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AUGUST 2011

tunnels & tunnelling
INTERNATIONAL



Middle East

T&T cuts in on Qatar's World Cup tunnelling plans and progress on the UAE's mega jobs

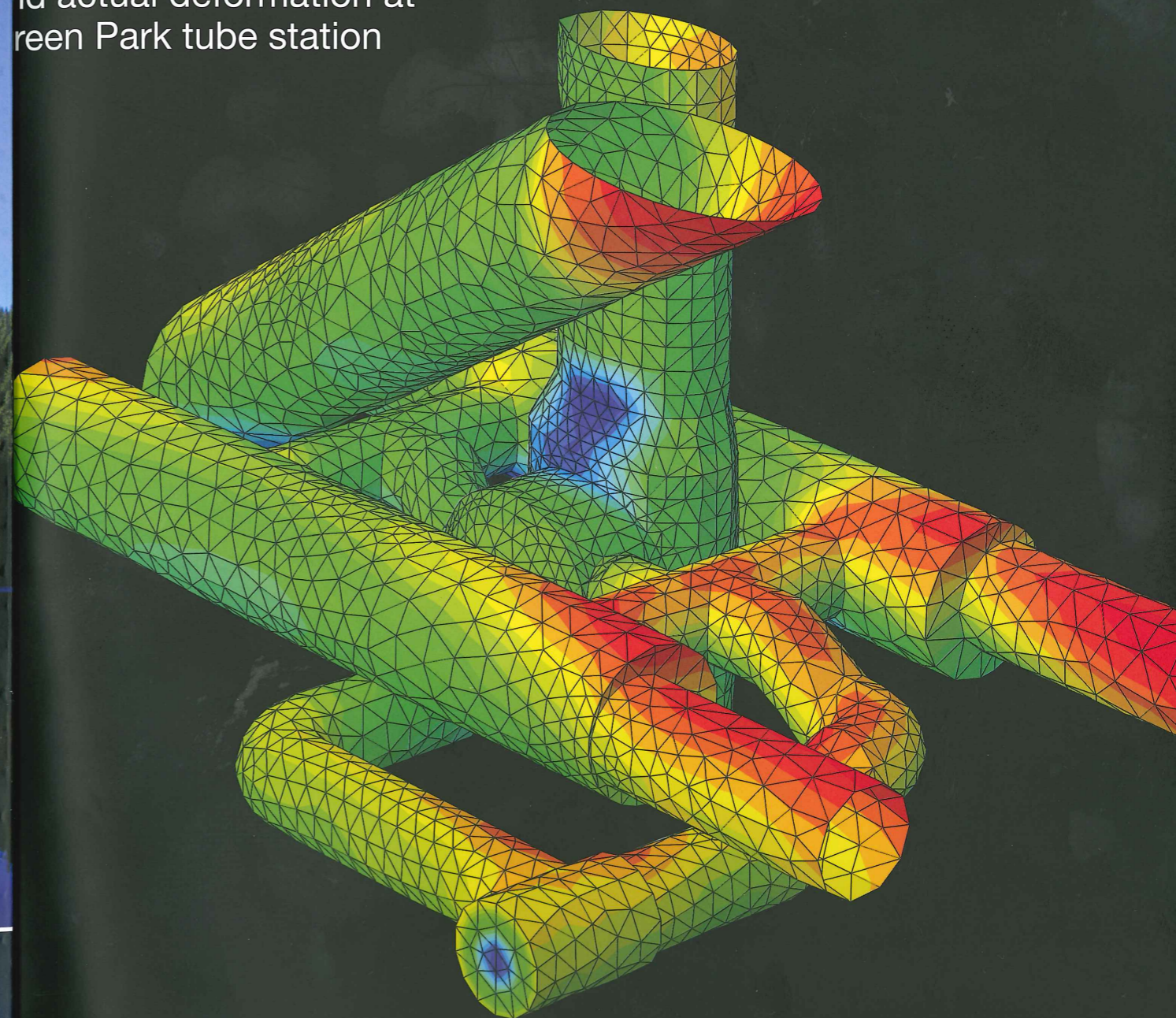
Structural Grouting

Preparation is all as ground treatment pushes the possibilities for tunnelling

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Model metro

comparison of predicted
and actual deformation at
Green Park tube station



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Wishful thinking

So the global economy has taken yet another down turn. As I write, the stock markets have tumbled on the US, Asia and this morning European stock exchanges. The biggest fall since 2008. Greece has defaulted on its loans. Spain and Italy are both crying out for EU assistance in paying back their debts. The Germans look grim-faced as theirs and others' dream of a single and stable European currency proves to be unachievable.

The US sent shivers down the collective spine of the ratings agencies when it voted to raise the limit on its borrowing. And Standard and Poor's reacted by downgrading the country's credit rating from AAA to AA+. If the US, the world's largest economy, can't manage its debt and Europe can't get a handle on its crisis, the coming years will be very harsh. Perhaps it is too soon to speak of a double dip recession. Perhaps not.

Daily newspapers are awash with stories questioning whether the failed Greek bailout would inspire market confidence by showing that faltering Eurozone countries are backed up by their larger siblings. But instead many see it as an unsuccessful knee-jerk, panicked defence of the single currency Eden. The hopes and fears of the masses are suddenly causing sleepless nights in many an ivory tower.

Like many of you I am wondering what this could mean for tunnelling.

T&TI has started running opinion polls, sent out over email every Thursday in the weekly newsletter. More than 10,000 readers receive the email and voters last week gave hope for the tunnelling industry in casting their vote. Some 77.8 per cent of respondents said that the industry was supported by emerging economies over developed economies (see page 8).

If these voters accurately reflect the industry, then as a whole the tunnelling industry might not fare too badly. The large manufactures and consultants can find business supporting the still rapidly developing economies of India and China. International contractors can join consortiums in the regions while more local contractors may struggle.

The Middle East has offered further hope this month. On page 14 Bernadette Ballantyne goes into detail on Qatar's infrastructure plans, much of which is underground and needed for the 2022 FIFA World Cup. As T&TI goes to press, bids have been called for the Doha Metro project. The Qatari government has made clear that no projects will be won without the involvement of both international and local firms – good news for tunnellers.

