MAY 2010

tunnels & tunnelling INTERNATIONAL

Special report: Northern Europe

T&TI looks at the challenging jobs in Northern Europe including the work on Sweden's Hallandsas tunnel

Technical: Waterproofing

T&TI reviews the latest developments in wateproofing techniques

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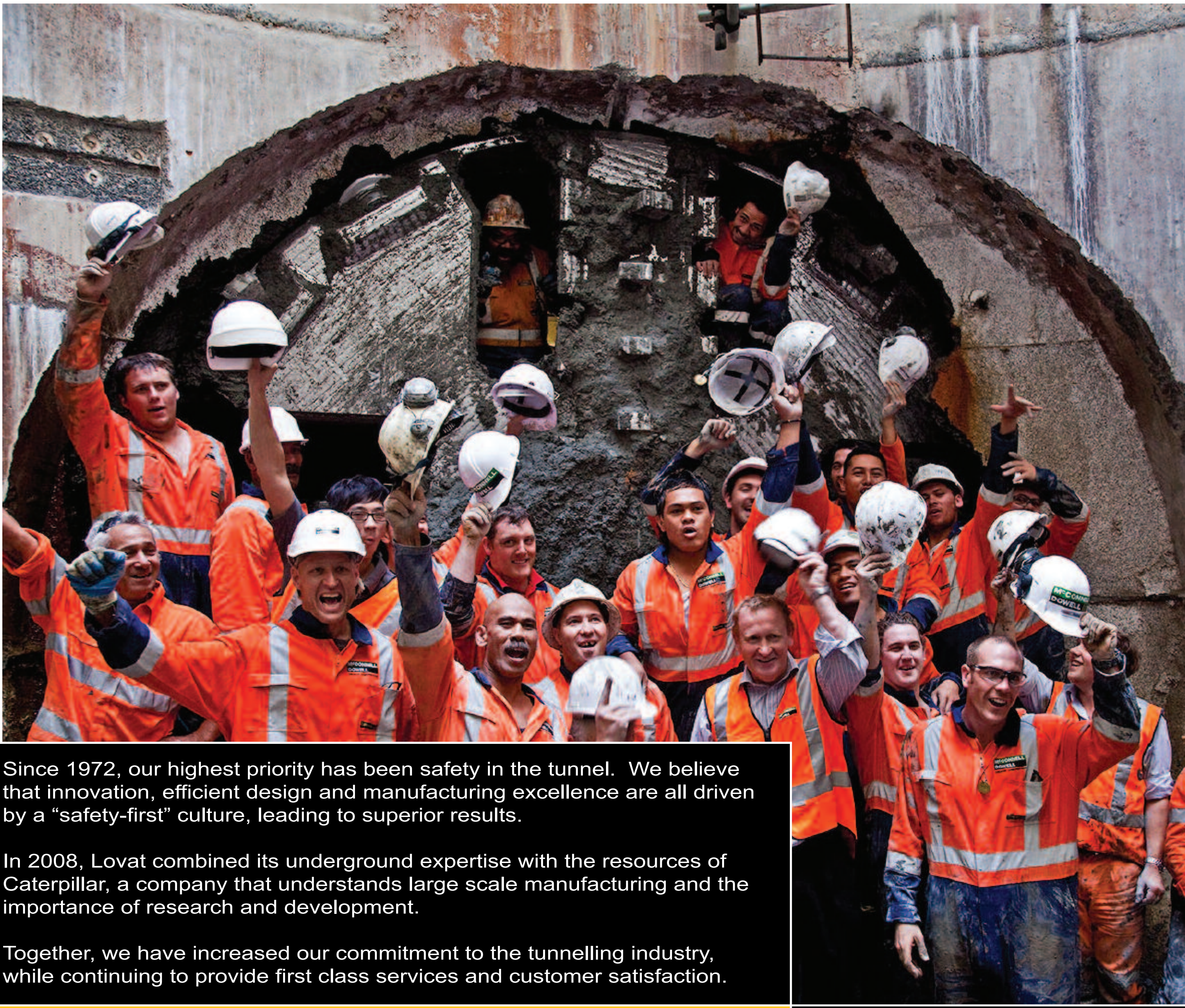
Protecting Gotthard's Road Tunnel

Sprayed waterproofing is overcoming salt corrosion

TUNNEL WITH CONFIDENCE START TO FINISH...



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T&TI looks at waterproofing efforts on the Gotthard road tunnel (page 47)

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T&TNA looks at the busy east coast and gives the latest on North America

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T&T gives a global project review in this World Tunnel Congress supplement

comment

It's all in the timing

At the December meeting of the BTS a diagram was displayed showing the pattern of work in the tunnelling business over the past few decades. The purpose of the diagram was to demonstrate that tunnelling in the UK and overseas does not often come when the industry needs it (*T&TI* March, page 37).

The UK tunnelling industry – and it is certainly not alone in this – sees severe peaks and troughs. A good example is the long break between the end of the Tyne & Wear Metro, the Fleet Line, the Second Dartford Crossing and the Liverpool Link/Loop in the late 1970s and the start of the Mersey Sewers, the Channel Tunnel and the Thames Water Ring Main in the late 1980s.

The lag between workloads is incredibly damaging to the industry. Companies cannot retain skills if they don't have a project to bill them to. Tunnelling experts have to look to other engineering sectors or look to overseas projects – in this case there was a stopgap in the Hong Kong metro.

But surely there is a better way?

When Joseph Bazalgette was building London's sewers in the late 19th Century he was part of a Metropolitan Board of Works. The Board was the principal instrument of London-wide government from 1855 to 1889. Its principal responsibility was to provide infrastructure to cope with London's rapid growth. This made it a single client for all London infrastructure projects and therefore arguably able to manage resources much more efficiently than the system we have now where multiple clients effectively bid against each other for the best team and lowest price.

A return to state built infrastructure is probably a dream. But perhaps there is scope for a system that brings the benefits of a single client to the system we currently suffer under.

Could the BTS develop a Tunnelling Board of Clients, which shares details on project demands and scheduling? And could the International Tunnelling Association (ITA) take it a step further and create an International Board of Clients made up of the chairman of each regional Client Board to better schedule works.

The benefits of a well-established system of cooperation would surely have a positive impact on the entire industry. The skills shortages that threaten so many projects would be eased.

More construction companies will get involved in tunnelling if they can see there is a steady and reliable flow of work. And ultimately, could the cost of tunnelling be reduced making it compete better with alternatives?

Perhaps this is something for the new BTS chairman and the new ITA presidents to take up.

Jon Young

News from T&TNA

Miami orders TBM
A USD 45M TBM for the 1.2km Port of Miami tunnel was ordered from Herrenknecht last month. When complete in 2014 the tunnel will link the port for the first time to area motorways in a bid to speed cargo traffic and ease traffic congestion in the centre of Miami.

WI wraps tunnel up
Construction of Milwaukee Metropolitan Sewerage District (MMSD) 3.2km extension of the deep tunnels was completed last month adding 123M litres of wastewater storage capacity to the underground system.

Alaskan Way contracts
Bids were submitted last month for contracts on the Alaskan Way Viaduct Replacement Tunnel in Seattle. The first contracts should be awarded this month.

Marmaray Tunnel reaches halfway mark

TURKEY

Some 50 per cent of the undersea tunnel that will link the European and Asian sides of Istanbul is now complete, Turkish transportation minister Binali Yildirim announced last month.

The Marmaray project, which runs under the Bosphorus Strait, arrived at this half-way point with the integration of the Yavuz Tunnel, running from Uskudar train station.

Yildirim told reporters at a ceremony held to officially integrate the tunnels, that 50 per cent of the tunnels, measuring a total of 13.6km, 1.4km of which are underwater, had been completed in the project.

The owner is DLH, the General Directorate of railways, harbours and airports construction, under the Turkish transport ministry. Construction is being carried out by a joint venture of Japanese contractor Taisei Corporation and

Turkish company Gama-Nurol.

Completion is scheduled for October 2013, and once complete the Marmaray Tunnel will be the world's deepest undersea immersed tube tunnel. The name 'Marmaray' (Marmarail) comes from combining the name of the Sea of Marmara, which lies just south of the project site, with 'ray', the Turkish word for 'rail'.

The Marmaray Project will upgrade the commuter rail system in Istanbul, connecting Halkali on the European side with Gebze on the Asian side with an uninterrupted, high-capacity commuter rail system. The entire upgraded and new railway system will be approximately 76km long.

Prime minister Recep Tayyip Erdogan laid the foundation for the Marmaray line on 9 May, 2004.

Tunnel starts on Xi'an Metro Line 1

CHINA

The first TBM was launched late last month for Line 1 of the Xi'an Metro, China. Two 6.2m diameter Robbins EPBs will excavate Lot 12 of Xi'an Metro's Line 1, boring under the 3,100 year old city. The first of the two was assembled in Chengdu in March and launced on April 28.

The machines will excavate parallel 2.3km tunnels, and will pass through four cut and cover stations stretching from Kangfu Road to Chang Lepo areas.

The two TBMs will be the first to start excavation on Line 1, and will be followed by eight other machines excavating their respective lots.

The geology includes sand, pebbles and clay with significant ground water. Spoke-type cutterheads and 800mm diameter shaft-type screw conveyors will aid in TBM advance while maintaining a watertight seal and balanced pressure.

China Railway 11th Engineering Bureau Group Limited signed a total supply contract with Robbins in June 2009.

The line will pass nearby a number of ancient structures, including a bell tower and city wall dating back to the 12th century. Due to the sensitive area, city regulations stipulate a maximum of 15mm surface extrusion or settlement on tunneling projects. Subsidence and vibration will be carefully monitored throughout excavation to avoid any structural disturbances.

Once complete, the 26.4km metro Line 1 will travel from north to south through downtown areas of the city. Line 2 of the Xi'an metro is currently under construction and will be operational in 2011. Three more lines are planned for excavation in the next five to seven years.

Three vie for ITA President

INTERNATIONAL

Three candidates are seeking support prior to the elections for International Tunnelling Association (ITA) president to take over from Martin Knights at the General Assembly in Vancouver this month. All are currently vice-presidents of the ITA. They are:

Prof Eivind Grøv (Norway): President of the Norwegian Tunnelling Society (NFF) and research manager for rock engineering. Director of SINTEF Byggforsk Geologi og bergtechnikk (Rock Engineering), Trondheim, the largest independent research organisation in Scandinavia. In candidature statements Prof Grøv emphasises the expectations of ITA members to see greater benefits from the activities of the Association, as disseminating technical information from working groups to tunnelling sites is a key activity. He has likened the planning the future of the ITA and the tunnelling industry to planning for unforeseeable ground conditions during tunnelling, with being prepared a great help.

Yann Leblais (France): Global director infrastructure, Arcadis Corporate, Arnhem, The Netherlands and Le Plessis, France. He says the ITA is to connect people, knowledge and projects in order to develop our industry and to serve the tunnelling family worldwide, in real life conditions. He points out we are facing huge changes in the market with a tremendous increase of activities in Asia and India, meaning high levels of accumulated knowledge created there. There are also large opportunities in Russia, the Middle East, South America, the US and Africa, while Europe is still active he says. This means big changes in the information and business flow, with a reverse flows starting to develop compared to the West-to-East and North-to-South of the past.

Prof In-Mo Lee (Korea): School of Civil, Environmental and Architectural Engineering, Korea University, Seoul. Bidding to become the first ITA president from the Asian Region, he emphasises harmony in leading the ITA and that now is the time the ITA has to diversify its world, including harmony between the western and eastern, harmony between the aged and the young, and harmony between the active and the newly joined member nations. Prof Lee has spent five years in the US where he gained his higher degrees (MS and PhD in geotechnical engineering from Ohio State University). He has published more than 200 papers in journals and at conferences. His main underground research area is in geomechanics including seepage force, face stability, predicting ground conditions and blasting-induced damage.

In addition to the election for president there are also four vice-presidential candidates, and nine candidates for six vacant Executive Committee places. At the General Assembly there will also be a decision of the host nation for the 2013 World Tunnel Congress and ITA General Assembly between Greece and Switzerland.

HS2 anger

GREAT BRITAIN

London residents have expressed concerns over plans to build a high-speed rail tunnel under their homes. Transport secretary Lord Adonis announced plans in March for High Speed Two, a rail link taking trains from London to Birmingham and Scotland at up to 400km/h.

Councillors in Primrose Hill, one of London's wealthiest areas, fear that vibrations from trains will cause structural damage to homes and noise disturbance.

According to plans, 300 council flats on the Regent's Park estate will be demolished to make way for the line that is scheduled to be built from 2017.

The tunnel will go underground close to Delancy Street in Camden, and below homes in Primrose Hill, Swiss Cottage and Maida Vale.

At its deepest, the proposed track will run 43.4m below ground. (See in depth article p15)

Volcano fallout revives tunnel talks

FINLAND-ESTONIA

A recent transport collapse in Europe caused by a cloud of volcanic ash inspired a renewed interest in construction of a railway tunnel between Helsinki and Tallinn, the project which implementation was suspended several years ago due to its high costs.

Olli-Pekka Hilmola, a well-known Finnish professor from the Technical University of Lappeenranta, said that, taking into account the regular strikes of workers of sea ports and possible natural disasters, both sides should revive an idea of tunnel's construction.

According to Estonian media reports, the authorities of both cities are also still interested in the tunnel project.

The construction of the tunnel could be partly funded by the European Union as part of the Rail Baltica project, which would link the Baltic states with Poland by rail.

According to local experts' calculations, the cost of the tunnel project may exceed EEK 100bn (EUR 7bn).

They also said that the length of the tunnel, depending on the route, should be at least 60-80km, 50-70km of which will pass undersea.

Moreover, in order to serve the tunnel, there is a need to build an artificial island with the area of 6 hectares, where wind turbines to power the tunnel will be placed. The estimated deadline for the tunnel construction is 10-15 years

One of the major weaknesses of the project is the lack of medium-term predictions regarding with expected freight traffic of the future tunnel. The Mayor of Helsinki Jussi Pajunen backs the tunnel as part Rail Baltica.

Some local experts also believe that it will be more reasonable to implement an alternative of the project and to connect both cities by ferry.

For comparison, the construction of the Channel Tunnel between France and UK with a length of 50km, cost investors in the project more than GBP 4.6 bn.

News in brief

Thieves tunnel into vaults
Robbers in Paris tunnelled into the vaults of two high street banks last month. The first robbery was a success but second was interrupted before the robbers could finish.

Shell seeks Mayo tunnel
Oil firm Shell will apply for permission to lay a EUR 100M (USD 133M), 5km, 3.5m diameter pipeline under the seabed off the Mayo coast in the Republic of Ireland to get gas from the Corrib field.

Algeria contact awarded
Spanish construciton firm FCC Construccion has been awarded a contract to build a 185km railway line just west of Algiers in Algeria. NATM will be used to build five tunnels on the line. The contract is worth some EUR 1bn (USD 1.3bn)

Rains lead to road tunnel disruption

BRAZIL

Heavy rains caused major problems for residents and travellers in Brazil last month. Among the hardest hit areas was the city of Niteroi, where 67 deaths were recorded until 7 April.

Resultant floods led to the obstruction of traffic through some tunnels in the hills surrounding Rio de Janeiro, whilst scheduled maintenance work was suspended in others so that drivers could be released from cut-off areas to go to their destinations.

On 6 April access to the Noel Rosa Avenida Marechal Rondon tunnel in the Sampaio neighbourhood was banned after a hillside fell as slime, closing the route to Vila Isabel. Access to the Cosme Tunnel Rebouças and was banned and a landslide near Joah Tunnel on the Lagoa-Barra highway towards Barr de Tijuca caused flooding allowing only the middle lane to be used.

Earlier, works on the Tunnel Zuzu Angel, as part of the PAC (neighbourhood Growth Acceleration Programme) in Rocinha, were cancelled by CET-Rio, the municipal transport company, so that stranded motorists could use it in both directions. PAC is responsible for slope retention and infrastructure works, including sewerage, in designated areas.

Emergency redirection work was carried out by CET-Rio with 750 personnel of CET-Rio and the Municipal Guard on site.

At the time of writing more heavy rain was forecast and more landslides expected.

Left: The mudslides have left parts of Brazil devastated

Repair work starts on Malad tunnel

INDIA

Repair work began last month on the 12km Malad water tunnel in Mumbai, two months after it was closed. Hindustan Construction Company (HCC) quoted an estimate of INR 5 crore (USD 1.1M) for the work.

The Malad tunnel, 76m deep, had been leaking five million litres of water a day since it was damaged in February after two men were caught illegally digging a bore well (T&TI, March, p8).

As per the plan, the hydraulic department will de-water the tunnel to facilitate repairs. Closed circuit cameras will be used to survey the extent of the damage. To stop water from seeping out from the borehole accidentally created on the tunnel during the illegal bore well digging, the HCC team will then use internal expanding packers.

During the work, which could last a month, an old pipeline will continue to supply water to the region.

Patong residents demand tunnel

THAILAND

Some 100 people paraded through Patong Beach in Thailand last month waving signs saying, "We need the tunnel." The protest came before a public meeting about whether a tunnel should be excavated through Patong Hill to link Patong and Phuket City.

About 500 people gathered for the meeting held as part of the THB 40M (USD 1.2M) feasibility study for the tunnel. The tunnel could cost as much as THB 2.4bn (USD 74M).

The meeting heard six variations of a tunnel route, and that research will take about 20 months, having begun last year. In some of the plans, the tunnel runs for 2km, while the entire route of the project could be as long as 3.25km. Construction would take three years.

The governor of Phuket Wichai Praisangob and Phuket's regional director of the Tourism Authority of Thailand Bangornrat Shinaprayoon attended the meeting. Mayor of Patong Pian Keesin is a keen supporter of the tunnel and has used the tunnel as a major part of his re-election campaign.

Supporters of the tunnel idea argued that the current winding route over Patong Hill is too dangerous. Opponents claimed that a crash in the tunnel was a higher risk.

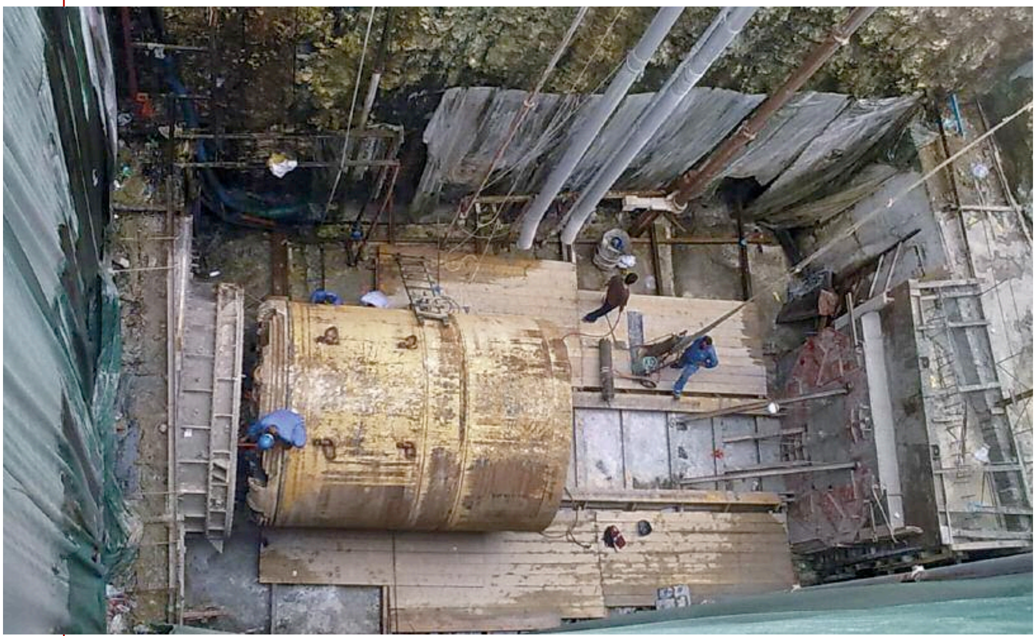
News in brief

Bauma survives flight ban
Despite temporary closure of European airspace due to volcanic ash, the 2010 Bauma tradeshow saw more than 415,000 visitors from 200 some different countries, with 50 overseas exhibitors unable to attend.

Manila aims for June finish
Manila's presidential office has assured Cebuanos that the Cebu South Tunnel project will be completed before President Arroyo hands over power to the next president on June 30.

China completes bore
Excavation work was last month completed on China's 7.8km Qingdao's Jiaozhou Bay Undersea Tunnel. It is only the second undersea tunnel constructed in China.

Breakthrough in Doha



Left: Contractors are nearing the end of the storwater tunnel bore in Doha, Qatar

QATAR

Contractors from the local Combined Group Contracting Company are about to finish boring a total of 4,250m of stormwater tunnels in Doha, Qatar. The Herrenknecht M-1198M microtunnelling machine of the type AVN2400AB, is eating through the fine to medium grain limestone creating a network of collection tunnels with a 3,625mm internal diameter. The TBM is being followed by pipe jacking of 3m internal diameter reinforced concrete pipe sections, each with a length of 3m and a wall thickness of 600mm. Cutting tools on the Herrenknecht machine are being changed using an airlock system under air pressure for the first time in the Middle East.

Following completion of the collection network a second phase will get underway, to create a 9.5km long pipeline that will transfer this water from the city to a pumping station at New Doha International Airport.

From the NDIA pumping station the water will outfall into the Arabian Gulf. The stormwater system is will absorb the heavy rainwater which can fall between December and April. Although average precipitation is only 100mm per annum, it tends to be concentrated and torrential. Client for the project is Ashghal.

Other Gulf states such as the UAE and Saudi Arabia are also looking at increasing their own stormwater storage capacity. The general increase in tunnelling in the region has led Herrenknecht to establish a UAE manufacturing business "Herrenknecht Tunnel-Boring International LLC" with a local partner Aabar investments.

Shetland tunnel in doubt

GREAT BRITAIN

Shetland Island Council (SIC) officials last month slammed plans for a tunnel linking the Island of Whalsay to the mainland. Councillors said it would be too expensive and the idea should be abandoned in favour of building a new ferry terminal (*T&TI* December 2009, page 8).

