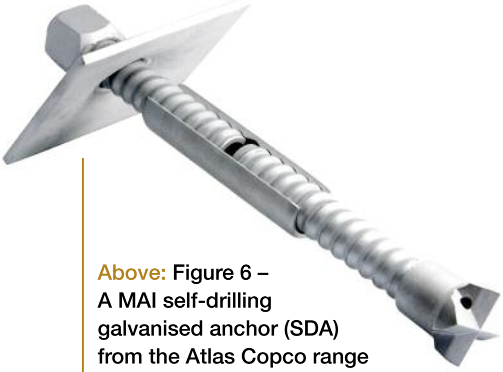
WJ Groundwater designed and operated a deep-well dewatering system to treat sand bands within boulder clay over limestone for the Dublin Port Tunnel. One of the sectors treated was a 100m x 40m area for a railway underpass constructed using a pipe-arch structure. Other structures aided by dewatering were a 50m-diameer shaft, 30m deep; and a tunnel approach structure 300m long, 22m wide and 15-20m deep. WJ also produces computer models for the design and operation of groundwater control systems.

Strong elements

Of course structural elements also have a place in ground stabilisation. The use of multiple structural elements, chiefly made of rebar steel or wood spiles, inserted from within the tunnel to strengthen the ground has a long history. Purpose-designed rock-bolts of various types are chiefly to support the tunnel crown or walls, although self-drilling forms have also been used to stabilise the tunnel face. In recent years new materials, principally glassfibre-reinforce resin plastic (grp), have become more common for reinforcement used in the face and invert.

Spiling can be effective not only in a structurally weak rock mass but also in soft ground to deter deformation. The spiles are normally placed in pre-drilled holes and fully grouted in place without tensioning. Sireg's patented Durglass-FL elements are commonly used by drilling from the face to the later excavation zone, but they can also be used for radial insertion from a pilot tunnel and for consolidation of the tunnel profile in fan patterns.

Hollow-bar grouted spiles from the Dywidag Systems International range were used by main contractor Nishimatsu Construction to help secure broken limestone for the TBM launch chamber of the Dublin Port Tunnel. These were installed by either simultaneous drilling and grouting, or by water-flush drilling followed by grout injection through the hollow. Grouting



Above: Figure 6 – A MAI self-drilling galvanised anchor (SDA) from the Atlas Copco range

Above: Image 7 - Sireg drainage pipes with slots used to dewater soft soil around a tunnel excavation to prevent ground degradation

increased the structural support locally in the crown of the chamber.

The Omega –Bolt from DSI Alwag is one of the latest in a variety of expansion profile friction bolts for ground strengthening. The Omega, so called because of the shape of its section before hydraulic expansion, is intended mainly for temporary rock reinforcement in tunnels and mines, and is available in three minimum load ratings: 120, 160 and 240kN. It provides full load capacity over the complete bolt length once expanded with the bonding force promoted by the bolt expansions and friction transfer with the borehole wall. As an expansion device it is suitable for different and viable hole diameters. It was used in the Mato Forte Tunnel on the A10 motorway for BRISA in Portugal to the north of Lisbon. 6m lengths of Omega-Bolt were used in marl and limestone strata and installed with equipment rented from DSI Portugal.

MAI self-drilling anchors (SDAs) from the Atlas Copco geotechnical range have been used to stabilise poor ground in the face of the Mitholz Tunnel and others. The standard steel product is also available galvanised for use in corrosive ground. Since agreement on global co-operation with Minova International of the Orica Group at the end of last year the two companies are now able to offer a wider range of bolting systems including the Wiborex Bolt and Lokset resin cartridges.

SDAs can be used as mini-piles but these are used chiefly in supports for surface structures. One of the latest designs from Sireg is glass-fibre piles in diameters of 200-1500mm used in tunnel construction in Spain and other countries. Over 60,000m total length of these piles have been used for a tunnel in Spain's high-speed rail programme, chiefly for insertion into the invert in place of steel as they are corrosion–resistant in the presence of the sulphates found in the ground.