But the largest economies are still home to the biggest tunnelling projects and it is vital that tunnellers protect them. Italy is on the brink of a very major crisis and that can not be allowed to disrupt the Bologna to Florence motorway's Sparvo tunnel, which is currently employing the worlds largest TBM. Likewise the Seattle viaduct replacement scheme, which has just ordered the next record breaking TBM at 17.7m from Hitachi Zosen (see page 5), must not fall foul of any cost cutting stemming from the latest economic turmoil.

The industry's best lobbyists from the local and international associations and the largest tunnelling firms are going to have to work hard to protect our projects and ensure that any double dip in the economy is not seen in tunnelling.

Jon Young

contents

NEWS

- 5 **WORLD NEWS**
- 11 **BUSINESS NEWS**
- 12 **NEWS IN DEPTH**

SPECIAL REPORT: MIDDLE EAST

- 14 **OVERVIEW**
Qatar set for next tunnelling boom
- 19 **CAIRO 3D ANALYSIS**
Cutting into the shaft
- 25 **ABU DHABI GROUND TREATMENT**
Collapse and recovery in Abu Dhabi

TECHNICAL

- 30 **SOPHISTICATED GROUTING**
Grouting supports tunnelling market
- 34 **DRILLING IMPROVEMENT**
Standards set for pre-grout drilling
- 39 **CONVENTIONAL TUNNELLING FORECASTING**
Forecasting tunnelling behaviour

INSIGHT: UK WATERPROOFING

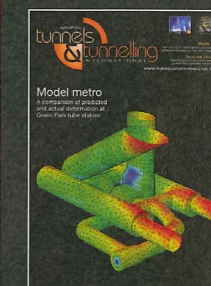
- 45 **SPRAYED WATERPROOF MEMBRANES**
Experiences with sprayed waterproofing

BTS

- 51 **HARDING PRIZE RUNNER UP**
Predicted and encountered deformations

DIRECTORY

- 55 **BUSINESS DIRECTORY**
- 58 **BTS CORPORATE MEMBERS**



On the cover:

An ABAQUS model of the construction work at Green Park tube station on the London Underground



And in the supplement:

T&TNA takes a look at tunnelling in the Southwest including a new Water Treatment plant in Texas



AIRPORT TUNNEL REVOLUTIONIZES TRAFFIC IN THE NORTH OF BRISBANE.

The construction of a tunnel network is in full swing in Brisbane, to relieve the city highways aboveground. At the moment, the construction timetable of the double-tube Airportlink East-West Tunnel has reached a milestone: The tunnel specialists of Thies John Holland JV celebrated breakthrough with the Herrenknecht EPB Shields S-514 (Rocky) on July 4 and S-512 (Sandy) on July 6 in the parallel tunnel. The tunnel is planned to significantly shorten the journey between the city and airport.

Sandy and Rocky, with a diameter of 12.45 meters each, are the largest tunnel boring machines ever seen in Australia. The TBM tunnelling was completed within one year with the help of H+E Logistik (conveying systems), Herrenknecht Formwork (lining segment moulds) and VMT (surveying and navigation systems), all from the Herrenknecht Group. Anna Bligh, Queensland's Premier spoke about "the revolutionizing of traffic in the north of Brisbane" on the occasion of the breakthrough.

BRISBANE | AUSTRALIA

PROJECT DATA	CONTRACTOR
S-512, S-514 2x EPB Shields Diameter: 12,450mm Installed power: 4,900kW Tunnel lengths: 2,270m, 2,380m Geology: mainly Tingalpa/Aspley formation, Brisbane tuff	Thies John Holland Joint Venture



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Hitachi Zosen to build world's largest TBM for Seattle's Alaskan Way tunnel

USA

Seattle Tunnel Partners (STP) last month announced it has chosen Japan's Hitachi Zosen to supply the 58ft (17.7m) diameter TBM that will bore the tunnel replacing the Alaskan Way Viaduct. Hitachi Zosen will be responsible for designing, manufacturing, assembling, testing and commissioning the machine as well as training STP personnel.

Herrenknecht (Germany), Hitachi Zosen (Japan), Kawasaki-SELI (Japan, Italy), and Robbins-Mitsubishi (United States, Japan) submitted boring machine proposals on May 31.

A press release issued by Washington State Department of Transportation's (WSDOT) said Hitachi Zosen was the "best value manufacturer based on overall technical requirements, support capabilities, price and schedule."

STP, the design-build contractor joint venture of Dragados USA and Tutor Perini, had met with all



The Alaskan Way tunnel will replace the existing viaduct, which is being demolished following earthquake damage

of the manufacturers numerous times during the evaluation, and issued a letter of intent to Hitachi Zosen on July 15, which allows them to begin preliminary

design until the project receives federal environmental approval next month.

Once approval is issued, WSDOT will direct the contractor

to proceed with final design and construction, and the design-build team will execute a contract with Hitachi Zosen to design and manufacture the boring machine.

WTP4 halted

USA

Issuing notice to proceed on the Water Treatment Plant 4 (WTP4) in Austin, Texas, has been brought to a halt by the City Council, which approved the measure in a 5-2 vote taken last month.

The resolution directs the city manager to determine cost estimates of postponing construction on the plant for five and 10 years. These estimates are expected on or near August 18.

Part of the resolution includes an amendment that notices to proceed will be suspended until September 2, the day after the council expects to discuss the project cost estimates.

Four killed in parking row

CHINA

Four tunnel workers were killed and 16 injured in an explosion after a fight broke out over a parking space in Longnan City, Gansu Province, China.

Workers from the construction crew of the Wuguan highway, a section of the Lanzhou-Haikou highway, fought with workers from the Lanzhou to Chongqing railway tunnel construction team.

The Lanzhou to Chongqing

workers later detonated explosives in revenge, reported the state-run Xinhua news network.

The four deaths were all from the Wuguan team. Two were pronounced dead on site, one dies in the ambulance and one in hospital. A further 16 remain in hospital care.

The Wuguan highway and Lanzhou Chongqing railway where part of the reconstruction program following the Wenchuan earthquake, which struck in 2008.

Trapped tunnellers break free

CHINA

All 12 workers trapped by a tunnel collapse in China have been rescued. Prior to rescue, some four ventilation and supply holes were dug and mobile phones were lowered.