SIC's head of finance Graham Johnston and head of transport Michael Craigie presented two reports to councillors, revealing that the basic capital cost of a fixed link would be between GBP 76M and 83M (USD 117.2M and 128M),

Some GBP 23 to 28M (USD 35.4M to 43.2M) more than for the ferry service.

The report also said it would take at least eight years to develop and build the tunnel, which would have to be 6.3km rather than the 5.5km first thought, when the estimated remaining lifespan of the existing terminal at Symbister is just five years.

Members of the council's infrastructure committee will discuss the findings and the recommendations at a special meeting as *T&TI* went to press, followed immediately by a meeting of the full Council to ratify any decision they might reach.

Northern Link gets government backing

AUSTRALIA

Brisbane's 7km Northern Link tunnel was given state approval last month, opening the door for work to begin later this year. The cost of the tunnel is an estimated AUD 1.7bn (USD 1.5bn).

Bids to build the toll road will close later this month. The Brisbane City Council (BCC), State and Federal Governments are funding the infrastructure project jointly.

BCC is proposing to build the twin-tunnel underground toll road linking the Centenary Motorway at Toowong to the Inner City Bypass at Herston.

Authorities said it will not require the resumption of any houses and will be subject to 34 environmental conditions.

The Queensland Government has spent more than two years doing environmental checks and has taken hundreds of public submissions.

Construction is expected to start by the end of the year. Brisbane Lord Mayor Campbell Newman told local media the commonwealth will contribute AUD 500M (USD 451.2M) and the rest will be borrowed from the State Treasury Corporation, and that it should be paid back using the tolls.

Normet acquires share in Tam

COMPANY

Normet Group has aquired a 40 per cent share in Tam International and will begin to sell construction chemicals to complement the company's concrete spraying equipment. Normet will represent Tam products in areas where Tam is not yet active and, in return, Tam will act as agent and distributor of Normet equipment and services in the UK, Hong Kong, Taiwan and ASEAN.

Normet supplies underground tunneling and concrete spraying services, while Tam is a construction chemicals manufacturer and distributor. Normet, strengthened by its shareholding, will form a close working partnership with Tam and create a broader offering around the tunneling process. This will also enable Normet to cut cost.

Normet chairman Aaro Cantell said "the addition of underground construction chemicals to Normet's range of mechanised underground equipment is a logical step in our path to becoming the world's leading expert in selected underground construction processes such as concrete spraying".

Tom Melbye, COO of Normet Group and managing director of Normet International added, "we have had great results with Tam from our recent co-operation in Hong Kong and Taiwan. This partnership will strengthen Normet's position in underground construction and mining."

Above: **Normet will sell Tam underground construction chemicals**

Victor Bellanti, CEO of Norman Hay plc commented: "This is a strategic alliance which will considerably strengthen both companies. The partnership will bring together the consumable construction chemicals of TAM with the international manufacture and distribution of Normet's application hardware. Both companies share a common global marketplace in construction solutions for waterproofing, injection and repair of structures together with major constructions projects in civil engineering, tunneling and mining".

News in brief

HATS Haggloaders
GIA will supply three of its compact Haggloader 7HR-B digging arm loaders to contractor Leighton-LNS JV for use on the HATS sewage conveyance system in Hong Kong.

Motorway bids for June
Bids open for Norway's E6 motorway contract including the 1.195km Kaejfjord tunnel and 680m-long Skjaeholmen tunnel. Deadline is 10 June.

Norway metro bids
Tenders invited for ground works on construction stage 2 of Bergen City Line, comprising 3.6km of twin track, two tunnels of total length 850m, two bridges and associated works.

Paris orbital contract
Sonovision has been awarded the contract for the design of central monitoring systems and road traffic control equipment in eight tunnels more than 300m-long on the Paris orbital motorway, France.

Radius, Senaat reach deal
Plastic pipe systems manufacturer Radius Systems has struck a joint venture agreement with Abu Dhabi-based Senaat Group.

PB appoints Richard Schrader chairman

COMPANY

Parsons Brinckerhoff (PB) last month announced Richard Schrader will become chairman of the company, succeeding Keith Hawksworth, who is retiring after 33 years with the company.

Schrader is currently executive vice president and chief financial officer (CFO). In his new role, he will also undertake additional duties in service of the broader Balfour Beatty Group.

PB president and chief executive officer (CEO) George Pierson said, "I look forward to having Rich as a partner in guiding PB going forward. I will continue to rely on Rich's extensive expertise in financial management and will look to him for assistance in determining PB's strategic direction."

PB has now begun an executive search process for a CFO to succeed Schrader, who has been with PB for 27 years and has been a member of the company's board of directors since 1992.

Prior to joining PB in 1983 Schrader served on active military duty in the U.S. Army Corps of Engineers for 11 years with assignments on military construction projects, including command of an engineer company in Germany. He has also served on the faculty of the United States Military Academy at West Point as Assistant Professor in the Department of Social Sciences. He has a bachelor's degree from West Point, a master's degree from The Johns Hopkins University School of Advanced International Studies and an MBA from Long Island University.

Above: **Richard Schrader was appointed chairman**

Hawksworth, who joined PB in 1976, served as CEO from December 2007 through December 2009 and during that time led a strategic planning process that resulted in PB's October 2009 merger with Balfour Beatty,

The PB Board will consist of George Pierson, PB's CEO; Ashok Kothari and Schrader.

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TBMs for Guadalquivir highway

HIGHWAY

NFM Technologies signed two contracts for two EPBMs earlier this month. The contracts were signed with two Spanish groups, OHL/Sando/Azvi and Copisa/Aldesa/Bruesa for the company Sociedad Estatal de Infraestructuras del Transporte Terrestre (SEITT).

The machines will be used in the construction of a 2180m tunnel, part of a new ring road, the SE-40, in Seville. The tunnel will run under the Guadalquivir river.

The contracts, worth around EUR 450M (USD 602.9M) provide for the design, manufacture and on site assembly and dismantling of the TBMs, as well as assistance during the operational phase. Manufacture of the TBMs will mainly be carried out at NFM's Le Creusot plants in France and is scheduled to finish in February 2011.

The TBMs will each dig two 1900m long tubes under the Guadalquivir, in terrain principally composed of sand, gravel and marl. The machines will be designed to withstand a pressure of five bars and make hyperbaric interventions easier. They will comprise four independent injection systems, with the aim of ensuring better control of earth pressure under the river – bentonite, limestone load, foam and polymer.

Kublis Bypass Tunnel contract awarded

HIGHWAY

The contract for the Kublis Bypass Tunnel in Switzerland was awarded last month. The CHF 85M (USD 80.7M) contract went to Strabag. The contract for the 2.2km highway tunnel in the Gaubunden Canton includes construction of the safety gallery and the management of the Schanielatobel disposal site neighbouring the bypass.

Construction will begin in June this year and is expected to be completed in November 2015.

"The Kublis Tunnel is not the only project in Switzerland in which Strabag's tunnelling competence is needed. Strabag was also involved in the Uetliberg Tunnel, which was completed in 2006, and the Gotthard Base Tunnel, which is to be put into operation in 2017," said Strabag chief executive officer Hans Peter Haselsteiner.

The bypass is part of National Route A28 Landquart-Klosters and will serve to relieve the traffic in the town of Kublis.

Seli and Kawaski sign five-year partnership

COMPANY

Italian tunnelling company Seli has signed a five-year collaboration agreement with Japanese company Kawasaki Heavy Industries. Seli and Kawasaki will combine resources and experience on engineering, manufacturing, field service and TBM operation. The agreement also covers developing new technologies and servicing the operation of TBMs.

The agreement will focus on EPBMs from subway tunnel diameter to super-large diameter as the two groups claimed EPBs that be in most demand over the coming years, especially in European countries and North/Latin America countries.

Kawasaki developed their EPB technology more than 30 years ago, while Seli developed their double shield TBM more than 40 years ago.

A Seli spokeswoman said the two companies' plan, through the agreement, is to increase their share in the TBM production market and be stronger in competing worldwide with the other major TBM manufacturers.

Seli's new factory in Aprilia, Italy will support the increased number of orders.

World bank approves Sao Paulo loan

Funding for the Sao Paulo metro will build an access tunnel

METRO

The World Bank last month approved a USD 130M loan to support the Second Phase of the Sao Paulo Metro Line 4 that will include a 1.5km access tunnel.

The project loan will help complete four stations initiated during Phase 1 (São Paulo-Morumbi, Fradique Coutinho, Oscar Freire and Higienopolis-Mackenzie), build one new station at Vila Sonia plus its access tunnel, build additional facilities at the Vila Sonia yard, and acquire and install the necessary systems to make these stations operational.

Once the second phase is completed in 2013, Line 4 is expected to increase the number of São Paulo Metro passengers per day by over one million, to a total of 4.8 million. Line 4 is expected to carry some 70,000 passengers a day by the end of this year, when Phase 1 will be operating with all of its first six stations.

This is the latest in a string of operations on São Paulo's metro system that has included the first phase of the Metro Line 4 (USD 304M total loans), the Trains and Signalling Project (USD 550M), the Integrated Urban Transport Project (USD 45M) and the recently approved Metro Line 5 Project (USD 650M).

The project, which aims to help the city improve its public transport network, ease congestion and protect the environment, will link key employment and service areas of the city and reduce travel times by building a new station and 1.5 km of access tunnel.

This is a USD 130M, USD denominated International Bank for Reconstruction and Development (IBRD) flexible loan with variable spread option, commitment-linked with all the conversion options repayable in 30 years with 5 years grace period. Since the first loan in 1952, the World Bank has invested approximately USD 4.8bn in São Paulo, including this latest loan.

No fuss.
Just drilling

The Sandvik DTi tunneling jumbos are designed with user comfort and successful operations in mind. Together with the iSURE tunnel management program, their intelligent but easy-to-use operation system and advanced features offer an unbeatably accurate drilling result. Whenever a challenging tunneling job is at hand, turn to the Sandvik DTi jumbos. They guarantee that there will be no fuss. Just drilling. With precise results. And happy operators.

SANDVIK

HIGH SPEED TWO

HS2 tunnels

Tunnels may look like they feature little on the recently unveiled route map of the UK's next high speed rail project – High Speed Two – from London to Birmingham with spurs for further extensions. But those stretches of twin tube, clustered at the southern end of the 207km long line, would call for major excavations.

The line is the preferred route of the government's own project developer, High Speed Two, or HS2, and is referred to as "Route 3". It would run from London Euston to the West Midlands, initially, and the net present value cost to build the infrastructure for the line is estimated to be almost GBP 18bn (USD 28bn) at 2009 prices.

Two major sections of tunnels are planned:

- the first section would extend approximately 7.1km from Euston to a new box station west of Paddington, and then about 1km beyond to a portal at North Acton. The box would be used to launch TBMs in opposite directions to drive the twin 7.25m i.d. tunnels through soft ground. Cross passages would be built at 250m intervals, and three intermediate intervention shafts are envisaged;
- the second section of tunnel would run west for approximately 9.6km from the M25 to just beyond Amersham, emerging short of the Chiltern Hills. The twin tunnels would be larger – 8.5m i.d. – as trains would be well into journeys and travelling faster (320km/h) than in the city (225km/h) with consequently larger kinematic envelopes requiring more space to accommodate the movement.

Beyond that point, the line would run mostly on the surface to Birmingham with no intermediate stations and a few relatively short tunnels, principally: the 1km long Little Missenden tunnel, which would be a 9.8m i.d. single bore, double track tube; and, the Long Itchington Wood bore which would be 12.8m i.d. and 1.4km long.

There is a third possible major tunnel – a 46km long near-continuous loop that would run to Heathrow airport from the main alignment and rejoin farther north. However, it is seen as a significant additional enterprise with tunnelling costs estimated at more than £1.5bn (USD 2.2bn).

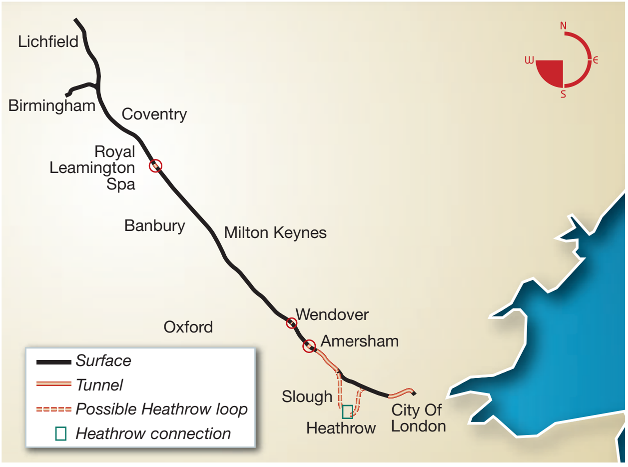
London – nodes, links

The new line is to be served by an entirely new, major underground station in London, at Old Oak Common, west of Paddington. Rail depots are currently on the site.

Nominally earmarked as the "Crossrail Interchange", the 850m long box station would be the main hub for high-speed lines into London, hooking them into the capital's transport system, High Speed One and also Heathrow – irrespective of whether a loop tunnel ever gets built.

Other possible tunnel works being considered for London include a fast rail link for High Speed Two to High Speed One, but cost is a major barrier. The study by HS2 Ltd estimated that a dedicated link would cost GBP 3.5bn (USD 5.4bn) and have to extend from Old Oak Common to the east of the city, only joining High Speed One in Barking, Essex.

Cheaper alternatives, therefore, are continuing to be examined for a possible link between the high-speed lines. Options include using an existing, but relatively slow, rail line in north London.



Above: HS2 will run, initially, from London to Birmingham

Another alternative is to have no rail link but instead have passengers decanting to use a "rapid transit system" between the Euston and St Pancras stations almost rubbing shoulders as they would serve as termini from High Speed Two and High Speed One, respectively.

High-speed rail vision

New high-speed rail plans for the UK were published by the Government for consultation on the strategic initiative beginning in the third quarter, though now the general election since called for 6 May could interrupt that objective.

Despite a long history in rail, the UK's first step into high-speed rail was only completed in 2007 with a 109km long line – High Speed One – from the Channel Tunnel to St Pancras station, in London. The line first brought the introduction of fast, direct international train services to Paris and Brussels, while also affording easier passenger access to transfer to other, high-speed rail services in mainland Europe.

More recently, domestic high-speed trains have been introduced in Kent to use the line.

Visions for a further high-speed rail line have been discussed since the first was in planning, but moves to explore possibilities were made in the last three years first by Arup in its independent study of how the infrastructure might extend across north London in a 24km long stretch of twin tube tunnel towards Heathrow. In that vision the airport would become the prime hub for future high-speed lines to the rest of the country.

Informed by the Arup study, the Government established HS2 almost a year and a half ago. Now, the backbone of a future network is seen as a line running from London to Manchester and Leeds via Birmingham, and connecting to the West and East Coast Main Lines near Preston and York, respectively, for an estimated cost of GBP 30bn (USD 45bn).

But the first step is the link to Birmingham, and HS2 was to develop a costed and deliverable proposal. The findings were submitted at the end of last year to government which then issued the report in March, along with its own 'Command Paper' giving the wider, national vision that it wants to consult on.

Meanwhile, HS2 will build on the momentum to study taking the high-speed line to Manchester and Leeds, and the work is to be finished by mid 2011.

The construction schedule for the first leg, to Birmingham, is pencilled for after Crossrail, which opens 2017-18. The new high-speed lines could be opened in phases from 2026.

Patrick Reynolds

Tunnelling out

For the past two years the British tunnelling industry has been eagerly looking forward to a boom in tunnelling works with the prospect of in excess of GBP 20bn (USD 30bn) of work planned over the next 10 years. As I prepare to hand over the Chairmanship of the BTS the anticipation and the excitement within the industry is building to a peak, together with a nervousness regarding the economic climate, the general election and potential delays.

Looking back over the past two years there have been a number of significant positive developments making the industry better prepared to deliver these significant projects. The BTS has been working hard to fulfil the aims and objects of the Society: "... to promote the art and science of tunnelling, including the creation and use of underground space by fostering understanding, experience, interest and research.

In particular the younger BTS members have come to the forefront with the BTS Young Members Committee showing that there is a core of young, dedicated and enthusiastic tunnelling engineers ready not only to design and build tunnels, but also to volunteer their time to promote tunnelling to the younger generation, to set up a "History of Tunnelling" lecture series and to attract new blood into the industry and the Society.

The December BTS meeting "Tunnelling into the Future" was organised by the Young Members Group to debate whether the UK tunnelling industry has a sufficient range of engineering expertise and resources to meet the challenges of future projects. The vote narrowly agreed that the expertise and resources were available.

There is no doubt that significant strides have and are being made to develop the necessary skills and produce best practice guidance.

The BTS together with TunnelSkills and the Crossrail Academy are working together to ensure there are sufficient suitably qualified and experienced engineers and a suitably skilled and trained workforce.

The BTS Tunnel Design and Construction Course has been updated and expanded to include a new module on sustainability.

The BTS Health and Safety Course first held in 2008 has proved to be very popular and has been significantly developed and extended to run for two days.

A one year MSc in tunnelling is being developed with Warwick University to fill the gap for tunnelling engineers.

The BTS Tunnelling Specification has recently been updated and re-issued. Best practice guidance on monitoring for underground excavations is just about to be published.

The amount of tunnelling work will undoubtedly stretch the tunnelling capability within the UK. However with the building blocks we have already put in place together with the dedication, resourcefulness and enthusiasm of the tunnelling fraternity I'm sure the industry can rise to the challenge.

We will need a willingness to develop the necessary skills, to make existing skills and resources go further, and to deliver efficient and innovative solutions. We undoubtedly will need some support from our European colleagues, but nevertheless I'm confident that these major schemes can be effectively and efficiently delivered.

I would like to thank all the BTS membership, particularly the hard working members of the committee, for your support and commitment over the past two years. The fact that the BTS is so successful, well-attended, and sociable is entirely down to you.

In particular I would like to thank Bob Ibell for his support as Vice Chairman over the past two years and wish him well as he prepares to take over the leadership of the Society.

Paul Hoyland

Digging in

What an inspirational time to take over Chairman of the British Tunnelling Society; rarely has there been such a workload for tunnellers, bringing with it new challenges, new improvements and new issues.

What an opportunity we have to bring new younger people into the industry, to give them a new skill, or better still, a set of skills that will allow them to have a good working life. Does it sound naive? Should it really be dumped in the 'too difficult' basket and we try all to muddle through like we always have? If we do, I suspect we will find that we will have lost a little bit more of our wealth creation ability and have even less of our tunnelling capability at the end of the current projects.

We have read a lot recently about the cost of projects in the UK. We are told we are too expensive and that it is done more economically abroad. I believe our tunnelling costs stand up to scrutiny. If you compare the CTRL costs per km with other costs per km around the developed world, they compare well. Can I say the same for the whole project costs – I am not sure. We do seem to specify 'gold plate' finishes, we do seem to have the wrong ratio between those doing and those watching and our projects seem to have layer upon layer of bureaucracy sometimes resulting in confusion and slow decision making.

Some of us thought, I expect, when we completed the CTRL and Heathrow Terminal 5 that the industry had cracked it – found out how to deliver projects on time and within budget. Have we learnt the lessons of CTRL and Terminal 5, what to do and what not to do? I believe we in the tunnelling side have learnt the technical lessons, I think our industry is better at doing that than many other industries, but as for the cost and risk management lessons I remain to be convinced.

This is a shame because it is in all our interests to keep costs down, improve competence across the board and deliver projects to time and on budget. Perhaps, of course, the problem is what we do with budgets, but that is another even murkier area. I do think that some time spent in trying to understand the overall costs of projects and produce a comparison that means something might be a worthy task.

As chairman of the BTS I hope to spearhead developments in how we share and pass on knowledge and expertise, how we learn from our mistakes, in short whether our improvement processes are sufficient and whether they are effective. I would also like to have more involvement from our industry clients and I would like to have more debate. Debating has always been a good way to learn and hear the other side of the argument; so much debate is conducted in sound bites and press headlines today instead of what engineers should do in arguing developed logic supported by technical information.

Bob Ibell

Starting Fall 2010, the University of Texas of Austin will offer an on-line Certificate in Tunneling directed to engineers or engineering geologists with an MS and BS in Civil Engineering, Engineering Geology or Mining Engineering who want to obtain a working knowledge of tunnel design or construction management by applying the fundamentals acquired in their BS and MS degrees (and possible professional experience). The program has received provisional endorsement by the International Tunneling and Underground Space Association (ITA); as such, it is the third program endorsed by the ITA at the international level after the Polytechnic of Turin and University of Lausanne (EPFL).

With few engineering programs offering even a course in tunneling, it is very likely that young engineers are not exposed to tunneling; many owners and agencies built their last tunnel 20-30 years ago, and they lost their tunneling expertise. The Certificate is a concrete opportunity to acquire working knowledge through a rigorous and well-structured learning experience beyond the nomenclature that can be acquired at short courses. The on-line offering allows engineers to keep working on their current assignment and to attend lectures at any time of the day. Over 40 homework assignments are reviewed and graded to allow students to effectively master the material. Over 40 seminars from industry leaders drill deep into specific topics and enrich the program with relevant examples and case histories; a multi-choice questionnaire is provided at the end of each seminar. An internship at a construction site rounds off the program and provides the opportunity to experience hands-on construction aspects, nuisances and rewards that cannot be conveyed otherwise.
www.ce.utexas.edu/prof/tonon

Heading South

Peter South has been involved in tunnelling for more than forty years. During this time he has worked on several major infrastructure projects both at home and abroad, and chaired the British Tunnelling Society.

"My career began in 1968 when I was still a student working on the Victoria Line with the Mitchell Brothers," he explains. Last year he was appointed Head of Tunnelling at Laing O'Rourke. During this journey, he has worked for a who's who of UK engineering firms including Mowlem, Nuttall, Balfour Beatty and AMEC.

"Some of the most notable projects I've been a part of are Cairo Wastewater, where I was with Lilley Misr International and I was also one of the main construction people on the Channel Tunnel planning and developing the initial marshall tunnels under Shakespear Cliff, procuring and constructing the seaward running tunnelling machines and bedding them in on their drive towards France," he remembers. "I became head of tunnelling for AMEC after we completed the Westminster to Waterloo section of the Jubilee Line, a position I held for some seven years. Then I spent about 18 months at Jacobs doing some very interesting consultancy work, before coming to head up Laing O'Rourke's tunnelling."