Creating a cantilever arch within the ground ahead of the tunnel face before it is excavated is another method commonly used. Depending on the method used this can be regarded as stabilising the ground that might otherwise collapse on being opened up, and could also form part of the permanent support. The methods range from crude forepoling with girders or pipes, through grouting in an arch or fan patterns, to the formation of a continuous arch structure by inserting interlocking pipes by drilling or microtunnelling, or by inserting a concrete arch in a slot excavated ahead of the face.

The last method employs a rig such as Bachy Soletanche's horizontal pre-trenching rig to cut a slot to a pre-defined arch profile. Concrete is then pumped inside the slot to cure and form a supportive arch. This method can be of particular use in forming portals in unconsolidated ground.

Cut-and-cover methods

Various forms of piling and diaphragm walling are common for the vertical or near-vertical sides of cut-and-cover tunnels, but where a larger 'footprint' space is available, tunnel portal slopes can be stabilised with soil nailing, anchoring, geosynthetics, etc.

As diaphragm wall trenches are excavated using slurry, it applies pressure to walls, thus supporting the ground around the planned excavation. As this can be carried out below the water table, groundwater control may not be necessary, depending on the pressures involved. Once excavation of the wall panel is complete, a reinforcement cage will be lowered into the slurry, and then concrete is placed in a continuous pour using tremie pipes to replace the slurry, which can then be recovered for later panels.

Whilst diaphragm walls are normally excavated in discontinuous panels, each 2.5-6.0m long, with vertical pipes for end support, a method variation excavates a continuous panel using self-hardening cement-bentonite slurry with retardant additive and then a pre-cast concrete panel is lowered into the trench.

Bachy Soletanche has been using a wide array of geotechnical rigs for diaphragm walling and piling to construction both north and south approaches of the submerged section of the new Tyne Tunnel in north-east England. On the north side diaphragm walling was used immediately, but on the south side 320 CFA (Continuous Flight Auger) piles were installed in diameters of 300-1000mm. Both form the main elements of retaining walls for some 1.1 km of cut-and-cover tunnel.

The variety of rigs were necessitated by the variations in soil types and structures near to the River Tyne, and were sourced largely from the Bachy Soletanche fleets in France and Spain. Rig types include rope grabs, hydraulic grabs, a hydrofraise mill and a geotechnical drill rig. The ground materials on the piled southern approaches include clay, mudstone, sandstone and made ground. In total the 1.2m-thick diaphragm walling for both approaches totalled 51 000m^3 in volume. T&T

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Cracking the problem – part 2