The tunnel collapsed on the morning of the 18 July. The workers were pulled through a rescue duct to safety by the afternoon. The entire ordeal lasted 36 hours.

The collapse occurred at a tunnel on Shengli Road in Dalian, a coastal city in Liaoning Province, northeast China.

News in brief

▼ Sparvo Underway

Work began on the 2.6km Sparvo tunnel in Italy last month with the launch of the world's largest TBM.

▼ Porr awarded Stuttgart 21

Austria-based Porr will deliver the USD 5.8bn Stuttgart-Ulm rail project in Germany, including the 9.5km Filderstadt Tunnel and 6km Ober-/Unterturkheim tunnel.

Work starts on Africa's first inclined sand tunnel

BOTSWANA

Work started last month on Africa's first inclined sand tunnel according to contractor Redpath South Africa. International diamond producer, Gem Diamonds awarded a ZAR 67M contract to mining giant Redpath for the development of the sand tunnel at the re-commissioned Ghaghoo Diamond Mine in Botswana. Redpath bagged the contract over its competitors because it opted for cost-saving conveyor belts over dumper trucks for muck removal.

Redpath mine manager Olaf Iversen said that project involves constructing the tunnel to 112m vertically below the surface at an

inclination of eight degrees. The site, which is located approximately 200km north of Gaborone, falls within the Central Kalahari Game Reserve.

"The first phase of the project is due to begin in July 2011 with the establishment of a box cut 25m deep and 171m long into the Kalahari sand, which will provide safe and secure access to the underground mine," he explained. "The box cut and portal support is expected to be completed in November 2011, by which time we will begin excavation work for the concrete-lined segmented sand tunnel, 403m in pure sand and 121m in transition from sand to basalt, which acts as a cylindrical shield to protect workers and equipment located underground."

Iversen said that labourers will work within the 50t shield in order to move the tunnel forward segment-by-segment, by loading the sand onto the conveyor belt before it is fed out of the mine. "The width of each segment for this particular project is 0.61m, and we are aiming to move forward six segments or 3.6m per day."

A Gem Diamonds technical representative said, "During the tender process, Gem Diamonds provided each contractor with a specific design for the segmented tunnel; however, the process of clearing the excavated sand was left open. Redpath South Africa was the only contractor that recommended the cost-effective use of conveyor belts for the removal of the sand, as opposed

to articulated dump trucks. Although the initial set-up costs of the conveyor belts are high, the long-term running costs are significantly lower than using trucks, which will ultimately improve the overall efficiency of the project."

The sand tunnel is due for completion at the end of June 2012, however, Iversen admits that Redpath South Africa faces significant challenges in the upcoming months, including managing the transition from sand to the hard basalt where water could possibly be intersected by the contractor.

The entire scope of the project will have to be undertaken using diesel-powered generators in a region with no electricity.

Safety in tunnelling Standard revised

GREAT BRITAIN

The British Standards Institution last month published the revised British Standard 6164 'Code of practice for health and safety in tunnelling in the construction industry' under code BS 6164:2011.

First drafted in 1982 as a 56-page document, BS 6164 was extensively revised in 1991 and

again in 2001. The new version, now some 170 pages long, provides comprehensive guidance on health and safety issues arising from tunnel and shaft construction and tunnel maintenance, renovation and repair. In addition to a general update and a revised bibliography, the clauses dealing with excavation and support have been extensively rewritten as has the clause dealing with shafts.

Both the BTS/ABI (British Tunnelling Society & Association of British Insurers) joint code of practice on risk management in tunnel works and the internationally applicable version published by the International Tunnel Insurance Group make reference to BS 6164:2001. It is anticipated that these documents will be updated in due course to make reference to BS 6164:2011.

Airport Link TBMs buried

AUSTRALIA

The 12.48m TBMs that excavated the Brisbane Airport Link were last month entombed with concrete in reception pits beneath the Link tunnels. Excavation finished on the project with the final breakthrough on 6 July.

The two burial pits were 14.5m wide and 16.5m deep and were

excavated by drill and blast and rock hammer by contracting JV Thiess John Holland. The TBMs were fully encased in 2,500m³ of concrete over 24 hours.

A spokesman told T&T, "The machines were lowered using a purpose designed and built steel bridge structure, connected to six 330-tonne specialist strand jacks. The lowering took around 6 hours from the initial pickup of the

beams until completely lowered in the shaft.

"The final lining in the burial shaft area will be formed in situ concrete on the walls and permanent shotcrete in the roof. By encasing the machines in concrete, no ground water will be able to come into contact with the machine shields and cutterheads, eliminating any possible contamination."

News in brief

▼ **Bauer wins Crossrail foundations contracts**
Bauer technologies was last month awarded two contracts for advanced works at Liverpool Street and Whitechapel stations.

▼ **Alstom to provide 293MW Indian hydropower boost**
French power conglomerate Alstom added three Indian hydro contracts to its order book. The Tashiding project, the Tidong One project and the Dikchu plant were each worth over USD 60M.

▼ **Designing Sydney's longest rail tunnels**
Aecom has been awarded the design contract for the 23km North West Rail Link in Sydney, Australia. It will include 14km of tunnel works.

▼ **Hindhead opened**
The UK's 1.8km A3 hindhead tunnel officially opened last month following tours.

Mott MacDonald to conduct colossal Indian rail study

INDIA

Public sector client Indian Railways Construction Company (IRCON) appointed UK-based Mott MacDonald to undertake pre-feasibility studies for a high speed rail service in India.

The study is part of the Indian Government's 'Vision 2020' national development scheme. Under the plan, the government has stated its intent to implement a the project in each of the four regions of India. The high speed rail project was developed as a response to the 10 per cent yearly increase in demand for public transport in India.

Mott MacDonald rail specialists

Michael de Voil and Jean-Pierre Quinaut will guide the study covering a proposed service between Delhi, Agra, Lucknow, Varanasi and Patna. The capital value of the corridor is approximately INR 1110bn (USD 24.54bn).

A Mott MacDonald spokesman said, "[We] will help to identify key issues for development of the project on a public-private partnership basis. This will include reviewing all technical aspects of the property and the corridor infrastructure development in relation to alignment with existing facilities as well as any environmental impacts and assessment of high-

speed rail technology.