With Laing O'Rourke's involvement in several major consortiums, Peter's position at the company is an exciting one, especially as until his appointment, there was no specific tunnelling division in the company. There are currently seven key people on his team, a number which will increase as their workload develops. "I'm heading up their international tunnelling efforts from here, we're currently tendering some major work in Australia, as well as looking elsewhere in Hong Kong and the world."

Peter found it hard to resist the lure of a new role with Laing O'Rourke. "It was the sheer dogged determination of Laing O'Rourke and the senior people who interviewed me to develop the world I love that brought me to this job," he explains. "Tunnelling is something that I can't do without, it got in my head and it's stuck. So anybody that's going to put the passion behind what I believe in gets my vote. So I'm here!" he laughs.

"We believe that we can achieve what we say we want to do in Laing O'Rourke, and I know the next twelve months will be when we see the huge benefits of what we're doing and we'll be a major force," he says.

One of the JVs Laing O'Rourke is part of is with Bouygues and Strabag. "The Laing O'Rourke/Bouygues/Strabag joint venture is huge in experience and, we're probably one of the robust consortiums going for Crossrail at the moment."

Of all the places that Peter has worked, London remains his favourite. "I like London due to the familiarity. I'm proud to be a London engineer. There are a lot of things to be done in London and to be part of that infrastructure development is fulfilling."

Along with his work on the Cairo Wastewater where innovation was required to complete the project, "We had to pretty much invent the way we worked as spares were sparce so we had to locally manufacture much of what we needed." The other high point of his career is his involvement in the Jubilee Line at Westminster and Waterloo. "That was a really interesting project and was probably the most difficult one I have ever done. It was far more difficult than the likes of the Channel Tunnel," he says.

One of Peter's many impressive accolades is being in charge of the AMEC Ring Main Project which struck up a World Output Record for segmentally lined tunnelling. "We put 501m of tunnel in to the ground in a week, in just five days in fact. No one's been near it since. It's still unbeaten." According to Peter, technological advances were not behind the success, "It was bored with just a normal TBM with segment lining behind it." He gives the credit to "a good team and tremendous effort from all."

Peter has also made impressive inroads above land. "I put together the The All Party Parliamentary Group for Underground Space (APGUS) with Helen Nattrass," he says. "It was very difficult to do, you don't just walk in to places like that, we had to tread water carefully and do it one step at a time, often one forwards, two backward. That was my key achievement as Chairman of the BTS and that's still going strong."

Safety for workers is an area of tunnelling

that Peter feels strongly about, and an area that he has seen evolve for the better. "I'm old world, I come from compressed air and open face working with no alternatives," he says. "We have slowly but surely built the world of tunnelling up in my career and we've created less risky methodologies as time's gone by. We have developed an ethos now where safety is king and we have a no nonsense approach to safety risk. The days of tolerance of impetuous behaviour are gone.

"With the growing use of closed face TBMs we've sealed the working face off with a bulkhead and we can now maintain pressure on the face without resorting to compressed air. As long as we understand what we're doing which is very important, modern methods can considerably de-risk tunnelling operations. It's where people don't understand what's going on in front of them with these machines that the problems start."

Peter has not only seen but been a part of many developments in tunnelling during his career. He introduced the use of wet spray shotcrete in the UK on the Jubilee Line. "It was under my control on that project, and since then its use has become internationally accepted as being the way forward." He also introduced the two-part annulus grouting system to the UK on the Channel Tunnel. He regards the international tunnelling community as being another vivacious area of development within the industry.

Away from tunnels, Peter is an avid yachtsman and has his own boat moored in the UK. "Sailing is a passion of mine, it keeps me alive. It's real adrenaline instead of this stuff we deal with on a daily basis!"

James Wilton

James "Jim" Wilton, former president and chairman of Jacobs Associates passed away on Saturday, March 13. He was 83 years old.

Jim was born in Los Angeles in 1926, received his discharge from the U.S. Navy in 1946, and then enrolled at Stanford University as an aspirant civil engineer. He received his B.S.C.E. degree in 1950 and immediately went to work for Macco Corporation. It didn't take long for him to realize that his vocation was construction engineering. In 1957, Jim joined Jacobs Associates. Jim immediately assuming responsibility for the firm's construction engineering services. He became a principal in 1963, was made president in 1974, and was elected chairman of the board of directors in 1985. Jim remained at Jacobs Associates for nearly 40 years.

According to Jacobs Associates' current president Bill Edgerton, "Jim was an engineer's engineer, with a reputation for being able to solve almost any construction problem. He was extremely detail oriented and was known for his meticulous construction drawings and calculations, which helped establish a quality standard within the firm. Jim was a recognized expert in excavation support for deep cut-and-cover structures, and the memory of his significant contributions will continue at Jacobs Associates."

Most of Jim's noteworthy projects have been underground structures, excavation support systems, cofferdams, and custom-built construction plants. Some of the designs he handled include tunnelling alternatives to open-cut construction on sections of rapid transit systems in both San Francisco and Washington, D.C.; the Yacambu Irrigation Tunnel, Venezuela; the Arenal Power Tunnel, Costa Rica; and the Renton Effluent Transfer System tunnels in Seattle. In addition, he undertook significant consulting assignments on more than 30 tunnels in the U.S. and abroad. In the 1970s he published several papers and studies on these subjects under federal research grants, and these papers are still relevant today.

Excavation support systems incorporating Jim's designs were used on more than half of the San Francisco BART stations; the N-1 and N-2 sewer tunnels in San Francisco; an 8,000-foot-long (2438m) open trench in San Francisco for the West Side Sewage Transport; the Chicago Deep Tunnel (TARP) project; the Victoria Arts Center foundations in Melbourne, Australia; and individual cut-and-cover contracts for subway tunnels in New York City, Atlanta, Boston, and Washington, D.C. After retiring from Jacobs Associates, Jim continued his involvement in consulting and dispute resolution through 2009. He was a Fellow of the American Society of Civil Engineers and received a Golden Beaver Award for Engineering in 1987.

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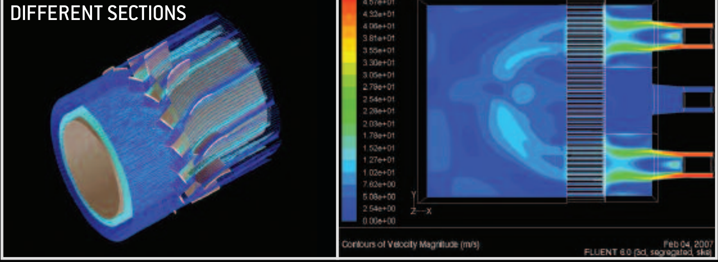

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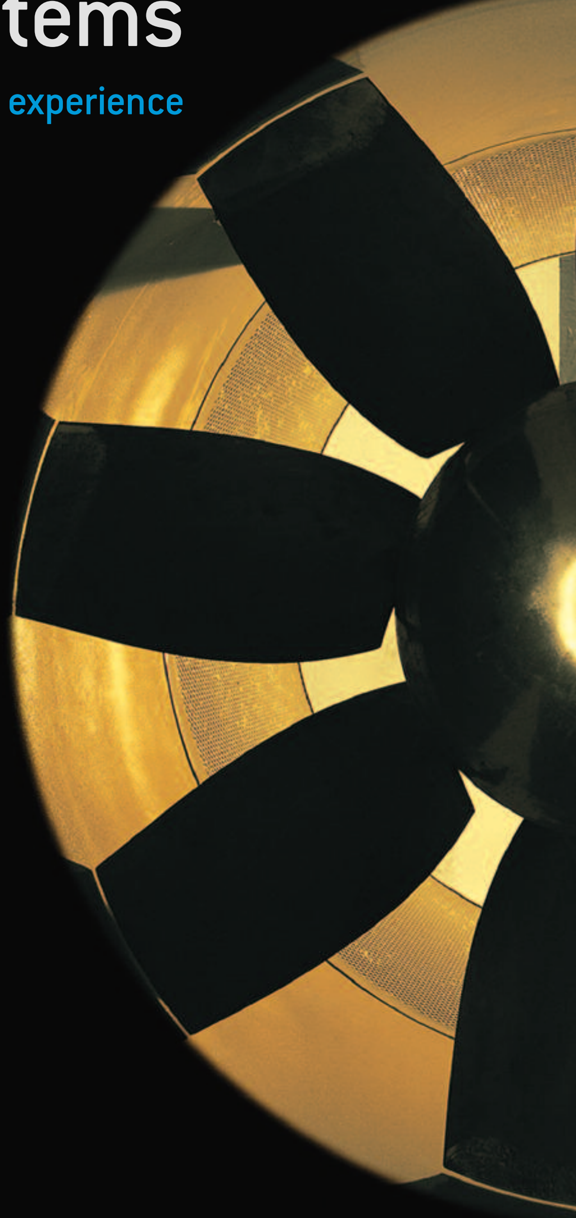

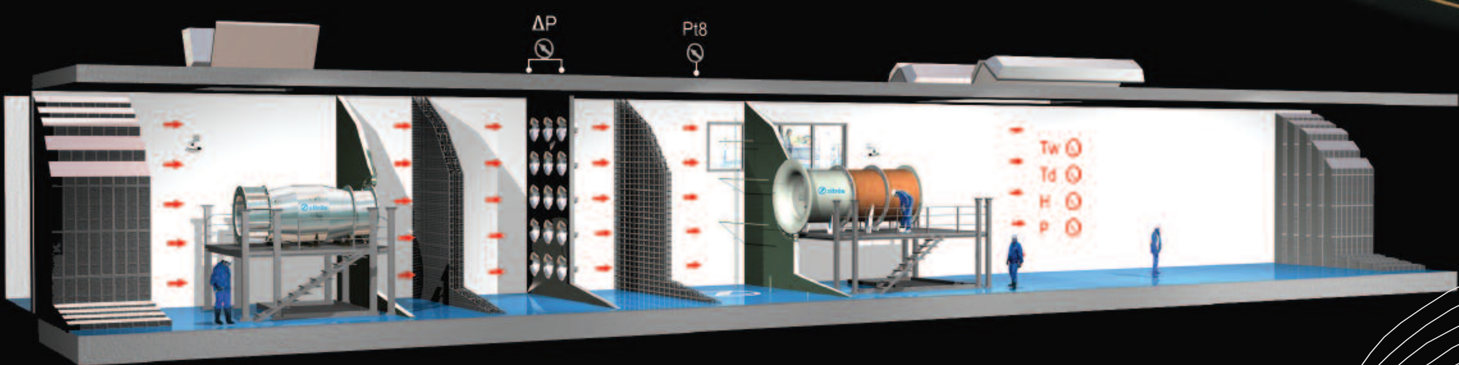

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High Speed Boom

Tunnelling in Europe is in a hot period at the moment as the continent meets its demand for flat, high-speed rail routes. Kris Mole reports

Europe is in a transition period as it attempts to leave behind the days of long train journeys across the continent, and replace them with quick and easy commutes courtesy of high-speed rail. This has led to some of the biggest tunnelling projects on the planet happening on the continent.

The biggest project currently under construction in Europe is the 57km Gotthard Base Tunnel, in the Swiss Alps. The USD 9bn rail tunnel project, once complete, will be the longest road or railway tunnel in the world, running between the Swiss cantons of Uri and Ticino. Four Herrenknecht gripper TBMs are employed on the job, which has an estimated completion date of 2017. In total, 153.5km of tunnels, shafts and passages will be constructed.

Another large project currently being undertaken in Europe is the Brenner Base Tunnel running through the Alps between Italy and Austria. With an expected completion date of 2025, the USD 6bn project will be the world's second longest road or rail tunnel after the Gotthard. The final design will consist of two 55km tunnels, with a centre tunnel used during construction as a guide tunnel to determine geological conditions, and later for drainage and emergency access.

The Italian and Austrian governments have each committed to pay 30 per cent of the construction costs, with negotiations underway concerning the rest of the funding. Once completed, 400 trains will pass through the tunnel every day, 320 of which will be freight.

The Brenner Base Tunnel will begin in Wilten, a suburb of Innsbruck in Austria, penetrating the Alps at a height of about 840m above sea level. It will tunnel at up to 1800m below the peak, before emerging in the Italian town of Fortezza.

Meanwhile, Germany's longest underground construction, the Katzenberg Rail Tunnel project, is currently being excavated. The 9.4km twin tube tunnel will form part of the Karlsruhe-Basel railway line.

The USD 681M project is expected for completion at the start of 2012.

The Leipzig City Tunnel, considered to be one of Germany's biggest inner-city infrastructure projects, is designed to end the inefficiency of reversals at a central terminus, improve connections and provide interchanges with surface running buses and trams. The USD 850M project is being carried out by Zweckverband for the Transport Area (ZNVL) and is scheduled for completion in 2012.

In Sochi, Russia, the Adler to Alpika Service Mountain Resort Rail Tunnel is being constructed at a cost of USD 800M. The 2.4km tunnel project was announced in 2007 and is scheduled for completion in 2013. The purpose of the tunnel, which is being built by the Directorate for Comprehensive Railway Renovation and Construction of Railway Transport Facilities (DCRC), is to reduce traffic congestion, travel time and distance across Sochi, close to the border with the Republic of Georgia.

Warsaw's USD 944M Metro Development Rail Tunnel project in Poland involves the construction of a 47.2km tunnel. It is being constructed using both TBM and top-down drill and blast method. The second line will link the east and west of the city. The line will run at relatively shallow depths, with an average of 9m between track and ground level. The metro facilities will be constructed in Quarternary soil formations, mainly by the cut-and-cover method.

In Scandinavia, tunnelling is in no less of a boom time, however the emphasis is more on the roads rather than the rails. In Norway, Skanska is constructing the USD 60M, two-lane, 6.5km long Kvivs Tunnel, on the E39 motorway. The tunnel is being excavated between More og Romsdal and Sognog Fjordane in the west of the country. Completion is scheduled for mid 2012.

Also in Norway is the 1.2km Loren Tunnel project, scheduled for completion in 2013, that will form part of the Ulven-Sinsen road project. The contract, worth about USD 94M, was awarded to Veidekke Entreprenor in 2008.

For the time being the future looks bright for tunnellers after a difficult period.

Above: **The Brenner Base Tunnel, one of the largest tunnelling projects underway in Europe**

Major projects

- **Gotthard Base Tunnel – USD 9bn**
- **Brenner Base Tunnel – USD 6bn**
- **Katzenberg Rail Tunnel – USD 681M**
- **Leipzig City Tunnel – USD 850M**
- **Adler-Alpika Service Mountain Rail Tunnel – USD 800M**
- **Loren Tunnel Project – USD 94M**

Beneath the barrier

The St Petersburg Flood Barrier is the largest and most complex flood protection project in the world including six sluice complexes, a road tunnel, a movable bridge, 23km of dams, a six-lane highway and two closable openings for shipping traffic. Garry Whitaker of Halcrow reports

St Petersburg's 25.4km flood protection barrier, designed to hold back rising waters from the Gulf of Finland, is nearing completion. Built at a cost of GBP1.8 billion (USD 2.7), the barrier also serves as a vital element of the St Petersburg Ring Road – a 115km highway which will encircle the city

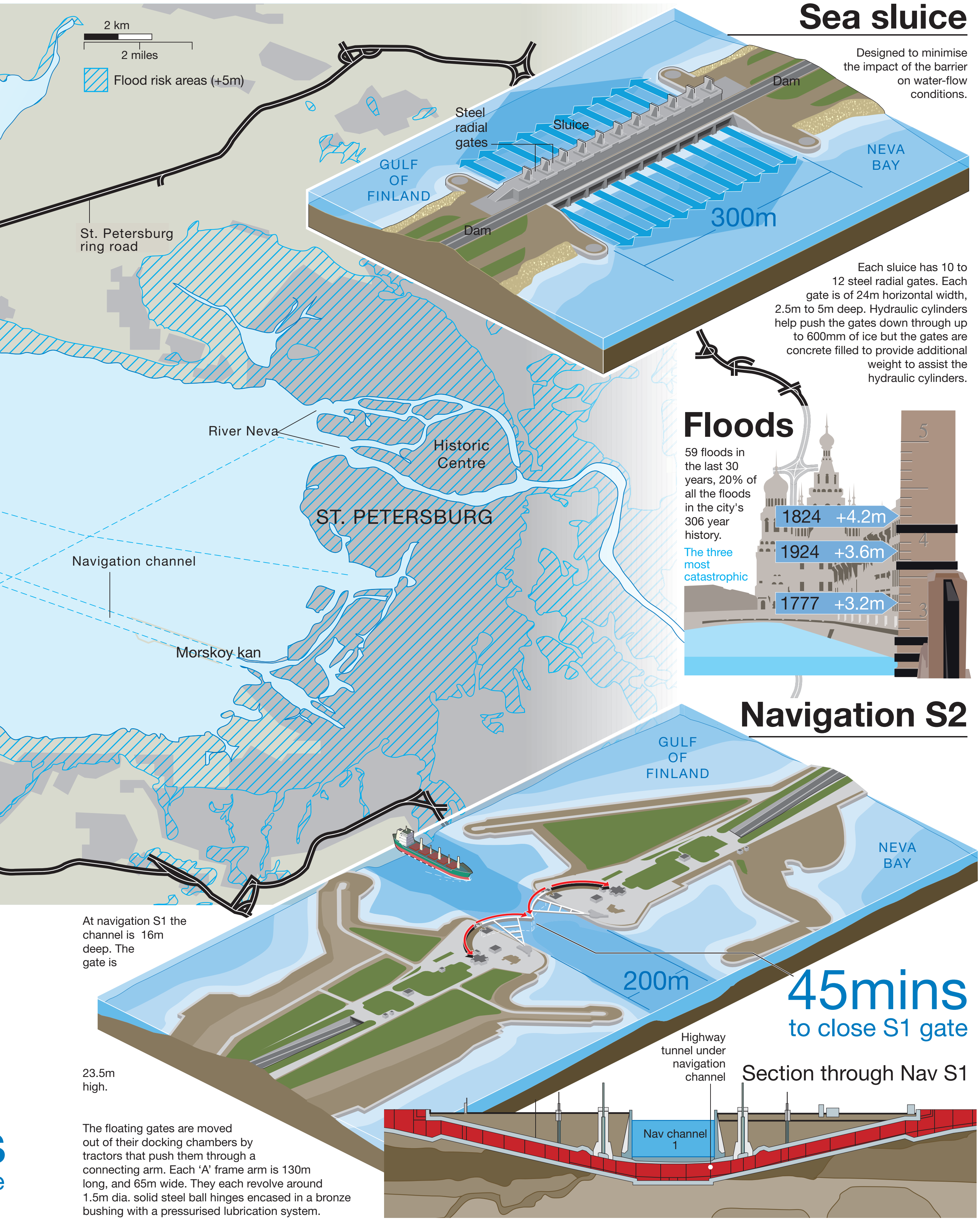
The need for the construction of a ring road around St Petersburg was first recorded in the 1965 General Development Plan of Leningrad (now St Petersburg). In 1984 the authorities of Leningrad and the Leningrad region started construction works.

However, construction was temporarily halted, firstly by the Soviet economic crisis of 1989, and then again by the dissolution of the Soviet Union in December 1991. In 1992, construction was stopped again as concerns were raised about the possible ecological damage resulting from the construction of the St Petersburg Flood Barrier.

In 2001, construction of the ring road was restarted, and, as environmental fears were allayed and concerns about climate change and rising sea levels grew, construction of the flood barrier continued in 2005 – almost 30 years since construction began.

Halcrow was awarded the overall design responsibility for the St Petersburg Flood Protection Barrier project. The project

The second navigation channel for local shipping has a channel with horizontal width of 110m, a lift gate of 119m width, depth 12m and thickness is 9m. The gate sits in a concrete slot below cill level. The closing time is 30mins. Navigation draught for ships is 7m. The lift bridge rises from 16m above the channel to 25m to allow ships through.


2 km
2 miles
Flood risk areas (+5m)
St. Petersburg ring road
River Neva
Historic Centre
ST. PETERSBURG
Navigation channel
Morskoy kan
Sea sluice
Designed to minimise the impact of the barrier on water-flow conditions.
Steel radial gates
Sluice
Dam
GULF OF FINLAND
NEVA BAY
Dam
300m
Each sluice has 10 to 12 steel radial gates. Each gate is of 24m horizontal width, 2.5m to 5m deep. Hydraulic cylinders help push the gates down through up to 600mm of ice but the gates are concrete filled to provide additional weight to assist the hydraulic cylinders.
Floods
59 floods in the last 30 years, 20% of all the floods in the city's 306 year history.
The three most catastrophic
1824 +4.2m
1924 +3.6m
1777 +3.2m
5
4
3
Navigation S2
GULF OF FINLAND
NEVA BAY
200m
45mins
to close S1 gate
At navigation S1 the channel is 16m deep. The gate is 23.5m high.
Highway tunnel under navigation channel
Section through Nav S1
Nav channel 1
The floating gates are moved out of their docking chambers by tractors that push them through a connecting arm. Each 'A' frame arm is 130m long, and 65m wide. They each revolve around 1.5m dia. solid steel ball hinges encased in a bronze bushing with a pressurised lubrication system.

management responsibility is shared between the PM/E (Project Manager/Engineer) and the PIU (Project Implementation Unit) - which are both Russian led consultancies.

The road tunnel

The cut and cover road tunnel runs beneath the flood barrier's 200m main navigation channel. Comprising two 13.25m wide main tunnels, each with a three-lane highway, and emergency access and cable tunnels, the 42.1m wide tunnel structure has been formed from reinforced concrete, with a double PVC waterproofing membrane on the outside.

A 3m service tunnel runs between the two main highway tunnels, whilst other service tunnels to the side of the main carriageways carry cables and utilities, serve as an additional emergency access and exit route.

The initial section of the road tunnel, which now runs beneath the navigation channel, had already been built by the time construction re-started in 2005.

Left to deteriorate, the initial works involved the rehabilitation of the existing construction and studies to determine the most effective way of linking the existing tunnel sections with the new sections needed to complete the project.