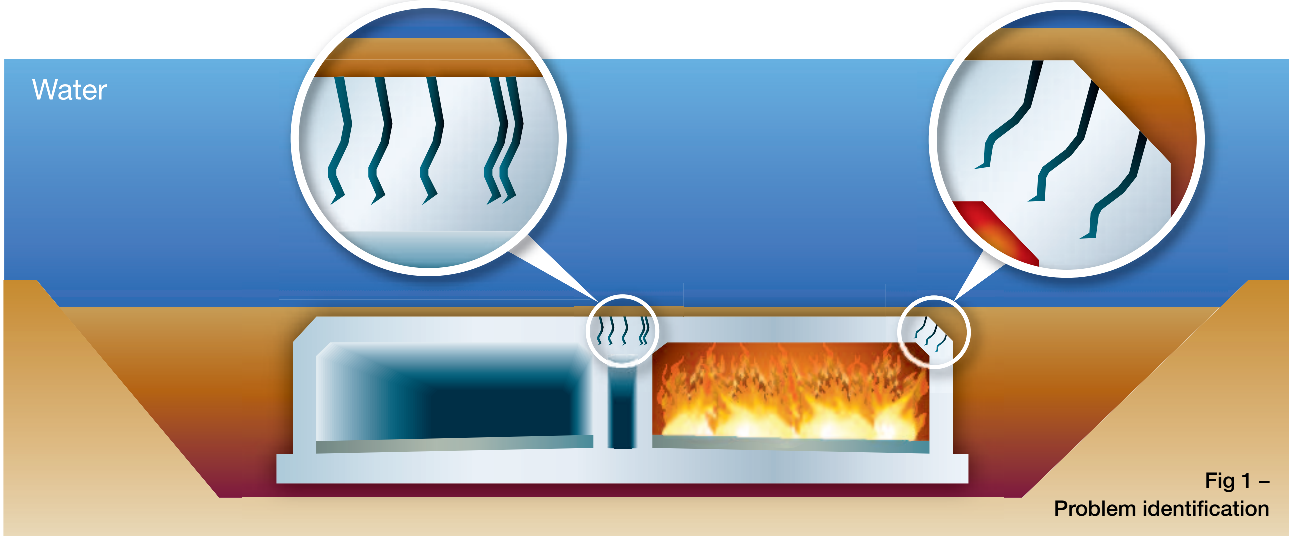


Fig 1 – Problem identification

C. Both, A.J. Breunese and P.G. Scholten of Efectis Nederland present the second part of an analysis of the fire behaviour of immersed tunnels

In the second of two consecutive articles, the results of a study into the fire behaviour of concrete immersed tunnels are presented. In this second article, computer simulations are discussed and final conclusions and recommendations presented. The results of the study are relevant not only for the industry involved in designing and construction of tunnels, but also for owners and AHJs with interest and responsibility for adequate fire safety assessments of immersed concrete tunnels. Full reports can be downloaded from the Efectis website www.efectis.nl, under the heading "news".

In the first article, published in an earlier issue of T&T, the results of initial research and the scale 1:10 fire tests were presented. The main findings were that typical crack patterns occur with three main cracks developing above the internal support and near the connections between walls and roof at the unexposed side. These cracks develop in width up to 1-2 mm, and clearly pose a high risk with respect to the durability of the concrete and especially the reinforcement at the unheated side and the shear resistance of the cross sections near the roof/wall connections. Although this may not lead to loss of structural integrity during fire, it may consequently lead to unexpected failure either shortly or long after the fire.

Computer modelling

The numerical analyses were based on a DIANA 9.3 model of the cross section of an immersed tunnel, using a random triangular mesh of continuum elements. This was done to avoid preference of crack development linked to the orientation of the mesh elements. Refer to Figure 2.

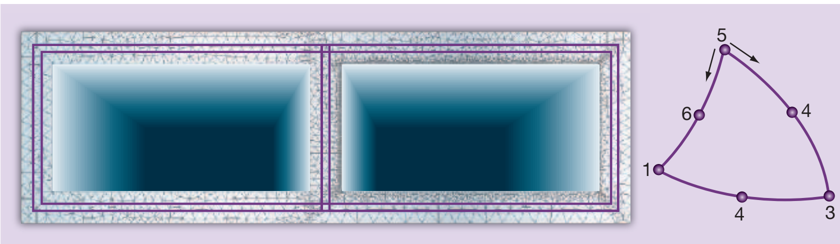
$$u_1 - a_0 + a_1\zeta + a_2\eta + a_1\zeta\eta + a_1\zeta^2 + a_1\eta^2$$

Simulation of fire tests

The model was validated by calculating the tested situations of the scaled tunnel segments. Typical results are plotted in Figure 3.

Calculations using this finite element simulation show that cracking on the unheated side is a realistic phenomenon that may manifest itself during a fire in an immersed tunnel. Although certain simplifications have been made while

Below: Fig 2 – Finite element mesh and used triangular 6 node elements, including interpolation function for displacements (ui) along the boundary of the element.



modelling, a comparison with fire tests shows that the model has a good predictive value for the behaviour of these specimens. Although only a limited number of tests were performed, it seems reasonable to assume that the model also has a good predictive value for a full size tunnel.

Relevance of cracks

The relevance of the crack development was further studied, using a simulation of a real tunnel (cross section). See also Figure 4.

The main results of these simulations is that serious crack widths on the unheated side will be reached during a fire, up to 1.8mm after 40 minutes for an unprotected tunnel. As natural fires will typically have a longer duration than 40 minutes, the resulting crack widths will evidently be even larger. In addition to a large crack in the roof adjacent to the middle wall, there will also be smaller cracks in the roof adjacent to the side wall (of the heated tube), and in the side wall just below the roof.