"It will also involve analysis of operational and business requirements, ranging from forecasting preliminary service ridership figures, estimating capital required, costs and benefits analysis and development of a planning and implementation schedule as well as an organisational structure for taking the project forward."

The pre-feasibility report was scheduled for completion in late 2011 as T&T went to press.

The spokesman added that eight further high-speed rail corridors are planned to connect economic, tourist and pilgrimage 'hubs' in the country.

First TBM launched at Mexico City's TEO project

MEXICO

An 8.93m diameter Robbins EPB machine was launched on 13 July on Mexico City's Tunel Emisor Oriente (TEO) 62km-long wastewater tunnel.

Six lots, using three Robbins TBMs and three Herrenknecht TBMs, were planned for the wastewater line, but problems with the first TBM on Lot One prompted the machine change. "A flood in shaft Zero delayed the Herrenknecht machine for six months," said David Juarez, site manager for Lot 1 contractor Ingenieros Civiles Asociados (ICA). "In order to compensate for time lost, we began boring with the machine at shaft Five of Lot One."

The TBM at Lot One has started excavation using umbilical cables

connected to the surface and a sludge pump for muck removal. Once it has bored ahead 150m, a continuous conveyor system and vertical belt will be installed for the remainder of the drive in mainly lake clays and sand.

Once the machine reaches the

end of its 5km drive to shaft Three A at Lot One, it will be removed and readied for its original 8.6km long bore at Lot Five.

Expected to complete in 2014, TEO will add about 150,000 litres of water per second to the city's wastewater capacity.



Right: Cutterhead assembly

Rare shafts conference scheduled

GREAT BRITAIN

The 3rd International Conference on Shaft Design and Construction is scheduled for 24-26 April 2012 in London. The full papers deadline is 31 October this year.

This will be the first conference in the UK for 23 years on international activities in shaft construction for both civil engineering and mining applications. All areas of design and construction will be considered in paper submissions.

The target subjects include planning, geotechnical and hydrogeological data acquisition, temporary support, shafts for mines of potash, salt and coal, permanent lining design, construction materials, nuclear waste storage, groundwater control, mechanisation, furnishing, rehabilitation, ground-freezing, performance monitoring, shaft closure, risk management and various case studies.

News in brief

▼ **Qatar Railways Company invites bids for Doha Metro**
Works will include some 22km of tunnels and 15 stations to be built underground.

▼ **Training in the art of tunnels for Bhutanese youth**
Gammon India, the contractor building the 7.5km headrace tunnel for the 1,200MW Punatsangchu power project announced that it will train 300 youths every year.

▼ **Triple win for Chun Wo**
Chun Wo was awarded three contracts by Hong Kong MTR worth a total of USD 301M covering the South Island Line, Express Rail Link and Kwun Tong Line Extension.

Companies should take lead in attracting students

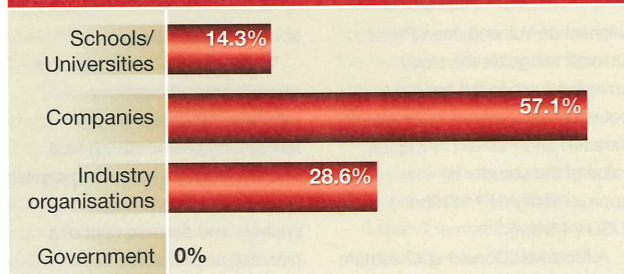
GLOBAL

Tunnellers last month called on companies to lead the charge in enlisting students into the industry. In a poll some 60 per cent of voters said companies should take the lead in encouraging students into tunnelling, while 30 per cent called on industry organisations and the remainder put the onus on schools and universities. Non believers the government should take the lead.

The poll was conducted by T&T as part of the new weekly opinion polls being carried out via the T&T weekly newsletter.

The results defied industry

Who should take primary responsibility for encouraging students into the construction industry?



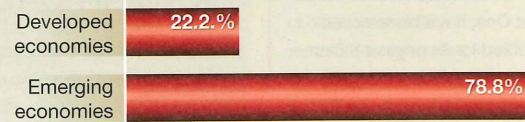
leader's expectations. Head of tunnelling at Halcrow and immediate past president of the ITA Martin Knights said, "My vote goes more to a split between industry organisations and government-funded education.

"I don't think it is fair to ask so much of the companies, they shouldn't be expected to shoulder as much of the burden as this vote indicates. There needs to be a better balance of responsibility in this matter."

A great majority of tunnellers believe it is the emerging economies that are keeping the industry sustained through the global recession. Economies such as India have maintained above eight per

cent growth rates despite the slow down. But still a minority of tunnellers believe developed economies with their large infrastructure demands and stimulus packages have kept the industry afloat.

Which is the main driver for tunnelling demand through the recession?



Skanska and Costain to build Crossrail's Paddington station

GREAT BRITAIN

Skanska and Costain were last month awarded the Crossrail Paddington Station project. The project will be undertaken in a 50/50 joint venture. The contract value is about GBP 150M (USD 244M). The new Crossrail Paddington station will be the first station contract to be awarded as part of the Crossrail program to connect

east and west London.

The new station has been designed to maximize space while preserving the historical features of the main line station Paddington. Work will begin immediately and is scheduled for completion in 2018.

Crossrail programme director Andy Mitchell said, "The contracts for Farringdon and Whitechapel stations will be the next to be awarded in late 2011."

GLA'S HS2 demands

GREAT BRITAIN

The Greater London Authority Transport Committee announced its support in principle of HSR development but charged the Government to rethink its proposals to address impact concerns.

The letter addressed to the Secretary of State was in response to the HS2 consultation and was agreed by Conservative, Labour and Liberal Democrat groups on the committee.

Changes called for included: a new London Underground line between Chelsea and Hackney to address the potential flood of HS2 passengers through Euston; alternatives to Euston expansion plans costly in green space, such as line stacking; tunnelling beneath Hillingdon to reduce surface disruption; a rethink on the effect of linking HS2 to HS1 on the North London Line and more detail on the interchange at Old Oak Common.

News in brief

QDVC claims Qatar LRT QDVC, a JV of Qatari Diar and Vinci Construction Grands Projets, has won a USD 535M design-build contract for further works on the light rail transit (LRT) system in Lusail, Qatar. The contract called for eight underground stations and a viaduct over the motorway between Doha and the north of the country.