Nine of the tunnel sections, each up to 60m long, were originally constructed during the 1980s, but not connected with movement joints. The movement joint design posed some engineering challenges, since once in situ, it would be impossible to access them for maintenance or repair – necessitating a design specification which called for a lengthy, high-performance lifetime.

The contract was awarded to Trelleborg Engineered Systems and the solution chosen represented the first use of their 40m-wide, 7m-high Omega seals, named after the similarity of their cross-sectional profile to the Greek letter, in a cut-and-cover tunnel of this kind.

Needing to exclude water at high pressure, but still maintain adequate three-dimensional flexibility, the installation uses a double-seal approach, an inner Omega seal backing up the outer one, built to withstand temperatures from -30 to +70 degrees Celsius.

The structure of the connecting sections, together with the Omega seals allows them to support the navigation pass' foundations, water pressure on the tunnel walls and the high traffic load from cars and lorries.

In 2008, the navigation channel was opened, submerging the tunnel and completing 70 per cent of the tunnel works. Work continued to build the remaining 30 per cent, involving another 362m of tunnel and a 356m ramp.

Founded on some 1,835 cast-in-situ piles with diameters up to 1200mm and up to 23m long, this stage of the project requires 176,900 cubic metres of concrete, 26,400t reinforcement, 4,900t of sheet pile walls and 2,200t of constructional steel.

Construction of the tunnel and approach roads is being undertaken by Boskalis, with responsibility for earthworks, dredging and backfilling; whilst Hochtief is responsible for the concrete and piling works.

The first section of the ring road was opened to traffic on the 26 December 2002. In December 2007 the Northern sections of the road were opened, linking up with the St Petersburg Flood Barrier from Kronstadt and also connecting with the train station at Gorskaya and other northern and eastern elements of the motorway. The southern half of the ring road is under construction.

St Petersburg flood barrier

St Petersburg has an amazing history – one that is blighted by a succession of catastrophic floods. Since 1703, the city has been flooded more than 300 times, the most catastrophic was in 1824 when the water level rose by 4.21m; the second , one hundred years later, was in 1924 when levels reached 3.6m. It has been 85 years since the last major flood.

At the worst the city would be flooded to a depth of 5.15m with up to three million of St Petersburg's five million inhabitants directly affected. Some of the world's most precious monuments would be swamped at unimaginable cost.

The barrier will help protect one of the world's most beautiful cities. Its lavish architecture, an extraordinary history; and rich cultural traditions have inspired and nurtured some of the modern world's greatest literature, music, and visual arts.

And it's for this reason, the Directorate for the Flood Protection Barrier of the Ministry of Regional Development of the Russian Federation, assisted by Halcrow, is spearheading the completion of the St Petersburg Flood Protection Barrier.

The two huge 4,500t steel gates across the main 200m wide navigation channel were recently closed for the first time. Each the size of an ocean-going vessel some 122m long, 23.5m high and 4.7m deep. Together, they are capable of holding back storm surges that would otherwise wreak havoc on the city.

History

The design for the flood protection barrier was developed by the Leningrad branch of the All Union Institute "Hydroproject" in the late 1970s. Mobilisation and construction started at Gorskaya, Kotlin and Bronka sites and by 1981 about 2,000 people were working on project.

While the construction pits were being built, working drawings were issued, surveys carried out, the necessary equipment procured, and the architectural design of the structures developed.

In 1986, the first stage of construction was completed and was marked by the opening of the 14km road between Kotlin Island and Gorskaya.

In December 1988, a series of structures allowing control of water flow in the northern part of the Neva Bay through water sluices was put into operation across the Northern section of the dam and construction of necessary specialised transport and power facilities was finished.

At that time, 7,000 people were working on the construction of the barrier.

However, the reality of the times made an impact. Democratisation, glasnost, the market economy, the absence of state financing, and new environmental thinking forming a negative attitude to the construction project, made the successful realisation of the project impossible. In 1987 construction was suspended.

An international commission concluded that the impact of the completed barrier on the environment would be broadly neutral and recommended prompt completion. This was underpinned as concerns about climate change and rising sea levels grew.

In 2003, Halcrow won the international design competition in association with DHV of the Netherlands and Norplan of Norway. The existing designs were reviewed, followed by technical documentation for tenderers that allowed the work to proceed. Design changes were made by the Russian design institutes under Halcrow's direction.

Construction restarted in 2005.

Hallandsas first drive approaches end

Construction of the Hallandsas railway tunnels in western Sweden has often been described as the most difficult tunnelling project in the world. Many readers would probably want to argue that point but there is no disputing how tricky it has been over the 18 years since construction began. Now, however the Vinci-Skanska contracting joint venture is making steady progress. Maurice Jones reports

Since its inception, Hallandsas has become a by-word for how nature can throw nasty surprises at tunnellers who have the temerity to believe that a project is going to be relatively easy. Now the project's third contractor is making relatively good progress with the Hallansas Tunnel against undeniably difficult ground conditions.

The missing link

The high-speed (up to 200 km/h) rail Scandinavian Link route, which the Hallandsas Ridge lies across, will join Oslo to Sweden, and, through the Oresund Link, Denmark, Hamburg and the rest of northern and central Europe.

Approximately 85 per cent of the West Coast Line has been expanded to double-track operation, leaving Hallandsas truly as the 'missing link'.

The route of the twin-bore tunnel of 8.7km length runs between the town of Bastad on the left, north side of the Hallandsas Ridge, and Forslov on the right at the south portal. It is a long-awaited link in the upgrading of the Gothenburg-Malmo high-speed line, the main advantage of which is to by-pass a circuitous single-track route over the ridge with steep grades that greatly limit freight train loads and speeds. The new tunnel route should allow at least twice the payload and virtually eliminate winter delays due to snow, track icing and leaf-fall.

The tunnel will also improve road safety by eliminating 20 level crossings as well as keeping traffic flows down.

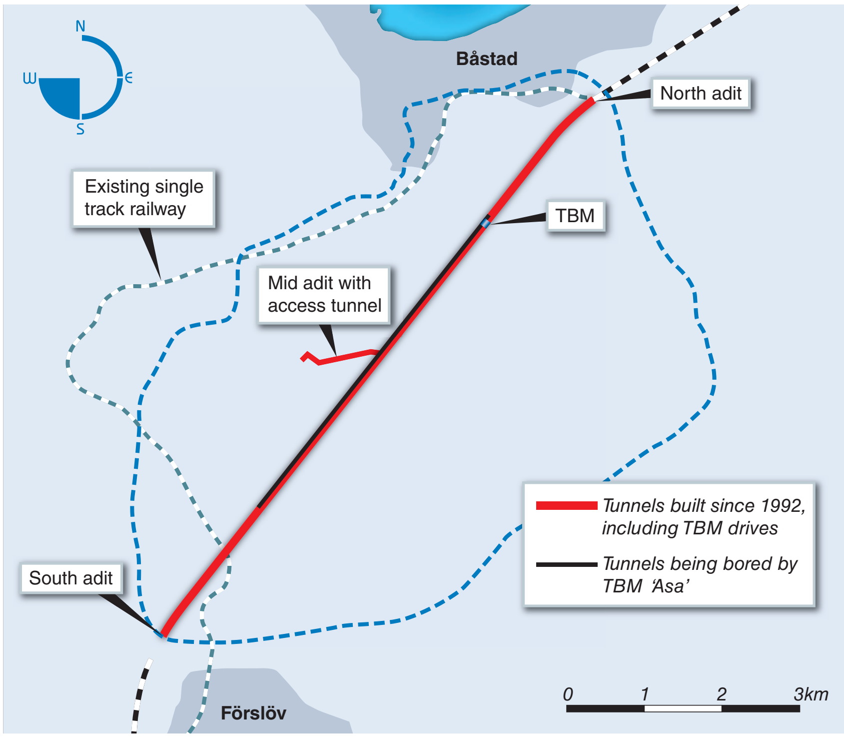
Geology

At 10km wide and tens of kilometres long, the Hallandsas Ridge is prominent above the flat landscape of southwest Sweden. It was thrust up as a 'horst' during mountain-building period at the end of the Cretaceous period, and so has complex disturbed geology. Fracturing of the rock mass is frequented with several zones virtually disintegrated and weathered to clay. The fractures give free passage for high potential flows of groundwater. When massive, however, the rock quality is hard and good, therefore creating challenging conditions for tunnelling. The most common rock type is gneiss, with amphibolite also common, and diabase.

History

Construction first began in 1992, but the contractor Kraftbyggarna only achieved 13m advance with an open, hard-rock TBM called Hallborr. A major problem was inadequate operation of the grippers against broken ground that offered no resistance for the forward thrust. Drill and blast was used instead from 1993 but progress was again slow, achieving a total of 3km before 1995 when the contractor abandoned the project.

In 1996 Skanska Sweden was awarded a second contract and chose drill-and-blast tunnelling. Despite excessive overbreak in poor rock sections, and high flows of water progress continued on eight faces. Those at the centre were gained by driving a central access tunnel, the Mid Adit.



Left: **Fig. 1 – Map of project area with TBM position at 21 January 2010. Dashed blue line indicates the surface zone influenced by dewatering from the tunnels**

Poison grout incident

One of the major obstacles in the development of the Hallandsas tunnel was actually a potential solution to another problem; the use of a chemical grout to stem the water flow through fractured rock, as the cementitious grouts then used did not penetrate the water flow paths sufficiently, or were washed away by high flows.

Much has been written about the incident in 1997 without repeating the details here, but to summarise, the grout used, Rhoca-Gil manufactured by Rhone-Poulenc, was found to have entered the surface waters above the construction, paralysing cows and fish. It was also found that workers coming into contact with the material suffered nerve damage and sickness, although fortunately no permanent effects have been reported. The cause was later found to be toxic acylamide in the grout product acting as a nerve poison.

The supplier and the users were found to be liable by the Swedish courts, resulting in heavy fines for Skanska and two employees.

As far as tunnelling is concerned the lasting effects of the incident were a delay in construction whilst investigations and negotiations on continued construction took place. At one time it was thought that the much needed tunnel would not proceed if an environmentally acceptable means of progress could not be agreed, but the Swedish government requested that Banverket did just that.

The non-construction cost penalties, including fines and compensation, were also great. As it happened the fact that the project had cost so much already until the construction hiatus was an incentive to complete the tunnels with a new contract.

Skanska introduced a new environmental management system including a control system for chemicals to prevent use of dangerous substances. From 1997 Skanska undertook an extensive quality and environmental control programme throughout its organisation, resulting in it becoming the first international construction group to be awarded certification according to the ISO 14001 standard.

Hiatus ends

Following an examination of the project by the Swedish Environmental Supreme Court, the project was allowed to restart in October 2003. The court set limits to the amount of water that could be drained from the total excavation over set periods, with both average and maximum flows. The chief aim was to preserve the wetlands habitat and agriculture at the surface over the tunnels route.

Originally the laws on water extraction, whether deliberate or 'accidental', were also to preserve the water supply to wells in rural communities although there is now a piped fresh water supply in Bastad and Forslov. Another requirement of the Court was that the ground had to be sealed before excavation, thereby requiring grouting of the ground in front of the tunnel face.

Tunnelling restarted in the winter of 2003, following the award of a design-build contractor to a joint venture of Skanska Sweden and Vinci Construction Grands Projets to complete the remaining two-thirds of the tunnelling. Skanska joined with Vinci due to the latter's extensive experience of TBM operation as it was decided that, in consideration of previous experiences, only a TBM could achieve reasonable progress in the difficult ground.

Under the contract, split 60:40 between the joint venture partners Skanska and Vinci, work is paid per metre of tunnel completed, and per treatment carried out, according to costs incurred relative to a bill of quantities. This was last negotiated with the client in 2008. According to the joint-venture's production director Francois Dudouit, since then everything has been working well.

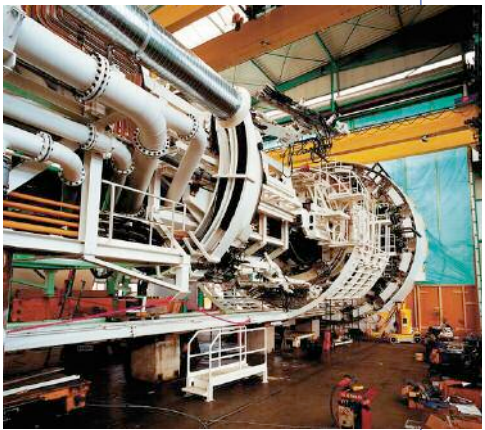
With a full geophysical survey over the length of the tunnel and other site investigation, plus Skanska' extensive knowledge of the geology from previous experience, the Skanska-Vinci could be better prepared for the conditions. Even so nothing could be certain. Especially difficult to predict are the location and geometry of amphibolite dykes.

Water controls

The permit granted for tunnelling specifies an average of 100 litre/s over a 30 day (one-month) period, plus maximum flows.

"The limit takes into consideration water leaking through all parts of the construction site and not just where tunnelling is taking place," says Dudouit.

In figure 1 the dotted blue line shows the extent of surface effects of tunnel dewatering. If the limits were not complied with it is likely that the effects would extend over a bigger area.



Above: **The Asa Herrenknecht TBM with the shield. Note the grouting/probe drill near to crown**

The TBM

The TBM chosen was a special form of Herrenknecht Mixshield named 'Asa' that can operate in open mode or closed slurry-shield mode. A key design is the openings in the cutterhead. Asa has openings (albeit small) within the face of the cutterhead, as in standard soft-ground machines to cope with the clay and crushed rock found in highly disturbed zones, but also it has peripheral

Project data

Overall Project:	Upgrading of main rail route (mainly for freight) in Western Sweden
Client/owner:	Trafikverket from 1 April 2010 (formerly Banverket)
Contractor:	Joint venture of Vinci Construction Grands Projets and Skanska Sweden
Tunnelling contract value (extended):	EUR603M (USD802M)
Full project cost:	Approximately USD1bn
Supervising engineer (TBM and pre-cast concrete) :	COWI
Tunnels:	Total running tunnels length 2 x 8.6km. New contract bore length of 5486m and 5424m, plus 12 cross-passages at 500m intervals by drill and blast. Running tunnel diameters 9.04m internal and 10.12m specified excavated. Accuracy +100mm over 5.6km
TBM:	Herrenknecht dual-mode 10.6m-diameter shield machine named 'Asa' – open or closed slurry-shield hard rock with 19 inches. (483mm) disc cutters

Above: **Thrust rams within the Herrenknecht TBM shield**

openings so that hard rock can be scooped up for passing to a belt conveyor.

Before TBM work could start a launch chamber had to be excavated some 1800m under the Hallandsas from the south portal, roughly where the previous tunnelling had halted. This was because the previous drill-and-blast drives were excavated with an arch profile only 7.2m wide, whereas the TBM is over 10m in diameter.

"Operating in open mode, as is usual, is the most efficient," explains Francois Dudouit. "Also, in closed mode progress is slower primarily due to significant maintenance on the slurry circuit, and additional time for cutterhead maintenance is required. Rock blocks from broken ground are difficult to transport in the slurry pipes." There is also the additional operational requirements of a slurry treatment plant, and the time taken to switch between modes. Although the specified changeover time is 24 hours, other considerations can mean it takes up to five days before the TBM can restart. However, as so often happens at Hallandsas, the decisive factor is water control. If it appears that the dewatering limits might be breached, then the face can be closed off and pressurised to hold back the water coming through the face. Then grouting has to take place (see below) before deciding in which mode to advance.

Mucking out in closed mode is by pumped slurry to the surface treatment plant, but in the open mode the rock is loaded onto a 150m belt conveyor to pass it through the back-up system, and thence onto another 7000m long, one metre wide belt. The maximum removal rate is 1000t/h. With the open system, any water make is pumped to the surface for treatment in a separate plant.

It has been found that cutter replacement rate is also affected by the size of the backloaded cutters themselves. The original cutterhead used 17 inch (432mm) diameter cutters. "Our big problem was blocks falling from the face and roof in fractured zones," reports Dudouit. "Although broken, they are hard, with impact loading on the cutters, breaking bearings and mountings, the cutter rings themselves, or flattening of the ring edge due to stuck bearings."

From the 'Mid Adit' access tunnel, 900m long, 40m of running tunnel had been excavated in both bores. When the TBM reached here the opportunity was taken to carry out intense maintenance and to replace the cutterhead with one that could accommodate 19 inches. (483mm) diameter cutters. "The new cutterhead with bigger cutters is better for impact loads," said Dudouit, "and gives something more robust. We now have 50 per cent less cutter replacement needed, saving costs (despite increased cutter unit cost) and time on cutter changes. Advance rates are also about 50 per cent better."

Cutter replacement rates were around one cutter per lining ring before the refit.

The closed-mode TBM can cope with groundwater pressures of up to 13 bar when operating, and and a rarely used 15 bar when static. It is regularly pressurised to 9-11 bar when static.

As the main water problem is flow, a development of the TBM by the contractors has provided considerable operational advantages. The water passes through the annular gap, normally 250mm wide and previously filled with gravel or crushed rock, to be subsequently extracted by pumps. At regular intervals barriers are constructed by injecting backfill mortar and grout to fill the allulus of four rings (the shield being pressurised to balance the water table) so detering water flow. When the TBM is in open mode the water carried out on the belt is separated from the rock within a flat conveyor section.

The TBM cutterhead permits drilling of the face, which is where most of the grout holes are placed, at the same time performing a probing function. Three drills are mounted inside the shield machine for this.

Grouting Programme

Grouting is necessary in many parts of the tunnels for water control, but only infrequently for the purposes of general ground consolidation, despite the broken rock. Since the poisoning incident there is a natural bias amongst all parties against chemical grouting. Consequently most grouting uses Rheocem 650 microfine cement grout, supplied by BASF Meyco and manufactured by Lafarge.

"Rheocem 650 has a particularly quick setting time (less than three hours)," says Dudouit, "which is quite important to minimise the duration of the grouting cycle. The results with the microfine material have been successful."

Grouting activities tend to delay excavation progress. Dudouit has reported two thirds of the team's time taken up by grouting, resulting in monthly progress of only 120m at times, compared to up to 250m in good months. However this is preferable to the progress achieved by previous contracts, and gives full compliancewith the environmental requirements regarding control of water flow.

Despite the overwhelming use of cement grout, some chemical grouts have been tried and used in special circumstances. Minova has developed some polyurethane (PU) products for use at Hallandsas in order

The new client

The Swedish government decided to amalgamate most official transport agencies into one body, Trafikverket – The Swedish Transport Administration, effective 1 April 2010. The former railway authority and client for the Hallandsas project, Banverket, is one of the original agencies. The new administration is tasked with the development of an effective and sustainable transport system including all modes of transport. The new web-site for the administration is at www.trafikverket.se.

to meet environmental demands. Francois Dudouit reports, “We have limitations concerning the quantities of polyurethane. We have used them mainly for tests of Carbopur WF and WFA, in very limited quantities. CarboStop (Minova specially developed a new version – CarboStop E) has been approved, but again we do not intend to use large quantities. In total we have only used about 5t of polyurethane from Minova. Another difficulty with chemical grouts is that we have to use a specially qualified sub-contractor. ”

So far around 3000m^3 of the Rheocem 650 grout has be injected from the TBM. A typical grouting cycle swings into action after about 20m of TBM advance. To seal water flow and probe ahead the drill pattern involves 10-15 holes in the face up to 40m long. These are injected with grout at up to 30bar to overcome water pressure and penetrate the fissures. Sometimes a fan pattern of holes may be drilled around the tunnel profile but usually only for weak ground consolidation or overbreak filling. “The grout pressure is monitored and we also limit the grout quantity to 5m^3 to avoid any chance of the grout reaching the surface,” explains Dudouit.

Backfill grouting also aids water control. This is injected through holes cast in the segments, from the back-up system. Normally this is carried out in two stages – bottom and then top - to avoid washout.

Freezing Molleback

The zone forecast to be the worst for rock condition and water flow and ground instability was the 300m-long Molleback Zone (MBZ). In the MBZ there is a mixture of weathered material with highly fractured and crushed rock. Where the rock is less weathered the fracturing permits major water flows backed by high pressure. It was decided that freezing was the only practical answer, but set-up was far from simple.

Dudouit explains, “Access was a problem but we could get near the zone from the north, and an access tunnel was driven from the old face. We needed 130m horizontal of ground freezing cover, but had to do it underground, and to achieve the necessary accuracy we had to limit the freeze-holes to 100m in length. Using oilfield directional drilling technology we bored a pilot hole surveyed by a gyroscopic and inclinometer device. Then, using electro-magnetic field guidance we drilled a ring of 16 holes referenced to the pilot hole. This ensures that the freeze-zone does not have any breaks in it once the freeze tubes had been inserted and connected to the refrigeration plant.”

Above: **Pre-cast segmental lining seen from the TBM erection chamber**

Brine refrigeration was used to withdraw heat from the ground. Direct freezing with liquid nitrogen was discounted due to the costs and possible safety hazards in a remote working area.

Once the first freeze-zone had been completed and the tunnel excavated, a second, shorter zone 30m long was generated by repeating the process. Finally, in a third phase, intensive use of cement grout from three holes formed another seal over a further length of 135m.

Lining

The TBM is equipped with an erector to install pre-cast concrete segmental lining of eight segments per ring. The segments are manufactured in Skanska-Vinci’s own plant at Astorp, some 20km south of the south portals construction site near Forslov, and transported to the portal site by rail. There was insufficient space for a manufacturing plant nearer to the tunnel. Together with the segment gaskets and annular grouting through the lining, this ensures that water leakage with the tunnel is limited, allowing the overall drainage limits to be met.

The design life for the lining is 120 years, which, in consideration of high ground pressures, places high demands on concrete quality, and the casting tolerance is only +0.5mm.

The mix employed for the 540mm thick, 2.2m long segments employs synthetic microfibres to improve fire resistance in the tunnel. A steel reinforcement cage is used in each mould to provide tensile strength against ground pressures and also the TBM thrust of up to18,850t. After casting each segment is transported to a steam-curing chamber to prevent surface drying and cracking, and then a Phoenix hdpe sealing gasket is fitted. The segments are stored in ring assemblies for at least 28 days before transport to Forslov. In winter at least four of these days storage are indoors.