Avoiding crack development and limiting crack width

To this end, a limited and tentative explorative parameter study was carried out. This investigated the level of insulation (thickness); tensile strength of concrete (although not a design parameter); reinforcement level and for comparison reasons the compressive strength of concrete.

In general there are two ways of avoiding these cracks. Firstly, the crack initiation can be delayed by applying insulation (which reduces the temperatures to which the concrete is exposed), or by increasing the tensile strength. However the latter is a less feasible option for actual tunnels, and in principle not really a design option. Secondly, one can accept that cracks will develop, but keep their size within acceptable limits, which can be achieved using (additional) reinforcement. As with any other concrete construction, the size of cracks can be limited by increasing the reinforcement area on the side of the cracks. As this pertains to the unheated side, there are no temperature effects here.

In Figures 5 and 6 the results of the parameter study are plotted in terms of the time until the first main crack above the internal support is initiated as a function of the parameter varied. However, the realisation that cracking may occur on the unheated side if this is not actively prevented is only a partial conclusion, as long as the question of how damaging such a crack might be is not yet addressed.

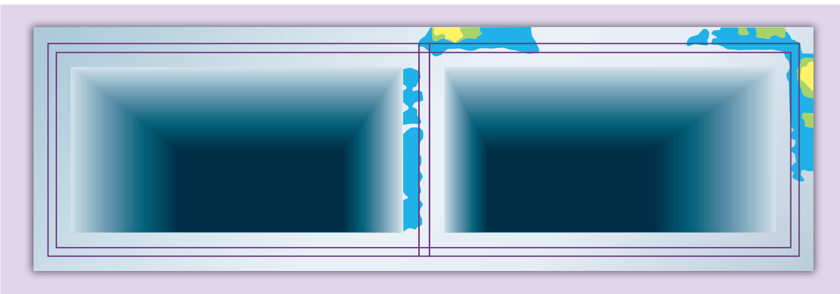
The structural integrity of the tunnel is not directly threatened by the occurrence of the cracks; even with crack widths as large as 1.8mm the sag will be limited to 10 mm in the middle of the span, which is well within acceptable limits. The durability of the heated region of the tunnel will be reduced during the crack, as the strength and stiffness of both the concrete and the reinforcing steel will decrease due to the high temperatures, and will not return upon cooling. However, this is a general risk associated with fire that has already been extensively described in other studies.

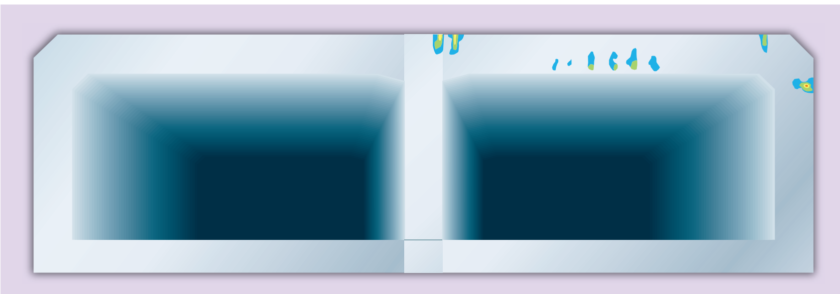
One particular structural aspect that is noticeably influenced by these cracks is the shear capacity at the location of the cracks. As cracks cannot transmit shear stresses, the shear capacity is reduced at the locations of the cracks, which coincide with the locations of the largest shear stresses. If shear reinforcement is applied this is not likely to become a problem, but it is important to keep the possibility of cracking on the unheated side in mind when designing shear reinforcement and chamfers in an immersed tunnel.

Beside this, it would seem that the main danger stemming from these cracks is a long-term one: the risk of corrosion of the reinforcement. How imminent this risk is, however, would be difficult to predict, as long as the cooling down phase is not analysed. The standard material models in DIANA do not facilitate the modelling of the cooling down phase, but with a user-supplied material model, this problem has been solved.