Xi Shi at Sai Woo The TBM set to bore the Sai Ying Pun to Sheung Wan tunnels has arrived at the Sai Woo worksite on the West Island Line in Hong Kong. Named Xi Shi after one of the four great beauties in ancient China, the 6.5m diameter machine was built by Herrenknecht.

Concrete collapses in Montreal tunnel A 15m wide beam fell collapsed bringing down part of the Ville-Marie expressway tunnel's roof last month in Montreal. The incident happened on a Sunday morning, causing no injuries or damage to vehicles.

East Side Access project buries TBM One of the two 22ft (6.7m) diameter TBMs used for excavating the East Side Access project in New York will be buried in the tunnel. Contractor and machine owner Dragados will seal the TBM in behind a bulkhead and encase it in concrete to prevent oxidizing and decay.

Dulles board reverses The Metropolitan Washington Airports Authority board of directors voted 11 to 1 last month not to construct an underground station at Dulles Airport, choosing an above-ground station for the Silver Line Metro rail extension.

Boring through future



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Short drive to Ollachea gold

PERU

Minera IRL has announced plans for a 1.3km tunnel to develop the Ollachea gold mining project in Peru. The tunnel is part of a prefeasibility study undertaken by Amec in developing the prospect.

The Ollachea Project, 100 per cent owned by Minera IRL

subsidiary Minera Kuri Kullu, will be developed initially from the slightly inclined tunnel from an adjacent valley after which the steeply dipping ore lenses will be mined by sub-level open stoping with cement paste fill. The geology of the location is a sedimentary belt that extends northwards from Bolivia through south-central Peru. The deposits are deformed slates

and sandstones close to surrounding intrusive bodies.

Coffey Mining of Australia worked with consulting giant Amec on resource aspects and underground mining design.

The current plan is for a 2014 start up and a rate of mining at 1.1Mt per annum to produce 117,000 ounces of gold per year, giving a mine life of nine years,

with potential for further development according to the geological indications. Project investment is estimated at USD 170M. Final consideration is underway to commence and exploration drive into the orebody.

The Minera IRL group already operates the Corihuarmi gold mine in Peru and the advanced Don Nicholas Project in Argentina.

Queensland Infrastructure Plan put to public consultation

AUSTRALIA

The state government of Queensland, Australia has requested public input on a new statewide infrastructure plan. The Queensland Infrastructure Plan (QIP) released last month allocated infrastructure priorities for the seven regions of Queensland.

The plan highlighted the AUD 78bn (USD 83.8bn) of infrastructure projects underway or committed in Queensland as of March as a response to the projected population increase from 4.5 million in 2010 to 6.6

million in 2031.

Prioritised projects included the proposed new tunnelled crossing under the Brisbane River, Cross River Rail (T&T January p22) as well as highway upgrades, mass transit and the Brisbane airport link (T&T January p19).

"Queensland is now the only State in Australia with a 20 year infrastructure plan for the entire state," Anna Bligh, premier for Queensland said. "It provides a clear outline of short-term infrastructure projects as well as forward planning for longer-term infrastructure priorities to meet the

future needs of our growing regions into the future.

"This plan is not just an investment in infrastructure for the people of Queensland; it's an investment in the state's future prosperity. The QIP will help drive investment and development to create stronger, more prosperous regions."

Consultation on the plan will run until 9 September.

A PDF of the full 100-page document can be accessed from the Queensland Government Department of Local Government and Planning website.

Kwun Tong Line Extension kicks off

HONG KONG

Construction on the Kwun Tong Line Extension (KTE) project in Hong Kong was launched last month.

Tunnel works on the 2.6km extension will be undertaken by drill and blast. This has presented significant challenges to planners due to Hong Kong's densely populated urban environment, said Chew Tai-chong, projects director for client MTR.

The HKD 2.97bn (USD 381M) contract 1001 for KTE tunnel excavation was awarded to Nishimatsu in May. The HKD

856.2M (USD 109.9M) contract 1002 for cut and cover construction of Whampoa Station as well as an overrun tunnel was awarded to a Chun Wo-Hip Hing JV in May.

Arup was contracted to provide consultancy services, with Davis Langdon & Seah, Urbis and Kenneth Ng & Associates as sub consultants. The architect was Integrated Design Associates.

Director of highways of the Hong Kong Highways Department, Lau Ka-keung said, "The extension of the MTR Kwun Tong Line will link up Kowloon City District with the rest of Hong Kong which goes

a long way to supporting the Government's policy of having railways as the backbone of public transport. It will also enhance transport efficiency, bringing about transport, economic, social and environmental benefits to Kowloon City, Yau Tsim Mong District, and Hong Kong as a whole."

The extension of the existing Kwun Tong Line will run from Yau Ma Tei Station to the new Whampoa Station, via Ho Man Tin. Ho Man Tin Station will provide an intersection with the Shatin to Central Link, due to be completed in 2020. The KTE is scheduled to open in 2015.

News in brief

▼ **San Francisco awards Central Subway bid**
The San Francisco Municipal Transportation Agency (SFMTA) awarded a contract worth USD 233M to a JV of SA Healy and Barnard for the Central Subway extension. Including two 6.4m-diameter, single-track 2.7km tunnels.

▼ **Pakistan road link delayed**
Construction of the Lowari Tunnel has ground to a halt again after the National Highways Authority failed to make the necessary payments to contractor Sambu JV. The USD 2.67M tunnel is 8.75km long, 7.3m high and 7.5m wide.

▼ **Busy Lizzie delivered to Lee Tunnel site**
The Lee Tunnel TBM arrived on site last month. The 8.8m Herrenknecht machine will start work in January.

▼ **Auckland's waterview tunnel approved**
The two to three lane project will involve a 4.5km long tunnel as part of the Western Ring Route motorway, which will be 48km when complete.

▼ **Connecting Jaipur's forts**
Two historical monuments in Jaipur, India: Amber Fort and Jaigarh Fort, will be reconnected by an ancient tunnel, currently in disrepair.