The segments are attached to each other by cone-shape dowels that give a strong connection and ensure an accurate fit without steeping between rings before bolting. Each has a 15t shear capacity.

In all, the pre-cast plant will manufacture 41,000 segments to line the entire tunnel in the current contract, as specified according to the new water-control measures.

Progress & completion

At the time of writing there remains only 790m to complete excavation of the east bore to join with the 1149m already excavated under the previous contract, thus forming a welcome milestone with completion of one of the bores. The ‘Asa’ TBM will them be disassembled and transported through the south portal of the west bore to be reassembled in an erection chamber within the Southern Marginal Zone (SRZ) where rock conditions are slightly better. Here 1712m of west bore excavation had been completed under the previous contract, and 1649m on the east bore. The TBM erection chambers were excavated to 16m wide x 18m high and 30m long.

Tunnelling is currently progressing according to a revised schedule due to the geological difficulties. The first trains should run through the tunnels in 2015, three years later than planned when the joint venture contract was awarded.

Cityringen will add a 15.5km underground loop to Copenhagen's existing y-shape network by 2018

Danish dash

More metro for Copenhagen and a possible undersea link to Germany are the new major plans involving tunnels in Denmark. Report by Patrick Reynolds

Taking forward its expansive, long-term transport plans, Denmark has a fresh surge of tunnelling-related activity underway with more metro to be built in the capital and a possible undersea road and rail link to Germany.

The metro project – Cityringen – will add a 15.5km long underground loop to Copenhagen's existing Y-shaped network by 2018. Due to start construction this year, the project to build a twin-bore line got underway in earnest three years ago, soon after studies were completed during construction and initial completions of the first metro lines.

Long before the metro studies, though, and even discussed back when plans were being developed for the country's first major projects involving significant large tunnels – the Great Belt ('Storebaelt') and Oresund crossings, both long since opened – was the prospect of a fixed link across the Fehmarn Belt, or channel, to Germany. Since last year consultants have been working to refine potential options for a tunnel across the 19km wide relatively shallow channel.

Both immersed tube and bored tunnel are being considered for the Fehmarn road and rail link, and so is having a ventilation island along the route. However, prior studies priced a tunnel crossing to be more expensive than a bridge alternative. At present both alternatives are being explored for construction of a link to start by 2013 for, again, completion by 2018.

Cityringen – set for build

While the decisions on whether a tunnel or a bridge will be chosen for the Fehmarn link and the route alignment are about a year away, this month should see the next milestone in development of Cityringen when bids are due for the tunnelling packages.

Four JVs were prequalified to bid for the tunnelling packages, and received the tender documents last October. The JVs are:

- Alpine Bau with FCC Construccion;
- MT Hogaard with Hochtief, Ed Zublin and E Pihl & Son;
- Salini Costruttori with Tecnimont and Seli,
- Bilfinger Berger with Vinci Construction Grands Projets and Per Aarsleff;

However, in February, the latter JV dropped out and as T&TI went to press the client still anticipated bids from the three remaining consortia.

Tenders for each of the two running tunnel and station construction packages are to be submitted by 4 May. The client, Metroselskabet, has said it expects to make the awards soon after, possibly in June.

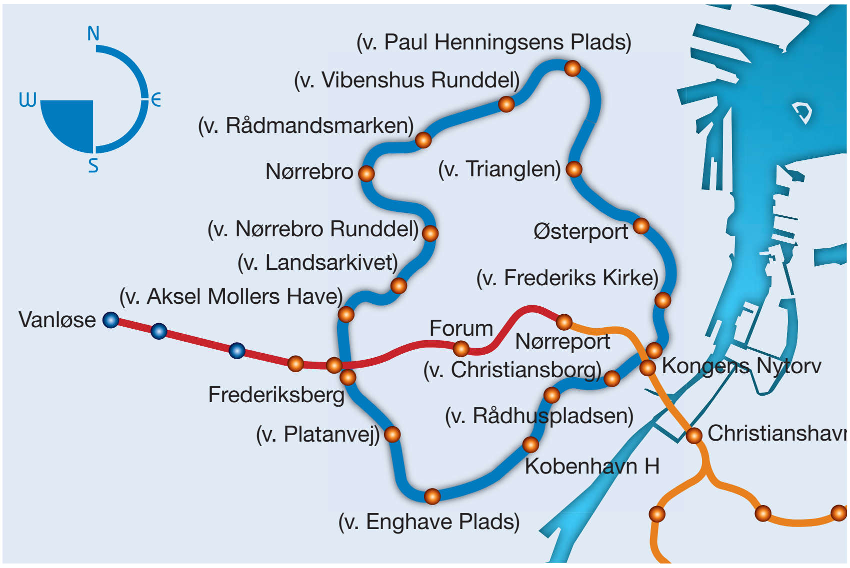
Cityringen – the works

Copenhagen has a high groundwater level and extremely strict environmental controls. Geology along the alignment of the twin tubes comprises glacial moraine over limestone, and there are some sand beds.

Metroselskabet has organised the tunnel works to be undertaken in two packages – North and South – covering construction of 17 underground box stations and TBM excavation of approximately 14.9km, or almost all, of the loop. The tunnels are to be driven at depths of approximately 15m-35m.

The boundaries between the packages are at Aksel Mollers Have station, in the west of the loop, and between Trianglen and Osterport stations – at Oster Sogade lake – in the east.

The project also calls for five construction and ventilation shafts to be sunk and four crossovers constructed, to be done by sequential excavation and sprayed concrete lining (SCL). Design



Above: Map of Copenhagen's metro and proposed route

development radically reduced the number of shafts from an initial plan of about 20, and also changed a few of the 62m long, standard length stations to be built at shallower depths.

Consultancy support on the civils works was given to the client by a JV of Cowi, Arup and Systra.

The metro network may spread farther. The current project work on development of Cityringen includes an element, funded by Copenhagen Municipality, to study branch lines off the loop and provide for such with construction of stub tunnels.

Fehmarn – rival concepts

While the design stage is giving way to construction for Cityringen it is only half way through the refinement process in the conceptual stage on the Fehmarn scheme – at least to determine which is the best tunnel option to square off against the bridge alternative.

The tunnel option is chasing behind the cheaper bridge, which has been estimated to cost EUR 4.5bn (USD 6.1bn) against EUR 5.5bn (USD 7.4bn) for the subsea solution.

But that margin was not enough to terminate the tunnel option when the figures were given in 2008, and it is to survive at least until 2011 while parallel, but separate, conceptual studies are performed to refine the tunnel and bridge options.

The studies were launched a year ago with the appointment of two teams of JV consultants by the project developer – Femern A/S, a subsidiary of Sund & Baelt A/S, which has experience from the construction and operation of the fixed links across the Storebaelt and Oresund.

The tunnel analyses being taken forward by a consortium of Ramboll Danmark, Arup and Tunnel Engineering Consultant (TEC). The JV is supported by a rake of subconsultants – WTM Engineers, HTG Ingenieurburo fur Bauwesen, Wilkinson Eyre Architects, Schonherr Landskab and Oriental Consultants.

The JV is working alongside the client's own tunnel team, under Steen Lykke, which most recently worked in Istanbul, leading the Marmaray project (see page 5). The scheme is centred on an immersed tube tunnel under the Bosphorus but includes significant other bored tunnel and station works, at grade infrastructure and rolling stock.

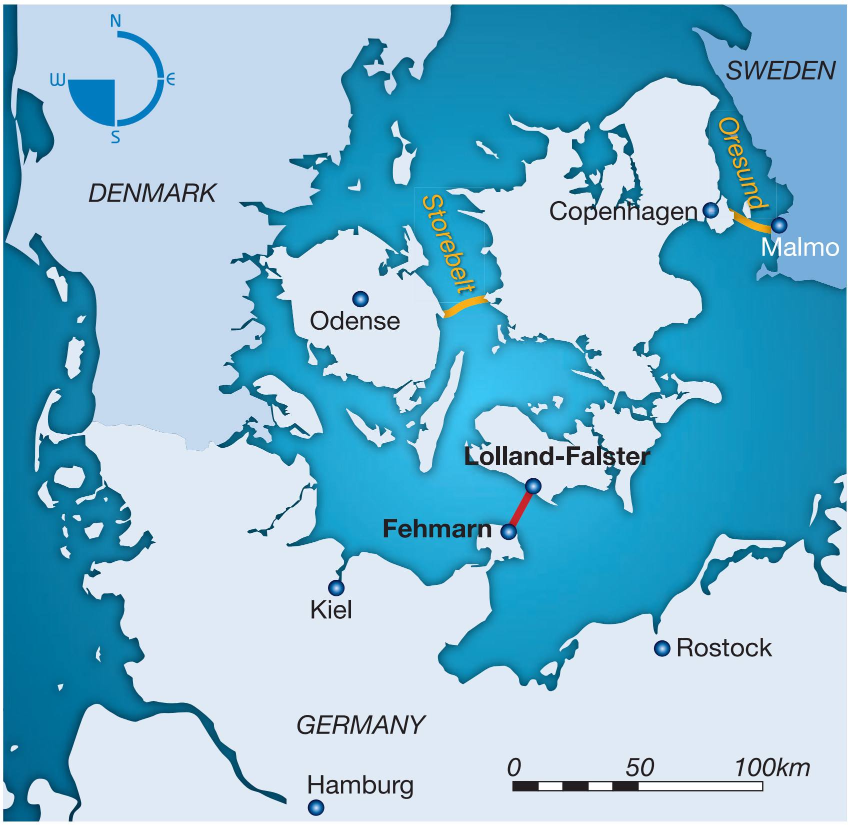
Lykke says: 'We are now well into the process of optimising the different tunnel solutions.'

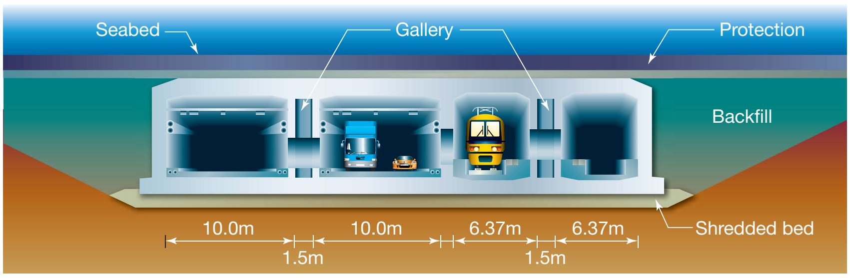
Fehmarn – tunnel studies

As the design studies for Fehmarn commenced, the prime focus for the tunnel option was a 18,565m long immersed tube tunnel – favoured as being a more robust solution than a bored tunnel as found in a feasibility study completed in 1999.

The immersed tube tunnel concept had a cross section comprising two 10m wide cells for road traffic and a pair of 6.37m wide cells for single-track rail lines. A ventilation island in the middle of the strait was also planned for the link between Rodbyhavn, Denmark and Puttgarden, Germany.

The study has been investigating 'a relatively high number' of cross section layouts, says Lykke – more than 10 for the immersed tube tunnel and more than five





Left, top: **Denmark's tunnelling projects**
Left, bottom: **Cross section of the proposed rail/road tunnel to Germany**

for bored tunnel solutions. These are to be compared on a range of parameters, such as robustness, environment, possibilities for arranging safety features and ventilation, construction time and risks, constructability, cost and connections of the alignment into the shore and beyond.

He adds that the process is more of a de-selection of candidates to arrive at the potentially best tunnel solution, and that will compete against what emerges from the bridge studies, also undergoing conceptual refinement.

While the process has not been finalised – and so bored tunnel options have not been ruled out – Lykke says it's believed that a solution with both road and rail tubes together, side by side, in the same structure would be superior on many of the assessment parameters. The indicative size of the tunnel cross section would then be approximately 40m wide by 9m high – "close to what was shown in the original feasibility study," he adds.

The layout is for an immersed tube and initial planning has considered production yards able to cast 200m long elements weighing approximately 70,000t.

Lykke also says 'one of our main focus points during the development phase so far has been to optimise the use of space inside the immersed tunnel', and a key aspect of that work involves a wider scope of potential ventilation systems.

The 1999 feasibility study had considered cross or semi-cross flow ventilation systems as the best options, and these are among those now being studied but do require substantial space for ducts in the running tunnels. But longitudinal ventilation systems are also being considered due to improved vehicle emission standards since the earlier study.

Other key areas being addressed included taking advantage of the tunnel length to possibly concentrate the mechanical and electrical installations in special, dedicated standardised elements to be installed at intervals.

A further possibility being analysed is to omit the need to build a ventilation island in the middle of the strait, with consequent benefits for construction costs and navigation.

Meanwhile, out in the strait, environmental surveys and site investigation work have been underway since mid-2009. The work is to be completed by late 2011 with approximately 25t of samples to be cored from pairs of 100m deep boreholes.

International perspective

When the field data are collected and the tunnel and bridge conceptual studies completed, the client will pass over the findings on the Fehmarn project – on the best tunnel and best bridge conceptual designs – to the Danish Minister for Transport to choose which of the alternatives to build. Once legally authorised, the client's procurement plans call for award of a design and build contract for the civil works.

Construction of the Fehmarn link was previously anticipated to begin in 2012 and this is now expected to be in 2013, still for completion in 2018 – the same year as Cityringen is due to come into service.

Offshore and onshore, Denmark has projects underway that hold challenges for tunnellers that draw global attention. In Copenhagen, the metro will be enlarged with an entirely underground loop that is a significant addition for any world capital, and vital to the city as it becomes an increasingly strategic transport hub between Europe and Scandinavia, already bolstered by the Oresund link.

Oresund, at 4km, is the longest immersed tube built and if the Fehmarn strait was to be crossed by such a tunnel then it would be the world's longest – even with an island in the middle, notes Lykke. It would also be the deepest road and rail tunnel as a single structure immersed tube, he adds.

Denmark may not have many tunnels but those that have been built, and are planned, are major structures that more than make their mark internationally.

Long bores in remote India

Freak monsoons, remote jobsites and hard rock are testing the limits of the machines boring the hydration scheme in arid Andhra Pradesh, India. Robbins technical writer Desiree Willis reports

Eastern areas of India's Andhra Pradesh state receive only 200mm of rainfall per year—an amount comparable to Africa's Kalahari Desert. The Andhra Pradesh Irrigation Department hopes to assuage the chronic drought conditions and contaminated drinking water in the region with a massive water transfer scheme consisting of over 120km of tunnels, all sourced at the Srisailam Dam on the River Krishna.

Tunneling with three Robbins TBMs has been ongoing at the Alimineti Madhava Reddy (AMR) and neighboring Pula Subbaiah Veligonda projects since 2008 and 2009, respectively. Isolated jobsites are located hours away from local villages, with at least three days road travel required for spare parts shipments and other project supplies.

"One of the biggest challenges of this project is logistics—getting spares and supplies from one place to the next," says Andy Birch, Robbins field service project manager at the Veligonda site. Due to the remote locations and similar tunnel specifications, the three 10m diameter Robbins double shield machines, their back-up systems, and continuous conveyors are identical. Parts and supplies are the same for all of the jobsites, which are about three hours apart by road.

Left: Water will be sourced from the dam

Once complete, the AMR tunnel will be the longest TBM-driven tunnel in the world with no intermediate access. The unusual alignment is a result of the project location: Both AMR and Veligonda tunnels pass directly underneath the Nagarjuna Sagar Tiger Reserve, the largest sanctuary for Bengal Tigers in India. The proximity to an environmentally sensitive area meant that traditional methods, such as drill and blast, had to be ruled out due to possible noise and vibration at the surface. The setup also meant that no intermediate access was possible for either tunnel project.

A combination of atypically hard rock, tunnel length, and jobsite location make the AMR and Veligonda tunnels among the most challenging projects in the country's history. Crews have overcome multiple obstacles including blocky ground, continual power outages, and a once-a-century monsoon.

AMR Water Tunnels

Stretching from the left bank of the Srisailam Damto arid areas of Andhra Pradesh, the AMR tunnels will provide water to approximately 1,200 sq km of farmland. The new water scheme will also bring potable drinking water to 516 villages currently using contaminated sources. Local water use from groundwater wells has become highly polluted with waste bacteria and excess fluoride, resulting in various illnesses and fluorosis, for which there is no treatment.

Planned since 1983, the USD 400 million AMR project includes the 43.5km long TBM-driven tunnel, as well as several miles of open canals and a second 7.25km tunnel excavated by drill and blast. The 43.5km main tunnel was awarded in 2006 to Indian contractor Jaiprakash Associates, with Robbins supplying two TBMs, continuous conveyor systems, spares, and operating personnel to complete the tunnel excavation.

Once in operation, the main tunnel will receive water from a head regulator currently being constructed on the foreshore of Srisailam Reservoir. Water will flow by gravity through a number of balancing reservoirs, using central masonry in overflow sections and rock fill in non-overflow sections. "Balancing reservoirs are required to cross all of the valleys and rivers along the system route. The reservoirs will also be used as storage facilities for overflow," explained Anil A. Kamat, senior vice president of Jaiprakash Associates. At the Dindi River, a second, 7.3km long tunnel will then distribute the water to a network of canals. The 8.7m diameter, horseshoe shaped tunnel is slated for completion within four years.

Each TBM drive, at 22km in length, is being excavated from portal areas at the opposing outlet and inlet ends of the tunnel. The outlet portal area was designed to accommodate the full length of the TBM and back-up at 45m wide by 160m long. However, a shortened launch setup is needed at the inlet site, where space is restricted to 120m by 45m. The inlet site is protected by a bund wall at the side of the reservoir, and sits below the water level in limited space.

Veligonda Water Tunnels

Also on the Krishna River, on the right bank of the Srisailam Canal, lies the future inlet site for the Pula Subbaiah Veligonda Project. Once complete in 2014, the system will draw 1.2bn cubic meters of flood water annually from the foreshore of the Srisailam reservoir. Two parallel, 19.2km long tunnels will transfer water via a network of five canals to over 1,600 sq km of farmland in the three districts of Prakasam, Nellore, and Kadapa. Up to 243 cubic meters per second of water will travel through the bored tunnels to a feeder canal.

The USD 180 Million contract was awarded to the Coastal Projects (CPPL) / Hindustan Construction Company (HCC) JV. A Robbins double shield TBM and continuous conveyor system, as well as spares and key operating personnel, were sent to the jobsite to excavate tunnel number two starting from the outlet end. The machine was launched in June 2009. Tunnel number one is currently under excavation by the NSC Consortium - a JV of local firms Nuziveedu Seeds, Swathi Constructions, and Coastal Projects - using a 7.9m diameter Herrenknecht double shield.

Ground conditions

The three 10m diameter Robbins TBMs are identical, and are all designed to bore in the hard rock of India's Deccan Plateau. Conditions at AMR include quartzite zones up to 450 MPa, layered and separated by shale for approximately 60 per cent of the length, with granite (160 to 190 MPa) for the remaining 40 per cent.

The Veligonda tunnel is located in sedimentary rock on the western margin of the Cuddapah Basin, where a number of faults and folds make for complex geology. Rock includes quartzite with interbedded shale (60 per cent) and shale with limestone and phyllite (40 per cent). Two major faults are expected along with some ground water.

In general the high quartz content of the rock in both tunnels causes high abrasive wear during tunneling, making a larger diameter, 20-inch (508mm) disc cutter the best option for longer cutter life. The quartzite sections with interbedded shales can also be very blocky in nature - the

Above: Three identical 10m diameter Robbins double shields are excavating India's AMR and Veligonda water tunnels; Right: Blocky rock conditions at the AMR outlet tunnel prompted crews to find a solution by adding extra grill bars across the muck buckets

layering of hard quartzite with thin, weak shale makes overbreak in the crown and shoulder of the tunnels a possibility. Tests have shown the granite sections to be fairly competent and less of a concern.

Double shield TBMs

The three machines are mounted with back-loading 20 inch diameter cutters for more efficient excavation, particularly in the high rock strengths present. Specially designed drive motors also allow each machine to run at a higher than normal RPM, compensating for low penetration rates in the hard rock. In squeezing ground, each cutterhead is also capable of vertical movement to allow for overboring.

Each machine is installing 300mm thick concrete segments in a 6+1 arrangement to serve as a final liner, making the finished tunnel diameter 9.2m. Stability of the segment rings is achieved through a combination of crushed aggregate injection and grouting to fill the annulus outside the lining.

Probe drills on the three machines allow for verification of geology 30m ahead of the TBM. The drill is capable of 360 degrees rotation and can alternatively serve as a grout consolidation drill. Large 40kW dewatering pumps located on the back-up systems have been specially designed to

pump any water away from the tunnel face.

To monitor TBM performance throughout the project, a newly designed data logging system was installed on each machine. Real-time meters allow the measurement of parameters including cutterhead motor amperage, RPM, cutterhead power, and gripper cylinder pressure. Information is relayed from the machines to computers viewable by the tunnel superintendent and engineers to allow monitoring and adjustment of all TBM equipment.

The bore paths behind all three TBMs are nearly straight, making powerful steel cable belt systems a good option. System components are identical, so that parts exchange and sharing of belt rolls between the jobsites is relatively easy. The Veligonda system tops out at 19.2km, making it the longest single conveyor flight Robbins has provided. The setup also allows maintenance and belt splicing to be performed outside of the tunnel in an optimal environment. The long steel cable belt system is powered by a total of four drive systems - one main drive with two

Above: **Extra grill bars were added to all three Robbins machines to prevent rock blocks from damaging the conveyor belt;** Left: **Cleanup is ongoing at the AMR inlet site, where a once-a-century monsoon submerged the Robbins double shield beneath 20m of water**

300kW motors at the tunnel portal plus three booster drives inside the tunnel.

Once outside the tunnel in the spoil handling area, muck is transferred to spoil dumps using trucks. The excavated granite from the TBM drives is then recycled for use as concrete aggregate and pea gravel. The same is planned at the inlet where the quartzites also make good aggregate.

AMR Outlet Tunnel

Initial conditions at the AMR outlet included intermittent power outages, which were supplemented by onsite generators, and unexpected geology. Severely blocky ground at the outset tore the conveyor belt and slowed the tunneling process. Large rock blocks made their way through the muck buckets, stopping in transfer hoppers and point loading the conveyor system. Crews found a solution by reducing the spacing of grizzly bars on the muck buckets and adding additional bars so the boulders could not pass onto the conveyor system. Grill bars were also added to the AMR inlet machine and the Veligonda machine in anticipation of similar ground conditions. In good ground, the grill bars can be removed to allow a higher flow of material into the muck hopper.