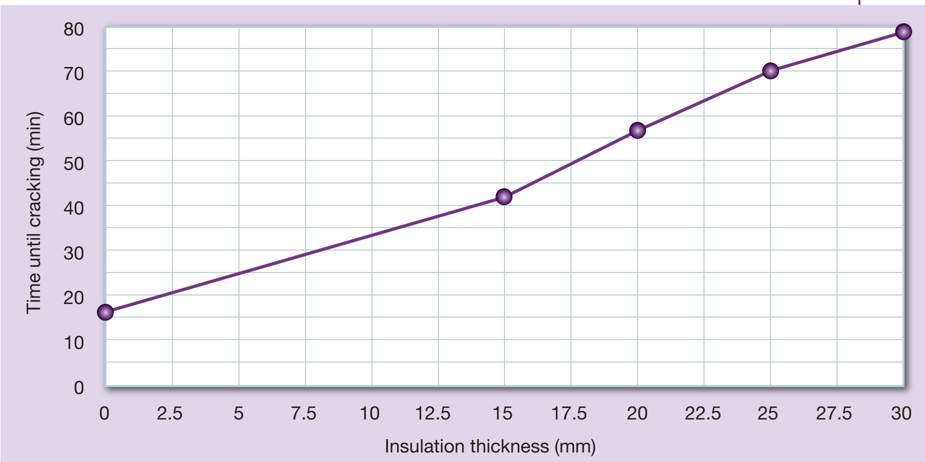
It is unknown if the crack width will increase or decrease during cooling down. The available material models are unsuitable to simulate this. Nevertheless, a justified question is whether a crack of 1.8mm width might fill up with debris or sand grains and therefore become unable to slightly close during cooling. Moreover, the calculated crack width of 1.8mm occurs after 40 minutes. For numerical reasons it was not possible to continue the calculation for longer fire durations, but it is expected that the crack width will increase. Even with fires of less extreme temperature or durations of less than 40 minutes, it is still possible that the cracks are there; the simulations show that the crack emerges at 17 minutes and starts to open up after 20-30 minutes of exposure to the RWS fire curve. When applying fire protection, the time of the onset of the crack can be delayed significantly. The simulations show that when a typical fire protection of 27.5 mm thick board is used, the crack will occur only after approximately 75 minutes (see Figure 5).

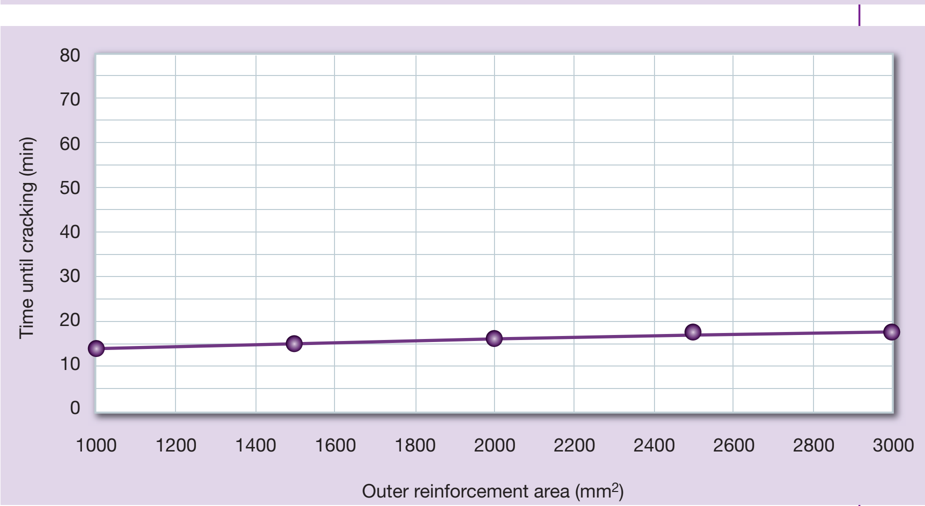
The rate at which the crack widens increases when applying fire protection to the concrete. Assuming a fire duration of 120 minutes, this means that the unprotected crack will open up during about 100 minutes, whereas using 27.5mm board protection, the crack will open up during only 45 minutes but at a slightly higher rate. The model did not include the effect of PP-fibres, because this would require material models that would explicitly take into account moisture content and flow. However, the reduction of the crack width which was observed on the small scale tunnel segments may also have to do





Below, top: Figure 3 Simulation of the fire tests on scale 1:10 models;
Below, bottom: Figure 4 Simulation of real tunnel (cross section).