Weeks buys McNally

USA

New Jersey-based Weeks Marine has acquired Canadian contracting giant McNally Construction. The marine construction and dredging company looks to

strengthen its activities in the North American tunnelling industry and views the purchase of McNally as a way to establish its presence in Canada.

"Bringing McNally into the Weeks family enhances our ability to compete with the increasingly

multi-national players in our industry," said Richard Weeks, president and CEO.

McNally will operate as a wholly owned subsidiary of Weeks Marine and will maintain offices in Ontario, Quebec, Atlantic Canada and Ohio.

Walder appointed head of MTR

HONG KONG

The Hong Kong MTR has appointed Jay Walder as its new CEO effective 1 January 2012. He was most recently chairman and CEO of the New York Metropolitan Transportation Authority. Walder will oversee all MTR operations.

Walder will succeed incumbent CEO, Chung-Kong Chow, who will retire from his position on 31 December. Walder will join the Corporation as CEO designate on 1 November 2011.

He said, "The MTR Corporation is an established world leader in railway services and I am honoured to be joining the ranks of the many women and men who

make it a success. It is an exciting prospect to be involved in the construction of five new rail projects at one time."

Walder was also the managing

director, finance and planning with Transport for London.

Below: Jay Walder will oversee all MTR operations



Arup background in latest Crossrail Board changes

GREAT BRITAIN

Former Arup chairman Terry Hill CBE will join the Board of Crossrail on 1 September. Hill was also technical director of Union Railways in delivering the Channel Tunnel Rail Link (now called HS1), and he developed Arup's transport activities, mainly outside the UK.

Andrew Wolstenholme OBE will also join Crossrail Board as chief executive in late August following the stepping down of Rob Holden CBE on 10 July following just over two years in the post. Holden saw

the project through the UK government's comprehensive spending review and achieved major project cost savings. A civil engineer, Wolstenholme joined Arup in 1985 after resigning an Army commission in the Irish Hussars (previously with the Royal Engineers), but was lately with Balfour Beatty.

Current non-executive board member Heather Rabbatts CBE has been reappointed for a further 3-year term from 13 August. She has served as CEO of local authorities including the London Borough of Lambeth, and is a

governor of the BBC.

Crossrail chairman Terry Morgan commented, "I am delighted that Terry Hill will be joining the Board. Terry has significant construction industry experience having led on of the UK's leading engineering companies and will bring invaluable expertise in major transport infrastructure."

Other members of the Crossrail Board as of 1 September will be David Allen (finance director), Ian Brown CBE, Michael Cassidy CBE, Sir Joe Dwyer, Phil Gaffney, Sir Mike Hodgkinson, Robert Jennings CBE and Andy Mitchell.

News in brief

▼ **John Holland opens Tasmanian office**
Australia-based contractor John Holland has opened a new office in Hobart, Tasmania. Newly appointed state manager Tom Finney will run the Tasmanian arm.

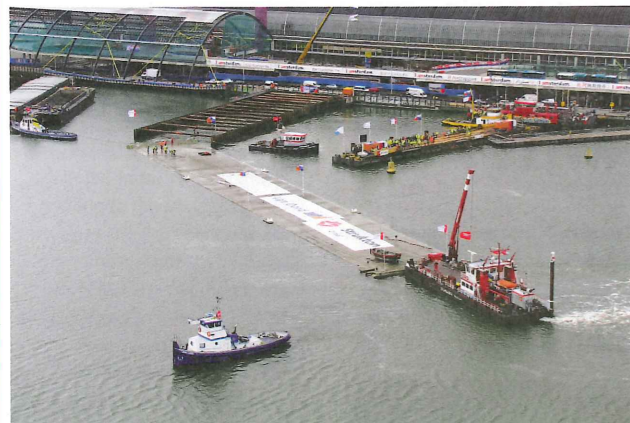
▼ **Louis appointed VP of Samsung C&T**
Samsung C&T, the global construction arm of Samsung Group, last month appointed Daniel Louis as vice president and technical director for the civil engineering division. In this new position, Louis will focus on tunnelling and underground projects worldwide, and will also develop new projects and opportunities in the Americas and Australasia.

▼ **Cadenhead appointed senior VP of Hayward Baker**
North American contracting giant Hayward Baker last month appointed Dan Cadenhead as senior vice president and in charge of its western region business operations. Cadenhead remains president of Hayward Baker sister company Anderson Drilling.

▼ **Nick Chen heads up Aecom's North American tunnelling practice**
"Nick brings significant experience in the design and construction of water and transit tunnels," said Andy Haubert, vice president of Aecom's specialty practices group in North America.

▼ **Aviapolis tunnel invitation**
Open invitation to tender for construction of the 2.4km Aviapolis tunnel section of the Ring Rail Line in Helsinki, Finland. Works to include a new station. Contact Maija Salonen of Liikennevirasto on +358 206373834 for more information. Deadline 16 Aug.

First metro element floated under Amsterdam Station



A joint venture of rail engineering company Strukton and dredging expert Van Oord last month successfully floated an immersed tunnel section called 'Priscilla' under Amsterdam's historic Central Station on the River IJ and lowered it 7m for securing later. After removing pontoons that had carried it into position, the tunnel section was left 'suspended' from rods of the Central Station constructed earlier. The work is part of the City's new North-South metro Line 52, and is just one of many engineering challenges being overcome, mainly associated with the soft, waterlogged ground of sand, silt and clay, and how to ensure support of historic building that currently rely on wooden piles.

The operation is believed to be the first ever of its kind.

Manipulation of the tunnel section included positioning by floating in a sort of temporary canal between pile walls and under a microtunnelled canopy, requiring considerable delicacy and accuracy in positioning. Following correct location and removal of the pontoons, work could start on backfilling around the precast tunnel element and final securing over a period of around six weeks.

Before the insertion operation could take place 3000 wooden piles had to be removed from under the station and replaced with a concrete slab to support the centre of the old building. The removals were carried out by divers using hydraulic chainsaws and underwater welding and cutting.

The tunnel element measures 136m long, 22m wide and weighs 20,000t. It was cast by a joint venture of Heijmans and Strukton Betonbouw at Suezhaven in the Amsterdam docks and towed-pushed with the assistance of tugs and pontoons along the river and into a specially constructed lock on the side of the river. The element was then rotated through 90° for hauling into the excavated 'canal'. In its contract the casting consortium has to supply a total of four immersed tube elements totalling 800m in length.