By March 2010, the Robbins outlet machine had entered into better conditions. "We are in very good ground, boring through sections of hard, massive rock. The ground is ideal as far as stability but does cause abrasive wear and higher cutter usage," says Malcolm Moxon, project manager at the outlet site. The machine has excavated about 5.9km, with advances of up to 149 m per week. Crews had also installed the first conveyor booster drive.

AMR Inlet Tunnel

Work to restore the TBM at the AMR inlet tunnel is ongoing - the machine was a week away from launch in October 2009 when a 100-year monsoon hit the region. The natural coffer dam wall at the inlet site was not designed to withstand a major flood, and was breached by the flood waters. Flood control doors were not opened in time to release the water downstream, causing the significant rise in water levels. The launch pit was inundated with over 20m of water, leaving the crown of the TBM beneath over 10m of water for approximately ten days until it could be pumped out.

The TBM and backup were jacked back 12m from the tunnel face to allow removal of the cutterhead and inspection of the main bearing. "Cleanup operations took us a further 14 days, which included jet washing the machine and removing 300 to 400mm of silt deposited on the equipment. In order to return the machine to an 'as new' condition, we are currently replacing a major portion of the TBM components," says Jim Clark, Robbins projects manager, India.

Veligonda Tunnel

As of March 2010, the Veligonda machine had excavated 1.5km of tunnel in soft and fractured rock. "We have had some water ingress, which was not excessive. There were points of heavy water inflows when we passed under three small rivers, which caused water in the head and ingress after each ring was built. We have successfully controlled water seepage in these sections," says Birch.

At the Veligonda site, an international crew of workers keeps the TBM in operation for two 10-hour shifts, plus a 4-hour maintenance shift. Typical operations during the shifts include ring building, pea graveling, and grouting to control any water inflows. During rotations the crew stays at a campground and living facilities 2km from the portal site, with electricity, air conditioning, and internet service.

Hard rock tunneling in India

For all its challenges and successes, the extensive irrigation scheme is seen as a renewal of the hard rock tunnelling industry in India. "The AMR and Veligonda tunnels are the largest projects ever undertaken in India. In the past, hard rock TBMs have been used in the Deccan Plateau for water supply and sewage systems. Recent attempts have involved the use of TBMs in the Himalayan mountains for power generation—attempts that have been plagued by geological problems including tectonically active mountains, large underground water bodies, faults and shear zones," says D.G. Kadkade, consultant for Jaiprakash Industries.

"These latest tunnelling projects are good for the Indian economy. Previous methods for tunnelling primarily consisted of drill and blast, but TBM usage has made it possible to excavate in sensitive environments for hydropower, irrigation, drinking water, and metros. These improvements are contributing to the growth rate of the country, which is increasing at 7 to 9 per cent per year despite the global recession," said Kapil Bhati, general manager for Robbins India.

According to Bhati, the possibilities for improved infrastructure using tunnels in India are immense: "There is still a huge potential for hydropower projects in India, particularly in the mountainous states of Himachal Pradesh, Jammu & Kashmir, Uttaranchal, and Arunachal Pradesh. In addition to this, there are many areas that need better systems for irrigation and drinking water. With so many of these projects in the planning stages, we expect the demand for hard rock TBM tunneling in India to rise substantially, by 20 to 40 per cent per year."

Thin barrier integrity – the easy way?

One of the major developments of recent years has been the development of sprayed linings, especially to control potential water make in an operational tunnel and to protect equipment and users from its effects. In this market it competes with many techniques, but chiefly coming up against the use of sheet membrane. So are sprayed membranes making serious inroads into this market and are there any limitations to this deceptively simple idea? Maurice Jones reports on some developments and applications.

Before deciding what waterproofing solution is desirable one has to know what the real problem is first. Similarly tunnel designers have to decide how the waterproofing measures can be integrated within the overall design of lining to meet the tunnel performance specification. Currently there are several accepted types of design involving sprayed or sheet membranes for waterproofing, but the opinions on how these can be achieved vary considerably. Whilst the newer concept of spraying a membrane on a tunnel surface to achieve waterproofing, or more often water-diversion to drains, sounds simple in practice, it is more complicated in concept and execution. Nevertheless it can still offer advantages over installing most sheet membranes if carried out properly.

The claimed advantages of sprayed waterproofing are becoming well known and include:

- much more tolerant of rough surfaces, with little need for 'fleece' layers to protect the lining from penetrating , sharp rock;
- equipment that is more mobile and less space-consuming than that for sheet membranes;
- not labour intensive;
- easier jointing, if necessary.

On the other hand, the advantages of the main competitor, sheet membranes, remain:

- cheaper materials;
- few airborne emissions during installation;
- established procedure.

Both methods are likely to require specialist installation, or at least until the correct procedures become more widely known. In addition to these two basis approaches, there are other methods of waterproofing that can aid or replace these methods providing the circumstances are right. These include wall drains or a drainage layer, injection grouting, less pervious concrete (with certain additives), well-sealed pre-cast lining and/or temporary dewatering.

Whatever the method chosen, the objective is to achieve the design specification for the effective life of the tunnel. It is sometimes revealed that there is no such thing as a 'waterproof' tunnel, or at least only in special circumstances. In most cases the objective is to divert water flow to where it can be managed while withstanding expected groundwater pressures.

The waterproofing membrane has to be considered as part of the whole lining, and its structural integrity to dealing with any ground movements and changes in groundwater pressure or potential flow. It is very difficult to achieve a 100 per cent impermeable layer in any case, especially when considered over the life of the tunnel. So the realistic waterproofing objective is to make water ingress totally manageable using a layer that is as impermeable as possible.

The type of sprayed material used is another important consideration since different plastic resins have different

Right: Waterproofing the Croydon Cable Tunnel using Stirling Lloyd material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properties is the areas of ageing, resistance to groundwater contaminants, bonding to other layers (if required) and safety.

One of the major issues in sprayed waterproofing is, ironically, how tolerant the material is of water. Despite manufacturers' claims of tolerance to wet surfaces, it is the case that none can actually be applied to surfaces with running water, and few securely against any free water. As such, other preparatory water diversion or priming measures have to be taken, increasing the complexity of the whole procedure, although perhaps not as much as sheet membrane installation.

Waterproofing specialist contractor and supplier Stirling Lloyd's business development director, Mike Harper, told 'Tunnels & Tunnelling International', "No sprayed membrane (regardless of what anyone else might say) will bond to a surface where water is running over it. It is not a problem as such, as long as there are clear ways of dealing with the different scenarios for water ingress."

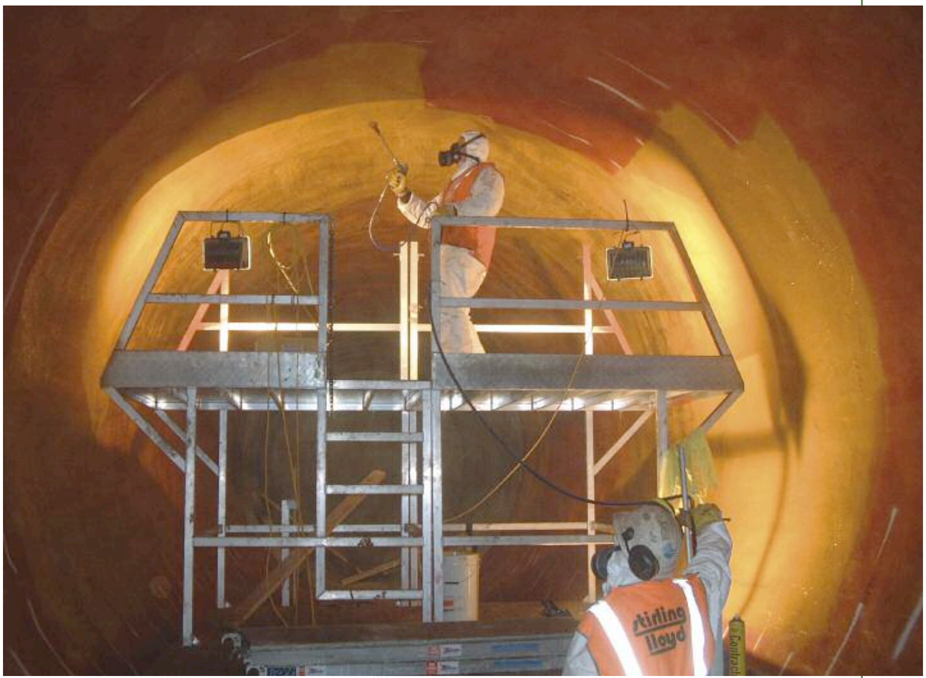
Masterseal

In the relatively short life of sprayed waterproofing, Meyco BASF's Masterseal 345 material has become perhaps the best known. It is promoted as part of a continuous structure to prevent water migration along the concrete-membrane interfaces on either side of the membrane.

The claimed bonding aspect can be important in that it allows the primary (shotcrete) lining to be considered as part of the permanent support structure with the inner final concrete lining. This is sometimes termed a 'single-shell' composite lining, although a single-shell strictly has only one layer of concrete with no membrane. According to the engineer's design, the primary lining may not be included in the permanent structure, but any future activity between the membrane and primary lining has to be taken into consideration.

Masterseal 345 is applied in the same way as dry-process shotcrete use a spraying unit like the Meyco Piccola. Such a unit must be fitted with a dust collection filter or similar dust collector. Although the product has not toxic components, the use of standard ppe (gloves, eye protectors and a mask) is recommended.

Meyco says that the concrete surface to which the lining is to be applied has to be thoroughly pre-wetted, and any contamination removed. Following application the membrane must not be exposed to extremes or great variations of temperature for five days.



Above: A custom-built platform give operators better access in the Thames Water Ring Main extension
Right: The Masterseal system

As with other membranes the roughness of the surface to be treated has to be considered. Meyco says that if the roughness necessitates more than 6kg/m2 of Masterseal 345 a smoothing layer of cementitious mortar is recommended, having an maximum aggregate size of 4mm, thus reducing the necessary consumption of Masterseal 345.

Stirling Lloyd

Stirling Lloyd's sprayed waterproofing products can be used in both cut-and-cover and immersed tube tunnel structures as well as excavated designs, but in such cases open-air application is often the case.

On wet surfaces requiring waterproofing, Mike Harper continued, "Damp concrete is not a problem for Integritank HF – its has a primer system specifically made for sealing and enhancing the strength of the bond of the membrane to the damp concrete. Where we draw the line is wet substrates (ie free liquid water on the surface). Such a surface needs pre-treatment to stem the water ingress. This is dealt with by a number of specialist products from Stirling Lloyd."

Another potential bonding problem is between layers of sprayed membrane, such as between shifts, or after similar stoppages. Commenting on this Harpur said, "The chemistry of some materials does not lend itself to achieving a truly seamless application. Well-known examples would be polyurethane resins for example. These have many good properties, but on of their limitations is that their surface chemistry becomes 'closed' after approximately 72 hours. Where a truly seamless installation is the goal, then any such mechanism that reduces the effect of intimate chemical bonding between new and old material is undesirable. This is one of the reasons that materials based on polyurethanes and polyureas are unsuitable for tunnel waterproofing, in addition to their toxicity. We do not use them for tunnel waterproofing for this reason."

Recent project references have included the Croydon cable tunnel, the 4DCF extension of the Thames Water London Ring Main to Honor Oak and various projects in the Emirates.

In the Honor Oak project Morgan Est employed Stirling Lloyd's Integritank HF as a sprayed membrane sandwiched between primary and secondary sprayed concrete layers for the back-shunt of the TBM launch chamber. The tunnel has continuous water pressure both inside and outside, with the tunnel around 52m below ground level. Typically the water table is around 15m above the axis level in permeable chalk Stirling Lloyd Construction applied the material as specialist sub-contractor. First the primary lining was cleaned of dust and contaminants, and then primer applied by spray to the whole concrete surface being lined.

Integritank HF is supplied in two IBC caged tanks for ease of handling and eliminating site addition of water. This avoids any risk of material variation, as does the use of a computer-controlled, airless pump for mixing the two components. An access platform was required to enable close access to the substrate all around the tunnel profile, for accurate application and inspection.

More than one coat is colour-coded to ensure proper coverage. Two spray operatives at different levels coated the whole 360 deg of the profile in one pass. Spraying is done by operatives manually, not by robot. Commenting on robots, Mike Harpur points out, "A robot operator spraying remotely cannot tell if it's 'missed a bit' and waterproofing is an exact science. A membrane is either waterproof or it isn't. There is no such thing as 95 per cent."

Trials

Phil Richardson of NCD (Natural Cement) has been engaged with Stirling Lloyd and leading UK tunnelling contractor Morgan Est in intensive trials of a wide range of spray-on waterproofing products to determine which of these works best, both in applications and longer term in situ. NCD products, including Natural Cement shotcrete, have even been used to treatment particularly difficult areas in the construction of the Hindhead Tunnel lining, that otherwise used mainly Meyco Masterseal 345. This shows that not only synthetic chemical materials have to be used for waterproofing.

Right: **Applying methacrylate resin waterproofing in Dubai**
Below: **Applying Masterseal memebrane in the UK's new Hindhead Tunnel**

Part of the de Neef range of waterproofing products is Aquatek Super XA that is applied as a cementitious slurry coating that can be used against water pressure. The company also offers Denepur 200. This is a polyurea-polyurethane hybrid hot-sprayed membrane applied in layers 2-3mm thick.

Phil Richardson highlights another potential problem with synthetic sprayed waterproofing. "The materials are expensive, and the layers applied have to be thin. Obviously, if a 2mm layer is required, applying 3mm in an attempt to ensure continuous cover increases the cost by 50 per cent. Consequently the development of peaks and troughs in the thin layer can be an issue. In comparison, the application of wet-process shotcrete helps to produce a smooth surface, but the layers are much thicker. Most sprayed waterproofing materials are fast setting, including polyurea, which is instantaneous, but still with variations. One supplier claims a 12-h cure time but actually 30h has been known."

On drying time, Shotcrete Technologies claim a 30-s 'tack time' for its 2-component ST Waterseal, with a curing time of around 60 minutes. The product has no toxic vapours and is resistant to attack from most other chemicals. Once cured it has a tensile strength of 600 lbf/in.2, allowing elongation of 500 per cent.

Testing

As with sheet membranes, testing of sprayed waterproofing membrane is necessary to ensure adequate protection of the tunnel and lining, because even with all installation procedures correct, there may still be tiny defect, such as an 'invisible' pin-hole. Once installed the membrane is almost impossible to repair with resorting to traditional waterproofing techniques such as grouting.

Stirling Lloyd and other contractors use an electrical discharge-testing device known as a 'holiday tester'. The testing procedure is based on the fact that the membrane is an electrical insulator so that a voltage applied will not result in a current if the membrane is continuous.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Securing the Gotthard Road Tunnel against salts

Salt water and concrete form a potentially lethal cocktail. When the salt is washed off winter roads and seeps into the pores of tunnel roofs and walls, danger lies ahead: dissolved chlorides in the water attack the steel inside the concrete. In this report, edited from that supplied by Wacker Chemie, action to protect the Gotthard road tunnel against is problem is described.

Salt corrosion can have serious consequences: crumbling concrete, accidents, and costly, lengthy renovations accompanied by congested traffic. Materials experts from Wacker have developed water-repellent special silanes, which protect concrete for years by preventing salts from penetrating into the concrete. Highway bridges in Bavaria, Germany, are routinely protected in this way already. Recently the roof of the Gotthard tunnel in Switzerland was also treated with special silanes.

Despite presenting a fabulous panoramic backdrop, the Alps are a real nuisance to traffic. In 2008 about 1.27 million trucks crossed over the four major Alpine passes in Switzerland alone. The burgeoning stream of traffic also flows underground through the more than 50 road tunnels through the Swiss Alps. Closing off just one of these extremely busy arteries, such as the Gotthard Tunnel, can be likened to an obstruction in a blood vessel, and the results can also be devastating with a serious risk of congestion.

The Gotthard tunnel is at the heart of the most direct road link between the North Sea and southern Italy. The flow of cars, buses and trucks under the legendary massif of gneiss and granite rarely comes to a standstill. Vehicles have been passing through the 16.9km-long tunnel since 1980, carrying holidaymakers, autoparts and electrical goods from north to south, and hauling tomatoes, machinery and textiles back from Italy to Germany, the Netherlands and Denmark. Every year, some 750 000 trucks trundle through the the depths of the Gotthard massif.

Salt on concrete

Every winter, these vehicles unintentionally transport additional material into the tunnel – salt water. The spray thrown up from the wet road surface by millions of tyres splashes directly onto the roof and walls of the tunnel. The deposited salt attracts more water, and the constantly damp conditions favour its slow penetration into the concrete. Over the years, the porosity of the concrete enables the chlorides to eat their way further and further inside. Then, once salt-laden moisture makes contact with the steel bars, or reinforcing cage, an ominous corrosion process is set into motion.

Usually the pH level of concrete is high enough to protect the steel, but it is powerless against salt chlorides, which cause the pH to fall and the protection to disappear. Because corroded steel has more volume it presses against the concrete from the inside and forces parts of the concrete to eventually break off. This can have serious consequences.

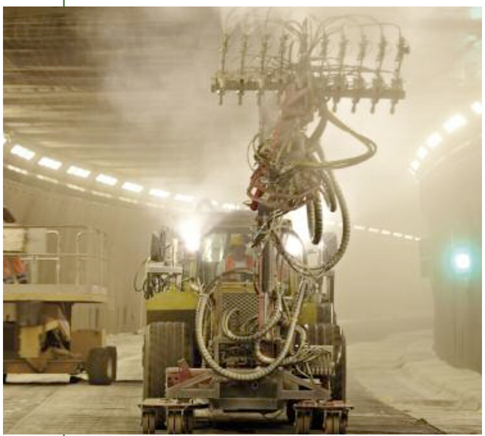
Since 2002, therefore, a special 'Suspended Ceiling' working group at the Swiss Federal Roads Authority (ASTRA) has been monitoring the structural condition of the Gotthard Tunnel, initiating repairs as needed. In 2006 it instigated rehabilitation work of the entrances, treating some 250m of the tunnel with a water-repellent. The concrete was impregnated with an active ingredient that lines its pores and renders them water repellent while retaining their vapour permeability. The concrete thus continues to 'breathe'.

Measurements and on-line monitoring of corrosion currents showed that these steps greatly reduced the extent of corrosion. It was therefore decided to impregnate a further 750m of the tunnel with water repellent. Although a complex coating already protects the concrete structure, the tunnel roof needed to be repaired.

Structural or rehabilitation work of this kind requires extensive preparation and safety precautions, and so both are very costly and almost impossible to do so long as the tunnel remains open.

This is especially true of the busy Gotthard Tunnel, which can only be closed for brief periods because of the huge volume of traffic. Comprehensive measures, such as the application of an epoxy resin coating, are nearly impossible

Right: Spraying the ceiling of the Gotthard Tunnel with Wacker's Silres BS Crème C to impregnate the concrete against moisture and salt



Left: **With the tunnel completely closed to traffic last September, a special spray rig applies the impregnation silane**

to carry out in such a short period of time.

For this reason, the tunnel operators opted for deep impregnation and arranged for more than 7000 square metres of ceiling to be impregnated with silane in a single night to protect the concrete in the ceiling against the ingress of salt water.

"It has been shown that highly alkylated silanes, such as Silres BS Creme C, are the best products for such tasks," says Dr. Johannes Ihringer, a Wacker materials expert. "Unlike conventional liquid products, they can be applied in the right thickness at one go. The substrate's porosity determines how quickly the active ingredient can penetrate." This was a key argument for the decision to use the Wacker product in the Gotthard Tunnel. After all, time was of the essence.

All systems stopped at precisely 20:00, 21 September 2009, and the tunnel was closed. Work started simultaneously on the northern and southern entrances. The workers at both ends of the tunnel had until 04:30 to finish the job, because the traffic could not be held up any longer than that.

Race against time

With all the proverbial precision of a Swiss watch, the repair gangs swung into action. As soon as the last truck has passed, some two dozen workers dressed in white clothing and high-visibility jackets begin 'Operation Gotthard' at the southern entrance. First, painters and concrete repair specialists covered the entire road surface with sheeting. Arnold Wyssen, a master painter, specially commissioned a device for unrolling the sheeting for the southern side: "We have to cover 7000 square metres of road in three hours," he says.

Afterwards, a Novapplica robot sprayed water repellent onto the tunnel roof. "The spray mist containing the silane cannot be allowed to get onto the road surface because that would make it as slippery as soap and cause drivers serious problems," says Ralph Minery, the responsible sales manager from the construction chemicals business team at Wacker, Switzerland. It was Minery's job to monitor the work's progress throughout the night.

After everything was covered, the spray gun could get to work: twice the automatic sprayer traversed the 750m of tunnel, its 12 nozzles covering the roof with about 500g of material per square metre. After around five hours of loud hissing, the job was done. The workers from Novapplica had sprayed around 3.5t of material onto the ceiling.

The tunnel ventilation system was run at full speed to dry the roof, not stopping until dripping has ceased. Then the workers quickly remove the sheeting from the road and clean up the site. At 04:04 the construction gang left the tunnel, some 25 minutes ahead of schedule.

At precisely 05:00 the column of trucks once again moved through the heart of the mountain. "It was a risky undertaking, and we all knew we had to work at full power. Never before did a project like this have to be done in such a short time," said Paolo Gattulli, branch manager of SikaLavori of Cadenazzo, Switzerland. This company, which was commissioned by ASTRA to do the work on the south portal, has been using silane active ingredients from Wacker for many years.

Prior to applying the water repellent, the SikaLavori experts had hosed down the roof with a high-pressure spray, and then hammered it by hand to sound out defects. Any that were found were cleaned out and repaired with special mortar. Only then could the waterproofing begin. Everyone knew the stakes were high – just one night had been allocated for the job, and any overrun would have cost tens of thousands of Swiss francs.