Above, top: **Figure 5 – Influence of insulation level on cracking initiation.**
Above, bottom: **Figure 6 – Influence of reinforcement level on cracking initiation.**

with the increase of ductility of the concrete. Such a ductile behaviour could be caused by fibres bridging the developing crack. However, with a crack width as large as 1.8 mm it is unsure if the "anti-spalling" type of polypropylene fibres would be able to bridge the crack and significantly contribute to the ductility of the concrete.

Cold side cracks are likely to occur during a fire. These cracks cannot be seen from the inside of the tunnel, but they will extend all the way to the outer surface of the tunnel roof (or wall). Even though the deflection of the tunnel roof remains invisibly small, the width of the cracks will be significant. Given this information, the following questions must be answered:

Is it a problem if cold side cracking occurs in a tunnel roof during a fire?
- Is the shear capacity of a tunnel roof after a fire still sufficient?
- Is the durability of the tunnel roof after a fire still sufficiently guaranteed?

And if it is concluded that there is a problem,
- Can the cracks be detected and repaired with sufficient reliability?
- Or is it worthwhile to take measures to prevent the cold side cracking?

The location of the cracks is exactly where the shear forces are at their highest. Nevertheless, even a cracked cross section can still accommodate some shear force provided that there is sufficient reinforcement. It is recommended for tunnel owners to assess their tunnels with regard to shear resistance assuming a cracked cross section.

The crack width of 1.8 mm will leave the reinforcement directly exposed to the external environment. This means that ground water, or possibly sea water, will affect the reinforcement. As the shear capacity is strongly reduced, the reinforcement becomes even more important, so it is a possibility that after time the tunnel roof collapses.

Injecting the cracks with a resin may be an option, but when the exact locations of the cracks are unknown this is not an easy task. Moreover, quality control of the injection is virtually impossible because the proper filling of the crack can only be observed from the outside of the tunnel.

Finally it is interesting to notice that: crack initiation can hardly be avoided, even with extreme large insulation levels and the level of reinforcement seems to only slightly positively influence the crack initiation (of course crack widths can be easily controlled with additional reinforcement).

Conclusions

The main conclusions of the study are:
- The 1:10 scale fire tests and the numerical modelling confirm the development of large cracks with large crack widths (up to several mm), at the unexposed (extrados) side, pertaining also after cooling down
- The parametric study suggested that the addition of (polypropylene) fibres is not an adequate means to prevent or mitigate the problem
- For existing tunnels, preventive measures such as passive insulation of the concrete or equivalent measures may need to be (re)considered
- As to whether or not for new tunnels the addition of reinforcement is adequate and cost-efficient (as compared to the as aforementioned options), is a subject for further study
- The issue is expected to become manifest also for other types of tunnels or construction techniques (e.g. cut-and cover tunnels)
- Further study into the durability aspects and influence on shear resistance of such large cracks is recommended, as well as a study into the adequacy of existing, or the development of new, repair techniques for such cracks T&T

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Dates & Events

NOVEMBER
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. Contact: Email: secretary@iom3.org.hk

4-5 NOVEMBER
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

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

01-03 DECEMBER
STUVA TAGUNG'09 Hamburg, Germany
Every two years the STUVA conference takes place with various topics from the fields of underground construction. The conferences draws some 1,500 tunnelling experts from more than 30 different countries. An exhibition accompanies the event. Contact: STUVA: email: info@stuva.de web: www.stuva.de