The project consultants on the first phase for Amsterdam City Council are a consortium called North-South Line Consultants (Adviesbureau Noord/Zuidlijn), including Royal Haskoning.

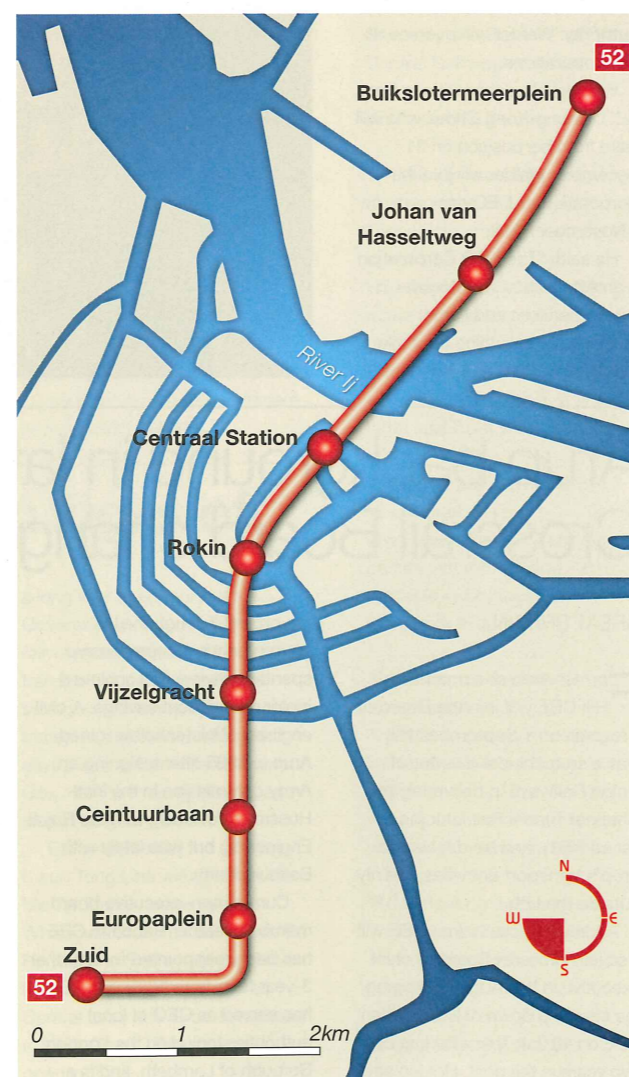
Meanwhile, one of two 6.88m-diameter Herrenknecht Mixshield TBMs, named 'Molly', used by the Saturn contractor consortium on Contract 4.2 of the project has been approaching the deepest

part of the 3.8km-long twin-bored route, at 30.7m below datum, whilst following under Apollolaan to Cornelius Troost Square another 160m away. After this there is a climb to Ceintuurbaan station. Saturn comprises Zublin and Dura Vermeer. Average boring progress has been 15m (ten rings) per day with a daily record of 23m, beating sister TBMs 'Noor' and 'Countess'.

The 9km-long new metro route runs from the A10 ring road and Amsterdam Zuid main rail station to the same ring road to the north

of Amsterdam city centre at Buikslotermeerplein on the reclaimed land that was formerly the Zuider Zee across the River IJ. In addition to the immersed tube tunnel in the river, other section will feature surface construction, TBM-bored tunnels through the city centre, and surface construction again at the southern end.

Left: Transporting the floating immersed tube element; **Below:** Map of the North-South metro route known as Line 52



ENTRY FORM

Award Category: _____

Entrant / Nominee: _____

Contact Name: _____

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Country: _____

Phone No: _____

Email: _____

Project Name (if applicable): _____

Project Location (if applicable): _____

Client (if applicable): _____

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YES, I certify that the information supplied is true and complete to the best of my knowledge.

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The T&T International Awards are open to all tunnelling professionals, designers, contractors and suppliers practicing anywhere in the world.

HOW TO SUBMIT AN ENTRY

For display purposes, T&T will produce two A3 pages on each submission for the judging panel.

For this we will require:

- A 1000-word entry submission written in English answering why you/your nominee/your project is eligible for the award.

We can accept:

- Microsoft Word (doc, txt)

- A maximum of ten images/diagrams is required, and all images must be 300dpi, CMYK colour space and of a large size.

We can accept:

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- Illustrator (ai, eps)

- A high-resolution image of your logo (minimum 300dpi).

We can accept:

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All entrants are encouraged to include copies of preliminary design, alternative schemes explored, information on context, precedents for the design or method and excerpts from working drawings.

AWARD WINNERS

The T&T International Awards 2011 will be announced at the The T&T International Awards Gala Dinner, to be held in Berlin on 8 December 2011.

Winning entries will feature throughout the Progressive Media Group product portfolio. If the submission should be shortlisted for any T&T International award, the entrant agrees to make available further information and publication-worthy graphic material as required by Progressive Media Group.

JUDGING THE AWARDS

Entries will be judged by a panel of experts, who will select category winners. Details of the winners will not be made known until the T&T International Awards Gala Dinner.

VERIFICATION OF AWARDS

Progressive Media Group reserves final decision on eligibility and accepts no liability in this regard.

RETURN OF ENTRIES

Progressive Media Group is unable to return any entry submissions.

ENTRY DEADLINE

The deadline for the receipt of entries and all supporting materials is **16 September 2011**. No responsibility can be accepted for non-delivery of materials.



Qatar set for next tunnelling boom



The main construction packages will be let as design and build agreements and awards will be made from June 2012. "We will need most of the world's expertise in design as these will be design and build contracts. We will only do 25 per cent of the design in house."

At the London conference Mee urged firms to get into consortium as soon as possible in order to be well positioned for the expressions of interest which are due to be issued over the coming weeks. He also made it clear that individual companies need not apply. Prequalification will only be granted to consortia. "We have been telling the industry time and time again - we are not going to prequalify individual companies, we will only prequalify consortia that are capable of doing the civil engineering package in total."