At the northern entrance Mapei performed the waterproofing. Its Swiss sales manager, Martin Schneider, also opted for Silres BS Creme C. "Because it is a paste, you can apply it much more thickly to every square metre. The cream sticks to the surface better, and that enables more of it to penetrate into the concrete," he said.

To do the work in such a narrow time span would 'not have been possible with any other material,' said Schneider, who has been working for over 20 years in construction chemicals and collaborating for some 15 years with Minery.

"The silane cream has a long contact time and is designed to ensure maximum penetration of the concrete by the active ingredient. That way it offers optimal protection against water absorption and damage by road salt," Minery explained. The depth to which the waterproofing agent penetrated the concrete was then examined by materials experts, who took drill cores when the work in the tunnel was completed.

"The goal of deep impregnation with our silane active ingredients is to penetrate to a depth of about 6mm, to provide a water-repellent lining within the concrete pores and to keep out salt water," Dr. Johannes Ihringer explained. The high viscosity of the WACKER silane active ingredients ensures that they are not washed away again by water splashes and that they provide long-lasting protection.

"Conventional repairs to concrete structures, such as tunnels and bridges, can cost ten times as much as preventive measures such as hydrophobic impregnation. With this innovative technology, it's possible to prevent the need for repairs – and so avoid high costs and consumption of energy and resources," adds Ihringer.

Paolo Gattulli, SikaLavori, is confident of winning further deep-impregnation contracts in the future – after all, there is no shortage of tunnels in Switzerland. "Salt water will always be the arch-enemy of reinforced concrete. And the concrete needs to be given lasting protection," said Gattulli. Speciality silanes from Wacker are clearly just as effective in tunnels as they are on highway bridges.

Silanes protection against moisture

Organosilicon compounds (silanes) are long-established water repellents. They feature excellent water repellency, and will not significantly impair the water-vapour permeability of concrete. On the concrete, they form extremely stable covalent bonds with the silicate matrix of the pores and capillary walls. The colourless, non-film-forming silane impregnating agent prevents water and dissolved aggressive substances, such as salts, from gaining ingress into the building material via capillaries. Silanes possess excellent durability and are extremely resistant to external influences, such as ultra-violet radiation, thermal stress, aggressive substances and microbes.

TBM performance prediction in Iran

This paper reviews leading existing methods of TBM performance and advance rate prediction, taking all applicable factors into consideration, and their suitability for the conditions of the Karaj-Tehran water supply tunnel project in Iran. The predictions for this project are compared with actual performance. The authors are Prof Kazan Oraee, Bahram Salhi and Arbie Sarkissian.

In order to prevent shortage of drinking and industrial water for the next two decades in the city of Tehran, according to growth requirements, many projects have been designed and implemented. The Karaj-Tehran water tunnel is one of these. This tunnel, approximately 16km long, is being excavated by full-face TBM to carry water from Amir Kabir dam to Tehran refinery no.6. Because of their rapid excavation speed, TBMs have a special place in more than 6km of tunnelling in Iran. Predicting the machine excavation work, especially in long-term projects, has become very important, considering the growth in the use of these methods from early 1990s. Many prediction methods are available, such as those of the Colorado School of Mines, Norwegian rock mass quality index (RMi of RockMass) and the TBM Tunnelling Quality Index (Q_{TBM}). In this paper, to analyse the Karaj-Tehran project the Norwegian rock mechanics method (RMi) and the TBM Tunnelling Quality Index methods were used.

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Min-Tech is not part of the Karaj-Tehran water supply tunnel project.

Definitions

In this paper advance rate is defined as the length of tunnel completed per unit of time. Also it is the length underground structure in which all excavation, support, pavement and other processes have been done per unit of time. This 'velocity' (AR) is expressed as metres per week or month.

Mathematically advance rate is equal to penetration rate multiplied by performance index. First the two parameters of penetration rate and performance index are calculated.

The penetration rate shows the velocity of machine penetration in rock and is expressed by millimetres for every rotation of the cutterhead or metres per hour. The machine penetration rate is proportional to the rotational velocity of the cutterhead. The rotation velocity of cutter head is limited and depends on the machine specification. Obviously the penetration velocity (PR) in soft rocks is more than in hard rock.

Efficiency or productivity means profitability, effectiveness and success (Oraee & Peymandar – 2003)[1]. Otherwise productivity is a ratio of available resources usage or output divided by the production factor (input). Productivity is an index for evaluation of the working unit or process. In this paper it has shown by U. Increase or decrease of productivity has a direct relationship with profitability.

Productivity can be expressed in two types: general and partial. The general productivity is ratio between the total output of the system and total input. If expressed as partial, will be composed of the ratio between its components. In TBMs time efficiency has generally been accepted to have an acceptable index that represents machine activity. This is because representing all factors such as machine parts supply, energy consumption, depreciation and also excavation conditions and convert all to a single unit is very difficult. Time productivity or performance generally represents machine work. Cutter disc consumption rate and their replacement time, machine depreciation, site stability and gripper movement all affect advance rate.

In time productivity or performance calculation, analysis of all data should be in a same range. By increasing the analysis time, the performance index decreases. That's because of an increase in machine rest time but not including it. In this project the total time of tunnelling operation is divided by available working time, less maintenance, support and lost time. The three elements in time efficiency are calculated by equation 1.

$$U = \frac{T_t - T_{M\&R} - T_L}{T_{available}}$$

Equation 1

Where:

$T_{available}$ = available profitable time
$T_{M\&R}$ = maintenance and support time
T_L = lost time.

Analysis method

In this paper the factors affecting advance rate of TBMs are as in Table 1.

Each method focuses on some effective parameters, and their interrelations, and avoids other parameters in calculation.

The Q classification was offered by Barton according to drill-and-blast tunnelling in 1974. He developed the Rock Tunnelling Quality Index (Q) method using filed research and, with some other parameters, to estimate the advance rate for TBMs, and presented the QTBM model (equation 2).

$$Q_{TBM} = \frac{RQD_o}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \times \frac{SIGMA}{\frac{F_{10}}{20_9}} \times \frac{20}{CLI} \times \frac{q}{20} \times \frac{\sigma_\theta}{5}$$

Equation 2

Table 1- effective factors on advance rate (Salehi - 2007[2])

Features	Components
Earth	Tensile and compressive strength, geological condition, ground water, discontinuities.
Geometry and tunnel design	Final tunnel section, diameter, length
Local factors	Workforce, local laws and provisions, working time
Management system	Workforce, means of machine use, maintenance and replacement, safety
Machine capability	Weight of TBM, thrust, power, effective moment, cutter diameter, maintenance and system installation

Where:

RQD_O = Rock quality in tunnelling direction

$\frac{J_r}{J_a}$ = Value relating to discontinuities, joints and layering of rock that most assist (or hinder) excavation

$\frac{J_w \text{ and } J_n}{SRF}$ = The same Q value (unchanged): SRF = Stress Reduction Factor, relating to the rock looseness and stress

$SIGMA$ = Equivalent factor of rock mass strength (resistance)

F = Average cutter load as extracted from machine catalogue (in tonnes force)

CLI = Cutter Life Index

q = Quartz content in per cent

□□ = Induced biaxial stress on tunnel face (approx. MPa), normalised to a depth of approximately 100 m (Salehi – 2007)[2]

The rock mass strength has been normalised using rock specification and Q value. It is calculated by equations 3 & 4.

For not suitable β $SIGMA = SIGMA_{cm} = 5.\gamma.Q_c^{1/3}$

Equation 3

For suitable β $SIGMA = SIGMA_{tm} = 5.\gamma.Q_t^{1/3}$

Equation 4

Where:

= specific gravity, and

where

I_{50} = Point load index

β = Angle between the tunnel face and the angle of weakness (e.g. not suitable angle = 90 deg; suitable angle = 30 deg)

By using the Q_{TBM} value we can calculate penetration rate and advance rate with equations 5 and 6.

$$PR = 5.Q_{TBM}^{-0.2}$$

$$AR = 5.Q_{TBM}^{-0.2}.T^m$$

Equations 5 & 6

Where:

PR = Penetration rate

Q_{TBM} = TBM tunnelling quality method index

AR = Advance rate

T_m = Time productivity or performance

M = Performance ratio (Estimated from standard Q-method graph of rock mass quality against advance in metres)

By using the Barton method analysts can calculate performance in different time ranges.

The Q model was developed in 1976 according to the empirical relation between geological parameters and machine performance by the Norwegian Geotechnical Institute (NGI) using 230km of tunnel excavation across Europe (Salehi 2007[2]).

In 1995 Palmström presented the RMi system to describe rock mass conditions. By development of a database and combination with the RMR and Q models, plus Norway Civil Engineering Department comments, the current RMi system was presented (Salehi 2007[3]).

According to this model penetration rate can be estimated by combining rock material boring and excavation data with rock discontinuity and machine parameters. The RMi model logic in TBM excavation capacity evaluation is shown in fig. 2. By using this, the analyst can estimate net penetration rate, cutter life index, machine performance and advance rate parameters.

In order to calculate these parameters the following values should be available:

- Rock mass compressive strength
- Rock mass drillability
- Cutter diameter and spacing
- Rock mass discontinuities
- Thrust per cutter
- Cutterhead speed (rev/min)

In this model the net penetration rate is calculated as:

$$I = i_0.RPM.60/1000$$

Equation 7

In which:

I = Net penetration rate

i_o = Basic penetration rate, as estimated from figure 2.

To use the graph in fig. 3, the two factors of equivalent fracturing factor (Kekv) and equivalent thrust (Mekv) must be available. These values can be calculated with equations 8 and 9.

$$K_{ekv} = K_{s\text{-}tot}.K_{DRI}$$

$$M_{ekv} = M_B \text{ x } K_d \text{ x } K_a$$

Equations 8 & 9

Where in equation 8:

K_{ekv} = Equivalent fracturing factor

$K_{s\text{-}tot}$ = Total fracturing factor from equation 10

K_{DRI} = Correction factor for DRI ≠49 from fig. 4; (i.e. correction for DRI if wrong as value 49)

and in equation 9:

M_{ekv} = Equivalent thrust

M_B = Gross average thrust per cutter, i.e. not the available thrust capacity of the machine, but the actual thrust used (kN/cutter).

K_d = Correction factor for cutter diameter from fig. 4

K_a = Correction factor for average cutter spacing from fig. 5

$$K_{S\text{-}tot} = \sum_{i=1}^{n} K_{si} - (n\text{-}1)0.36$$

Equation 10

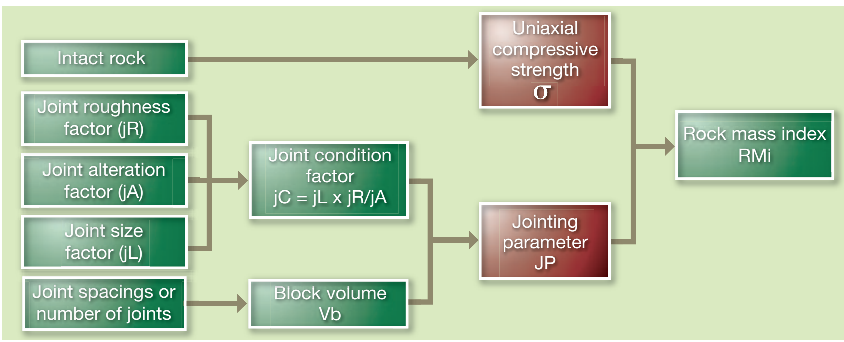
where:

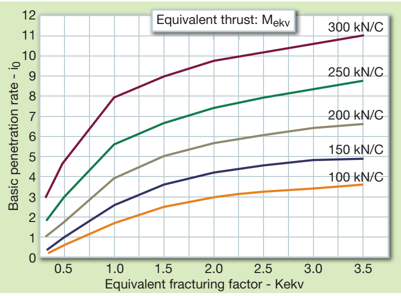
K_{si} = fracturing factor for set no. i,

N = number of fracturing sets (Bilgin & Balci – 2005[5])

The factor Ks can be calculated by having rock mass classification values with attention to existing fracturing and also the angle between the tunnel axis and fracture plane (fig. 3). Also, by having the fracturing factor and Drilling Rate Index (DRI) for each zone, KDRI can be calculated.

Below: **Figure 1 – The input parameters to RMi[4]**





Above: **Figure 2 – Basic penetration rate (Salehi 2007[3]);** Right: **Figure 3 – Fracturing classification (Salehi – 2007[3])**

In the RMi method the database has been based on 19in.- (483mm-) diameter discs and 70mm spacing. In a project where the two factors differ from this, the values should be adjusted. The graphs in figures 4 and 5 have drawn from database values.

Performance in the RMi model is drawn from the parts shown in equation 11.

$$U = \frac{100.T_b}{T_b + T_t + T_c + T_{TBM} + T_{bak} + T_a} \quad \text{Equation 11}$$

where:

T_b = boring time
T_t = regripping time (5.5 min. each cycle)
T_c = cutter change and inspection time (dependent on cutter life)
T_{TBM} = maintenance and service of the TBM from fig. 6
T_{bak} = maintenance and service of the TBM back-up system from fig. 7
T_a = miscellaneous activities including waiting for transport, laying tracks, water, ventilation, electric cables, surveying, cleaning, normal rock support and other loss of TBM operating time fig. 7 (Bilgin & Balci – 2005[5])

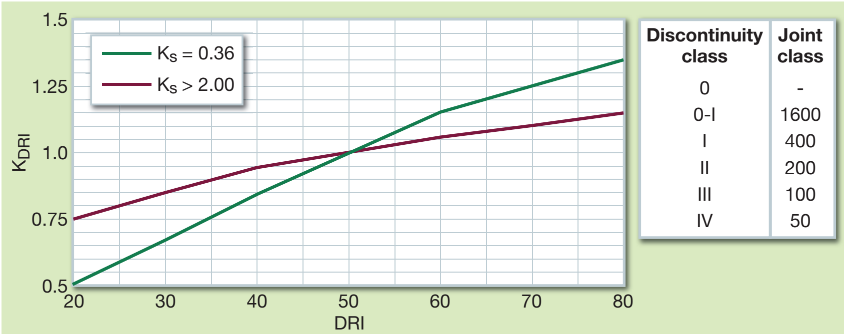
Advance rate calculation

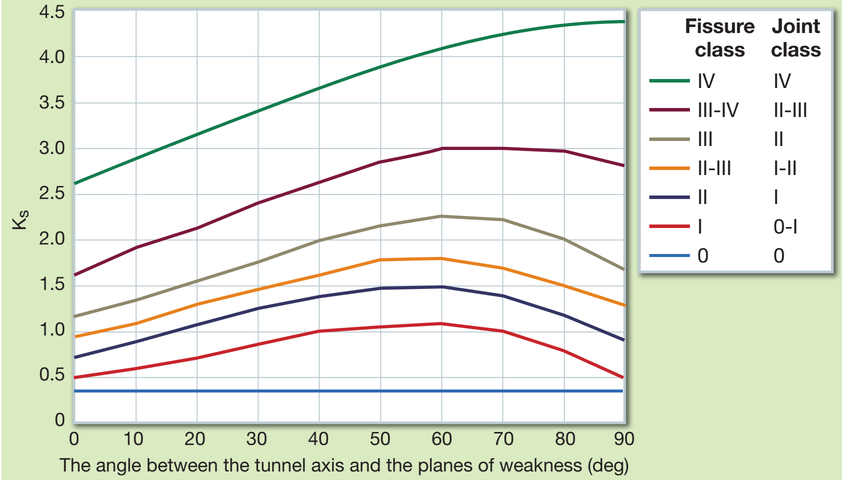
Each of the two presented methods for advance rate estimation needs parameters that sometimes require results from lab studies. In the QTBM method cutter life index (CLI), and in the RMi model the drilling rate index (DRI), both needing special tests, are very important. In the Karaj-Tehran project CLI and DRI tests were not done, and these indices's values have been estimated from charts and tables (Salehi 2007[2]).

In this project the cutting disc diameter is 17 inches (432mm) and their spacing 90mm. These values have been used after adjustments using figs. 5 and 6. For this project the correction factors for cutter diameter and for average cutter spacing are 1.15 and 0.9 respectively. The results of all calculations are given in table 2.

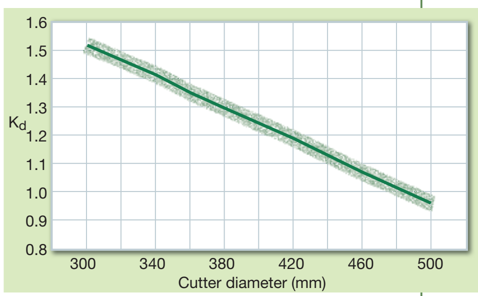
In the RMi method the actual thrust is used. Hence here 80 per cent of nominal thrust is given assumed as the MB parameter value equal to 200 kNs. According to the actual thrust, and diameter and spacing correction factors, the equivalent thrust calculation by equation 9 is:

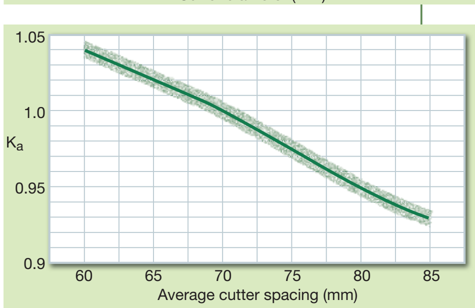
$$M_{ekv} = M_B \text{ x } K_d \text{ x } K_a = 200 \text{ x } 1.15 \text{ x } 0.9 = 207kN$$





Right, top: **Figure 4 – Correction factor for cutter diameter (Salehi – 2007[3]);** Right, bottom: **Figure 5 – Correction factor for average cutter spacing (Salehi – 2007[3])]**





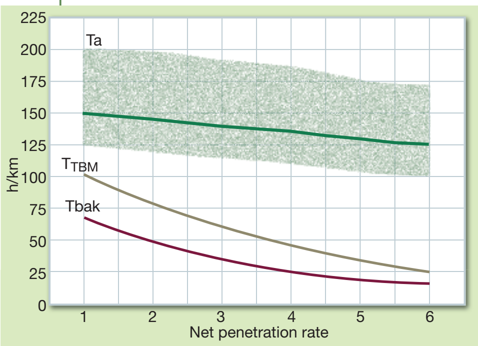
Conclusion

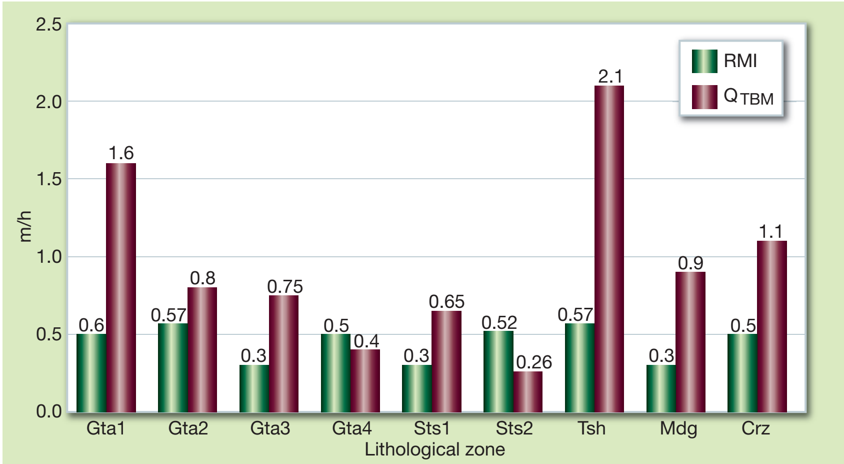
Both the Barton Q_{TBM} and MRi Norway methods are empirical, based on databases both a minimum of ten years old. In the Barton Q method joint properties directly affect calculation, but in the RMi method joint properties by joint equivalent factor are used.

Accurate calculating of RMi method parameters requires a DRI index value. Hence results have high dependence on the DRI index. In the current project the rock drillability index (DRI) values have not been tested and estimated values are used. The Barton Q_{TBM} method, because of its reliance the Rock Quality Index (Q) is capable of more measurement than the RMi method.

At the time of writing the TBM had advanced 320m per month. If the current progress continues the project will end within 50 months. By assuming 20 hours of work per day the tunnelling project time according to the Q_{TBM} method is calculated at 52 months and at 56 months by the RMi method (fig. 7).

The RMi method has predicted machine performance to within 17 per cent in nine zones, while in Barton Q_{TBM}





Above: **Figure 6 – Time consumption for TBM, back-up systems and losses; Right: Figure 7 – Advance rate prediction for various project lithological zones**

method this ratio varies as 4-20 per cent. Uniformity of calculated performance with the RMi method is because of standard timings in some activities. This is one weakness of this model, since if the parameters' values are invalid, such as from a water inrush or TBM breakdown, then project time will increase and machine performance decrease.

In a project where there was no possibility of doing drillability, bit wear index or equivalent thrust tests, using the RMi method will have accurate results. Because this method also includes site properties, it can establish the TBM specification.

Q_{TBM} method factors, except for cutter life index, do not need complicated lab tests. In a project with a variety of joint structures, for which high-level lab tests are not possible, and only basic primary information on geological data factors, using the Q_{TBM} method is suitable. Hence, in consideration of this project's jointing and the RMi method's dependency on lab test data, Q_{TBM} results are more valid.

Acknowledgement

The authors thank the Hara Institute for its unsparing information on the Karaj – Tehran water supply tunnelling project.