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

17-19 MARCH 2010
ISTSS 2010 Frankfurt, Germany
The 4th International Symposium on Tunnel Safety and Security. Manuscript abstracts should be submitted to the Secretariat by 01 June 2009, poster abstracts by the 01 October 2009. Contact: Anders Lönnermark, SP Technical Research Institute of Sweden; tel: +46 10 516 56 91; email: anders.lonnermark@sp.se; web: www.sp.se

19-25 APRIL 2010
Bauma 2010, Munich, Germany
The 29th International Trade Fair for Construction Machinery, Building Material Machines, Mining Machines, Construction Vehiclesand Construction Equipment will be held in the Messe Muenchen Messegelaende 81823, Munich, Germany. Contact: email: info@bauma.de; phone: +49 89 949 11348; fax: +49 89 949 11349; Web: www.bauma.de

2-7 MAY 2010
North American Society for Trenchless Technology No-Dig 2010, Chicago, USA
The 2010 NASTT No-Dig show will be held at the Renaissance Schaumburg Hotel and Convention Center, Chicago. The conference theme is "Rebuilding North America's Underground Infrastructure Using Trenchless Technology" and will include infrastructure investment; social costs and impacts; industry trends, advancements and new concepts. Contact: NASTT; web: www.nodigshow.com

14-20 MAY 2010
2010 ITA World Tunnel Congress, Vancouver, Canada
Not long after the 2010 Winter Olympics, the International Tunnelling Association (ITA) visits the spectacular city of Vancouver, British Columbia, for its yearly conference and exhibition. The usual combination of working groups, open sessions and technical talks will all be included. Contact: web: www.wtc2010.org

8-10 JUNE 2010
InterTunnel 2010 Turin, Italy
Tunnelling exhibition aimed specifically at clients, contractors and consultants involved in the construction of and equipping and operation of tunnels. Contact: Mack Brooks Exhibitions; web: www.intertunnel.com

9-11 JUNE 2010
Swiss Tunnel Congress, Lucerne, Switzerland
Tunnelling developments in the Apls will doubtless be a talking point at the Swiss Tunnelling Society's STC. The event will be held at the KKL Lucerne. Contact: fgu@thomibraem.ch web: www.swisstunnel.ch

14=16 JUNE 2010
International Conference Underground Construction Prague 2010 Transport and City Tunnels
The Czech ITA-AITES Tunnelling Association will host its 11th International Conference at the Clarion Congress Hotel Prague. Lectures will be simultaneously interpreted into English, German and Czech.
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email: ita-aites@metrostav.cz;
web: www.ita-aites.cz

BRITISH TUNNELLING SOCIETY

19 NOV: **The Belfast Sewers Project**
The Belfast Sewers Project comprises 9.6km of tunnels from 1.5m to 4m in diameter at depths ranging from 10m to 30m. It aim to ease flooding and polution in the city. The project is discussed by Alan Skates, Atkins; W Gowdy, Northern Ireland Water and Paul Ronicle, MorganEst/Farrans. 6pm start at the ICE.

10 DEC: **Debate by BTS Young Members Group**
Chaired by Kate Cooksey, chair of the BTS YMG. 6pm start at the ICE.

15-17 JUNE 2010
European Rock Mechanics Symposium (EUROCK 2010)
Eurock 2010 is an ISRM Regional Symposium of Europe. The Symposium covers all the aspects of rock mechanics and rock engineering, from theoretical research to engineering practice, with emphasis on applications to natural hazards prevention, infrastructural construction and sustainable development.
Contact: Jean-Paul Dudt,
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fax: +41 21 693 41 53; email: lmr@epfl.ch;
web: www.lmr.epfl.ch

19-23 JUNE 2010
North American Tunneling Conference, Portland USA
The 2010 NAT will be held at the Marriott Downtown Waterfront Hotel in Portland, Oregon. Conference and exhibition information and registration is available on the SME web site. Contact: Society for Mining, Metallurgy and Exploration (SME); web: www.smenet.org.

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition that is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site: Editor, 'Tunnels & Tunnelling International', John Carpenter House, 7 Carmelite Street, London, EC4Y 0BS, United Kingdom.
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