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Table 2: Advance rate calculation results by experimental methods

Parameter	Geotechnical unit								
	Gta				Sts		Tsh	Mdg	Crz*
	1	2	3	4	1	2			
Zone length (m)	2230	2300	1200	3280	620	3670	1410	750	520
By Q_{TBM}									
RQD_o	56.25	60	72.5	60	67.5	78.75	62.5	47.5	25
J_n	4	3	2	2	3	2	2	3	1
J_r	2	1.8	3	3	1.6	2.5	1	2.3	0.5
J_a	6	5.3	3.3	1	1.7	0.4	3.3	2.3	10
J_w	1	0.66	0.66	0.4	0.15	0.4	0.6	0.6	0.55
SRF	10	7.5	7.5	2	2.5	2	10	2.5	15
Q_o	0.468	0.6	2.9	18	1.27	43	5	3.8	0.046
UCS (MPa)	30	75	100	120	120	120	60	90	<30
I_{s50} *(Point Load Index)*	1.5	3.7	5	6	6	6	3	4.5	1.7
SIGMA	4.8	11.7	16.5	39	14	34	5.8	7.5	1.4
F (tonnef)	25.5								
CLI	115	38	16	11	11	11	50	16	150
Q	10-20	10-20	10-20	10-20	20-30	20-30	20-30	20-30	0-5
	19	26	26	43	14	28	19	12	25.5
Q_{TBM}	0.005	0.063	1.027	36.26	0.5	82	0.027	0.47	0.0003
PR(m/h)	14.43	8.69	4.97	2.44	5.74	2.07	10.3	5.8	25.3
U(%) yearly	11.3	9.4	15	16.3	11.3	12.4	20.4	15.4	4.2
AR (m/h) yearly	1.6	0.8	0.75	0.4	0.65	0.26	2.1	0.9	1.1
Time (months)	2.33	4.8	2.67	13.67	1.6	23.53	1.13	1.4	0.8
By RMi									
Number of discontinuities	4	3	3	3	3	3	3	3	4
$K_{s\text{-}tot}$	6	4.08	2.58	2.03	3.58	2.53	3.64	2.54	4
DRI	80	55	45	42	43	43	63	48	78
K_{DRI}	1.2	1.044	0.975	0.93	0.934	0.934	1.1	0.985	1.19
K_{ekv}	7.2	4.26	2.5	1.9	3.34	2.36	4	2.5	4.75
i_o *(mm.rev)*	7.5	7	6.2	5.7	6.7	6.1	6.8	6.2	7.2
I (m/h)	3.46	3.23	2.86	2.63	3.1	2.82	3.15	2.86	3.33
U (per cent)	17.5	17.7	18.5	19	18	18.5	18	18.5	15
AR (m/h)	0.60	0.57	0.3	0.5	0.3	0.52	0.57	0.3	0.5
Time (months)	6.17	6.73	6.67	10.93	3.47	11.77	4.13	4.17	1,73

*: Tunnelled after grouting

Design and construction of deep shafts

At the January meeting of the BTS Alan Auld of Alan Auld Group presented the methods and challenges of deep shaft design and construction

There is currently an emerging demand for deep shaft accesses, for water schemes such as Thames Tideway, coal extraction (although not in this country in any great quantity) and metaliferous mining for gold, tin, copper and others as well as mineral extraction, in particular salt and potash.

In addition to these varying industries there is the long running government mandate requiring the development of undergound nuclear waste storage facilities to be fully functional by 2040.

These demands are ensuring that the design and development of deep shafts is becoming and ever increasingly important issue.

Deep shafts can be categorised into two types:

The deep civil engineering shafts (up to 50m in diameter and down to depths of about 70m)

and mine shafts (Up to 10m in diameter and down to depths of more than 3000m).

The background that supports the distinction between these two groups is the Approved Code of Practice on the Mines (Shafts and Winding) Regulations 1993 under Section 16 of the Health and Safety at Work etc Act 1974 and New Brunswick Regulation 96 – 105 under the Occupational Health and Safety Act (O.C. 96 – 968). Both of these documents define limits for the maximum depth of shaft that a crane can be used. At greater depths the shaft must have a head-frame and winding gear.

This paper will focus on mine shafts and the associated design and construction practices.

UK shaft sinking

The present state of the UK's deep shaft sinking capability is a subject of concern.

Table 1

Project	Client	Contractor	Diameter (m)	Depth (m)	Date
Selby Wistow No. 1 and No. 2 shafts	British Coal	Cementation Mining Ltd	7.315	411 (No. 1) 383 (No. 2)	1977-81
Selby Riccall No. 1 and No. 2 shafts	British Coal	Cementation Mining Ltd	7.315	823	1977-83
Selby Stillingfleet No. 1 and No. 2 shafts	British Coal	Thyssen (GB) Ltd	7.315	708	1978-82
North Selby No. 1 and No. 2 shafts	British Coal	Cementation Mining Ltd	7.315	1043	1978-86
Selby Witemoor No. 1 and No. 2 shafts	British Coal	Thyssen (GB) Ltd	7.315	965	1979-85
Dearne Valley shaft	British Coal	Thyssen (GB) Ltd	3.658	300	1980-82
Castlebridge shaft	British Coal	Thyssen (GB) Ltd	6.1	413	1981-83
Dodworth-Redbrook shaft	British Coal	Amalgamated Construction Co. Ltd	6.1	413	1981-83
Maltby No. 3 shaft	British Coal	Cementation Mining Ltd	8	1000	1981-87
Asfordby No. 1 and No. 2 shafts	British Coal	Cementation Mining Ltd	7.32	527	1985-89
Total=16	**Total=16**	**Total=16**	**Total=16**	**Total=16**	**Total=16**

Table 2

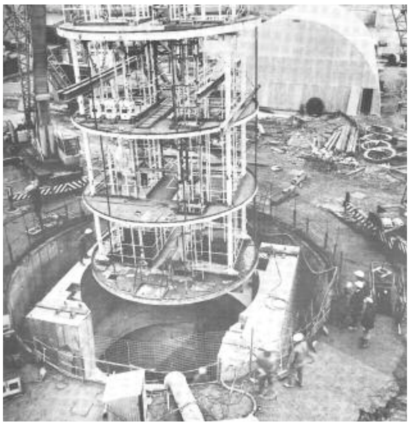
Project	Client	Contractor	Diameter (m)	Depth (m)	Date

NONE

Table 1 gives historical data relating to this subject. In contrast Table 2 reveals the stark reality of the state of the industry with the summary of shafts sunk from 1987 onwards.

The two major UK shaft sinking companies who have completed these works in the past, Cementation Mining and Thyssen (GB), no longer exist. This leaves Amalgamated Construction Company (AMCO) as the only current company to have sunk a deep shaft from the surface in the UK and that was only one shaft 27 years ago.

Most of the contractors' personnel with the specialist shaft sinking knowledge have disappeared from the industry. All of the contractors' specialist shaft sinking equipment, which they used to retain, including head-frames, scaffolds (in shaft working platforms) and winders have been scrapped. A major shaft sinking learning curve will be required in the future for any UK company to take on the construction of



Above: Sinking scaffold being lowered into shaft at Selby coalmine complex
Left: Table 1 and 2 comparing shafts built before and after 1987

deep mine shafts in the UK. This is particularly relevant for the future construction of an underground nuclear waste repository.

Global shaft sinking

The construction of deep shafts is progressing and flourishing around the world with ever increasing commodity prices making previously uneconomic deep reserves commercially viable. This increases the need for ever deeper shafts. The locations and numbers are too numerous to list but a broad brush example of some of these projects in which the Alan Auld Group is associated are:

In Canada

- Potash Corporation of Saskatchewan (PCS) Piccadilly Potash Mine Project, New Brunswick. Two shafts 5.5m diameter, 920m deep are presently under construction – groundwater control by grouting.
- PCS Scissor's Creek (Rocanville West) Potash Mine Project, Saskatchewan. One shaft 6.0m diameter, 1,130m deep under construction – groundwater control by freezing to 600m, grouting below.
- BHP Billiton Diamonds Jansen Potash Mine Project, Saskatoon, Saskatchewan. Two shafts 6.5m diameter, 1,135m deep out to tender – groundwater control by freezing to 525m, grouting below.
- Saskatchewan. Two shafts 6.0m diameter, 962m deep at pre-feasibility stage - groundwater control by freezing to about 500m, grouting below.

In the Russian Federation and Kazakhstan

- Eurochem – Volgakaliy Gremyachinsky Potash Mine Complex, near the town of Kotelnikovo in the Volgograd Region. One shaft 7.0m diameter, 1000m deep under construction – groundwater control by grouting.

In Ukraine

- Lubel Coal Company Lubelska No.1 and No. 2 Coal Mine Project in North West Ukraine. Two shafts 8m, 980m deep at feasibility stage – groundwater control by grouting.

Design

The geological and hydrological data for the ground are the key factors in shaft design. A shaft centerline borehole is drilled to give an understanding of the conditions. Work that will take place will include borehole logging, core logging, hydrological testing (water flow is a critical parameter in the design of the shaft lining and subsequent sinking operations) and lab testing of retrieved samples. Analysis of this data and information recorded during the drilling of the borehole (drill mud loss indicates zones of fracturing) will all build to form a model for the ground in which the shaft will be constructed and the associated measure to be adopted for sinking activities and the long term stability of the shaft structure. This pre-engineering requires constant re-confirmation during shaft excavation.

Once the necessary information has been gathered, development of the shaft lining design can progress. There are three basic types of shaft lining:

- Concrete Lining. Some of the key features of this solution are: it is hydrostatic pressure resisting, provides a dry shaft with acceptable residual water make < 23l/min (considered dry) over it's full depth, requires competent (self standing when excavated) rock lining and installed from the top downwards as sinking proceeds.
- Composite concrete and steel lining: Where greater pressures are likely to be encountered a composite concrete and steel lining might be a more suitable solution. This lining would be both hydrostatic and geostatic pressure resistant as well as 100 per cent watertight. Suitable for competent rock or unstable ground (sands, silts and clays frozen for stability). The drawback of this system is that the permanent lining cannot be built top down. The lining is installed upwards from a foundation after sinking downwards using temporary support.
- Tubbing lining: Spheroidal graphite cast iron or fabricated steel bolted segments are a hydrostatic/geostatic pressure resisting lining that provide a dry shaft. They can be installed quickly in difficult ground conditions as sinking proceeds downwards. Sealing is achieved using lead gaskets, PVC gaskets or lead caulking.

Above right: Chinese six boom jumbo drill
Right: Chinese catcus grab. Photo: Deilmann/Haniel

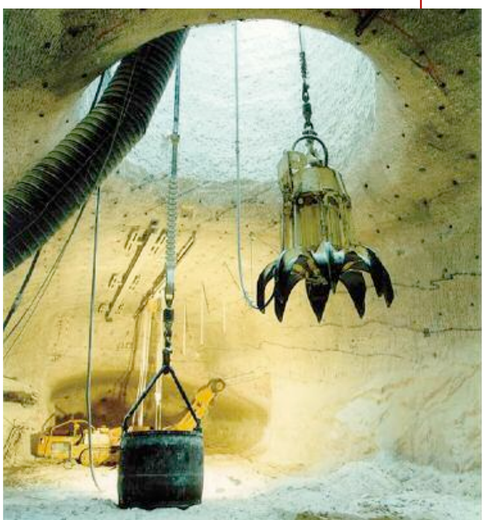
Construction

A key factor during the construction of the shaft is access and the work staging or scaffold. As the shaft sinks, everything is required to advance with the face. The scaffold carries all necessary equipment except for the muck skip or hoppit and a drill jumbo if it should be required for drill and blast excavation.

All of the necessary pit top infrastructure is established once the shaft is of sufficient depth to house the scaffold. This will include the headframe and winding gear, muck handling system and ventilation as well as any requirements for ground freezing.

The winding gear arrangement will incorporate a number of hoisting systems for the staging or scaffolding and muck hoisting.

The conventional hard rock methodology for excavation is by drill and blast. Drilling for blast holes utilizes multi boom drill jumbos



that are designed to close to a compact profile for passing through the scaffold during the mucking phase of the advance cycle. Typically these jumbos will consist of six drills with individual articulation permitting the drilling of six holes at a time.

Mucking of a face will normally be by use of either a cactus or clamshell grab slung on the underside of the scaffold.

In addition to these methods there are a number of mechanical systems that have been used around the world. Examples include oil industry drill rigs with over sized drill heads, raise borers and "V" moles which adopt a pilot hole drilled from the surface to existing underground workings where the cutting head is attached and pulled back to surface to create the shaft, the cut material falls back to the base of the shaft for removal. Of greater interest to the tunnelling industry are vertical tunnelling machines.

Examples of these are the Robbins 241SB-184 blind shaft borer developed between 1975 and 1983 operated by Cementation America and used in Oak Grove, Alabama. The machine has a 7.4m diameter and was used to excavate almost 180m of the shaft. It achieved a daily advance of 4.8m against a target of 7.6m. The main issue was the removal of excavated material from the face. The machine adopted a system of chain conveyors and buckets to lift the material from the bottom of the shaft up to the muck hoppit for transfer to surface.

In 1983/85, Redpath and Robbins developed an alternative machine utilising a rotating disc cutting head with a clamshell grab to remove spoil from the face. Although built, the machine was never actually used.

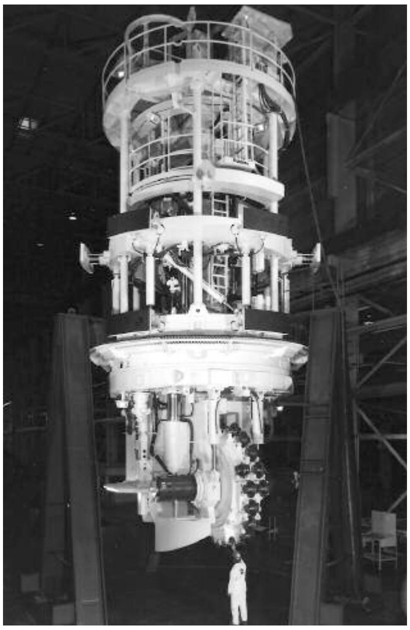
Ground stability and water control methods

As shaft excavation progresses, the ground conditions and water ingress are critical issues to the stability and safety of the workings. The pre-construction investigation works should have determined the level at which water will be encountered but during the sinking of the shaft regular boreholes should be completed to confirm the expected conditions.

Encountering water is inevitable. If the quantities are low (below 23l/min) then a pumping system can be installed to deal with the inflow, any greater amounts will warrant the adoption of a method of ingress control. This could be either grouting from surface, cover grouting from within the shaft or ground freezing.

The grouting from surface and the cover grouting adopt a pattern of drill holes around the perimeter of the shaft into which a suitable grout is pumped. The intention is for the grout to permeate the ground between the holes creating a barrier to the water path. The cover grouting will occur along the length of the shaft as and when ground conditions and water dictate. Under certain circumstances the drill pattern will incorporate a cut-off layer beneath the shaft to prevent ingress from below.

Ground freezing techniques adopt identical logic but cold brine is circulated through pipes installed into the drill holes which results in a frozen zone around each hole and subsequently the entire shaft preventing the flow of water into the shaft.



Above: Redpath/Robbins shaft boring machine

Lining techniques

Placement of the structural concrete lining adopts relatively common shuttering systems but with particular features to permit the lining to be placed below the previous pour not above as in standard casting operations. The joint detail is designed to permit placement of concrete into a bay below the previous one. Standard pours are 6m lifts with the shuttering suspended from the previous bay, a kerb ring and the bottom of the lift acts as the stop end at the underside of the pour. The mix design and rate of pour are selected to ensure that only half of the pour loads are ever taken by the previous pour through hanging rods. All other loads are transferred into the surrounding ground.

Each lift will then undergo back wall grouting to seal the bay and instead of a water bar, a high pressure grout hose is installed to enable the joints to be sealed from water ingress at the extreme depths and associated water pressures.

For the combined lining, the temporary lining will be installed, next the steel liner will be placed with fully welded joints between the lining rings before the final concrete lining is slip formed. The segmentally (tubbing) lined shafts are constructed in a very similar manner to the underpinning method.

Questions from the floor

Roy Slocombe – Herrenknecht
Question - noted and agreed with Alan's observations that generally, when attempting to use mechanised systems for the excavation of shafts, the cutting of material is OK it is the subsequent removal of excavated material from the face that results in difficulties. He further noted that Herrenknecht has successfully manufactured a machine primarily for use in civil engineering shafts and ready to be sent to a coal mine in Russia to enable shaft construction works to progress through the initial poor ground encountered close to surface. There was confusion as to why the South African system of two three boom jumbos worked.
Answer – It was a matter of size to enable the jumbos to pass through the scaffold.

Barrymore Nichols – Murphys
Question - In the remedial works in the squeezing ground at Boulby, has anyone considered drilling a fan of sacrificial holes around the shaft where the squeezing is occurring?
Answer - The response was that the ground squeezes too quickly for this option to be a viable solution. The ground squeezes and grips the drill strings.

Alistair Biggart – consultant
Question - Had previously visited Boulby and noted that at the location of the gap between sections of the lining mentioned in the presentation they had driven wedges in.
Answer - Alan responded that the gap had now been sealed.

David
Question - What is the deepest a shaft can be sunk.
Answer - In the past depths of 1000m were achievable with subsequent sub level shafts to permit access to greater depth. Rope stretch and winder capacity were limiting factors but new technology was permitting greater depths to be achieved.

Rapporteur: Roger Bridge

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Paul Hoyland, Chairman, British Tunnelling Society

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More information is available from Dave Sykes on 01773 582257

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dates & events

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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

19-21 MAY 2010
Tunnel China, Shanghai
With a focus on China 'The most dynamic market for the tunnelling and underground space industry in the world' the event will look at railway and highway developments and feature trenchless technology. Contact: web: www.tunnel-china.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. Contact: Czech ITA-AITES: tel: +420 266 793 479; email: ita-aites@metrostav.cz; web: www.ita-aites.cz

15-17 JUNE 2010
European Rock Mechanics Symposium (EUROCK 2010)
Eurock 2010 is an ISRM Regional Symposium of Europe. The Symposium covers all the aspects of rock mechanics and rock engineering. Contact: Jean-Paul Dudt, Laboratory for Mechanics of Rock (LMR). EPFL-ENAC-LMR Station 18 CH-1015, Lausanne; tel: +41 21 693 23 25; fax: +41 21 693 41 53; email: lmr@epfl.ch; web: www.lmr.epfl.ch

19-23 JUNE 2010
North American Tunneling Conference, Portland USA
The 2010 NAT will be held at the Marriott 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.

28 SEPTEMBER 2010
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23 – 26 NOVEMBER 2010
Bauma China 2010, Shanghai New International Expo Centre, Shanghai, China
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1 - 3 MARCH 2011
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The 2011 conference orgaised by the Tunnelling & Underground Space Technical Division (TUSTD) at The Institution of Engineers, Malaysia (IEM), will focus on tunnelling in South East Asia, future challenges and management of safety and risk. Contact: Conference Secretariat, Tunnelling and Underground Space Technical Division, The Institution of Engineers, Malaysia Bangunan Ingenieur, Lots 60/62, Jalan 62/4 P.O.Box 223 (Jalan Sultan), 46720 Petaling Jaya, Selangor, Malaysia; Tel: +(603) 7968-4001 / 4002; Fax: +(603) 7957-7678; Email: Tunnel2011@iem.org.my Website: www.iem.org.my

12 - 16 SEPTEMBER 2011
6th International Symposium on Sprayed Concrete, Norway
Sixth International Symposium on the modern use of wet-mix sprayed concrete for underground support will be held in Tromsø, in the north of Norway. Contact: Siri Engen The Norwegian Society of Graduate Technical and Scientific Professionals - Tekna; fax: +47 22 94 75 01

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition that is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site: Editor, 'Tunnels & Tunnelling International', John Carpenter House, 7 Carmelite Street, London, EC4Y 0BS, United Kingdom. Fax: +44 20 7936 6826 Email: editor@tunnelsonline.info Web: www.tunnelsonline.info

BRITISH TUNNELLING SOCIETY

20 MAY 2010: **West Ham Flood Alleviation Scheme**
Andrew Morgan of Costain will presents the West Ham Flood Alleviation Scheme. ICE, 5.30pm for 6pm start.

17 JUNE 2010: **Atlantic Sea Tunnels in Norway**
Prof. Eivind Grøv, vice president ITA and president of the Norwegian Tunnelling Society will speak on road tunnels and bridges being built along Norway's western sea coast. ICE, 5.30pm for 6pm start.

16 SEPTEMBER 2010: **Tunnelling in Seattle - Past, Present and Future**
How tunnels have been used in Seattle and why they are now starting to push the envelope in American tunnelling. The talk will look in detail at recent projects, particularly Brightwater, and at the planned 58ft diameter bore for the Alaskan Way viaduct replacement tunnel.
Brightwater is a $2 billion new wastewater treatment system, which includes 14 miles of soft-ground bored tunnel. Currently under construction, the tunnels are being bored using 2 EPB and 2 slurry TBMs, and are notable for their long drives and high mining pressures. ICE, 5.30pm for 6pm start.

21 OCTOBER 2010: **Sir Alan Muir Wood Memorial Symposium**
The British Tunnelling Society is presenting a symposium on tunnelling and geotechnical themes with papers looking at recent tunnelling case histories, risk, and the inter-relationship of current design and research. Confirmed speakers include, prof Robert Mair, Prof John Burland, Prof David Muir Wood, Robert Muir Wood, prof Paul Jowitt and Martin Knights. Contact: bts@event-logistics.co.uk

18 NOVEMBER 2010: **Pittsburgh Northshore Connector**
Stephen Woodrow and Andy Miller of Faber Maunsell (AECOM) will deliver this talk on the light rail tunnels in mixed ground conditions with challenging vertical alignment.
The tunnelling works for the Northshore Connector Project in Pittsburgh, USA, involved several engineering challenges. The construction included 6.5m i.d. bore tunnels, 660m long passing under the Allegheny River. ICE, 5.30pm for 6pm start.

16 DECEMBER 2010: **Baggage tunnel design and construction at Heathrow Airport**
Andrew Stephenson of BAA, Enrique Blanco of Ferrovial and Athur Darby of Mott macDonald give details on the challenges of constructing the tunnel under one of the world's busiest airports. ICE, 5.30pm for 6pm start.

contacts

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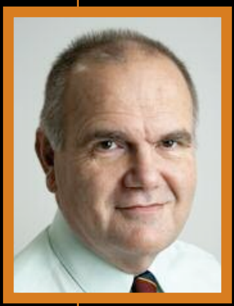

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Tunnels & Tunnelling International is printed at Stephens & George Print Group, Merthyr Tydfil.

Tunnels & Tunnelling International ISSN number 0041-414X is published monthly for US$226 a year by World Market Intelligence Ltd (www.worldmarketintelligence.com), a Progressive Media Group company, John Carpenter House, 7 Carmelite Street, London EC4Y 0BS, UK. Periodicals postage paid at Rahway, NJ.
POSTMASTER: send address corrections to Tunnels & Tunnelling International c/o BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001. US agent: BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001.


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