According to Mee this means design expertise, tunnelling and construction capabilities and equally importantly there must be some local Qatari involvement. "There is nobody in Qatar that has ever built a railway and there is no one that has

built a railway in Qatar. The logical conclusion of that is that you have to tie together local specialists with international specialists." In addition he says logistical planning in Qatar for all resources can be challenging. "Getting labour into Qatar is not easy so you need people who understand how to get through the immigration process. I would really recommend people form consortia with local companies. It would be a real shame if people put a lot of effort into bids and didn't have those vital components."

QRC envisages that boring of the four lines will begin from outside the city and move inwards enabling spoil to be removed from less congested areas. Upon completion by 2020 these central lines will then be extended further out to Dukhan in the west, out to industrial areas and the new Mesaieed Port in the south and also reach out north to Umm Slal and Al Shamal. The entire metro will be completed by 2026 (see figure 2,).

At the same time as phase one of the metro QRC also wants to install an

Mechanised tunnelling is finding favour in the Middle East as infrastructure plans increasingly call for underground development.

Bernadette Ballantyne reports

Projects in the Middle East and particularly the Gulf region have traditionally relied on drill and blast methods to remove hard rock and create underground spaces, or roads through mountainous regions, but times have changed. Today almost all countries in the Middle East from Qatar and the UAE to Iran and Iraq are planning to bring in TBMs to fulfil their new underground infrastructure plans.

By far the biggest driver is metro projects. By 2020 Kuwait, Doha, Abu Dhabi and Riyadh are all expecting to have light rail systems. And the nature of the growth of these busy cities, which do not have public transport networks, means that new rail systems will need to go underground.

Dubai's Road Transport Authority (RTA) has led the way in creating a metro in the Middle East, which opened in 2009, and Doha in Qatar looks to be the next city to begin construction of a light rail project. "Qatar has declared that by 2030 it needs to be self-sustaining providing a high

standard of living for all that live there. To be a world class city you need a world class transport system, one where 40 per cent of all journeys are made by public transport," explains deputy chief executive officer of Qatar Railways Company Geoff Brian Mee. Mee was outlining the plans at the *Middle East Economic Digest (MEED)* Qatar Infrastructure Projects conference in London in July.

Qatar Railways Company is developing a USD 35M railway system known as the Qatar Integrated Railway Project, that comprises 200km route of heavy rail links to Saudi Arabia and Bahrain, a light rail network for Doha, a people mover underneath the business district of West Bay and an LRT (light rail transit) system for the 35 hectare Lusail real estate development, which is currently under construction to the north of Doha. A major catalyst for the project is the award of the World Cup in 2020 but Mee is keen to stress that this is not the main reason for the rail network. "The project is a milestone

on the way to providing a public transport network for Qatar, and the World Cup is a milestone in the development of that public transport network, but that isn't what we are designing it for. It is about building something that is fit for purpose for Qatar as it grows."

For the tunnelling industry the implications of the Qatari investment plans are enormous. Mee estimates that the metro alone will require 12 TBMs, and the West Bay people mover another two machines. "The metro is going to be one of the most dramatic public transport systems attempted anywhere in the world. To go from a greenfield site to four major metro lines in one bound has never been attempted before. The scale of this job really makes the hair on the back of your neck stand up on end," says Mee. "None of the team that are doing this have ever attempted to spend USD 35bn in 10 years. But then no one else has either and we are looking for a lot of friends to help us with that."

Qatar's fast track metro

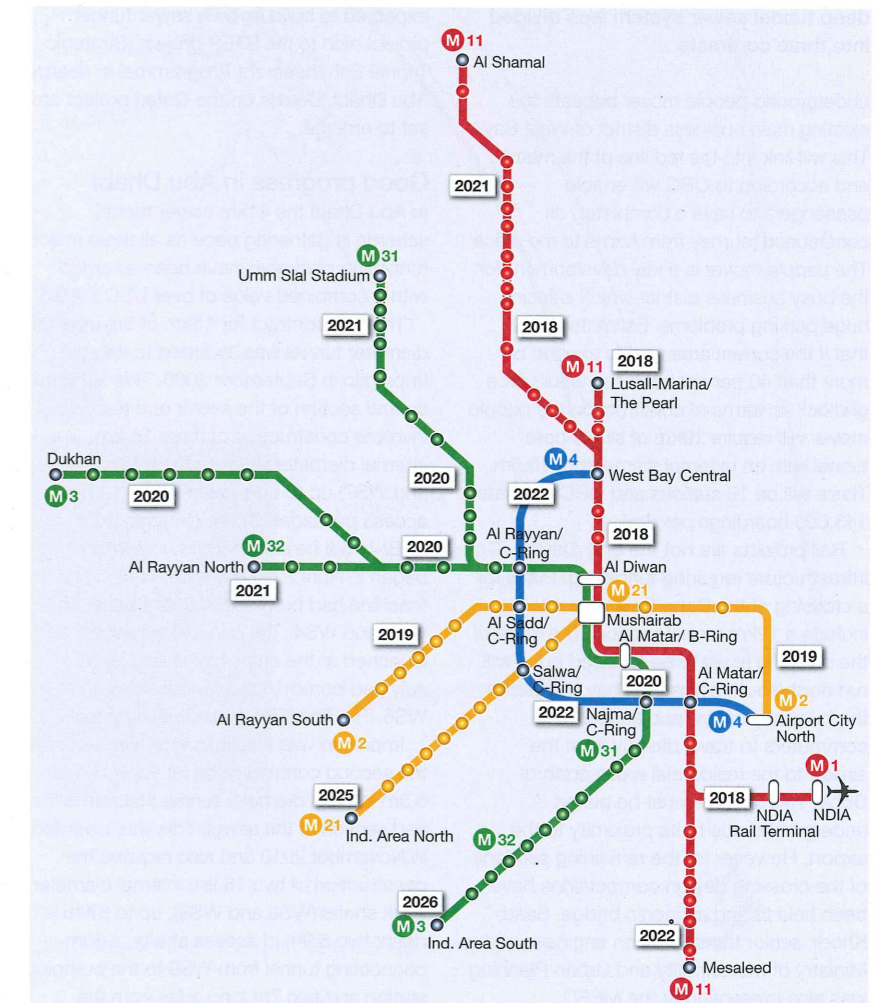
The metro itself consists of a route length of 350km over four lines, red, gold, blue and green. Mee considers the red most important as it is this north/south

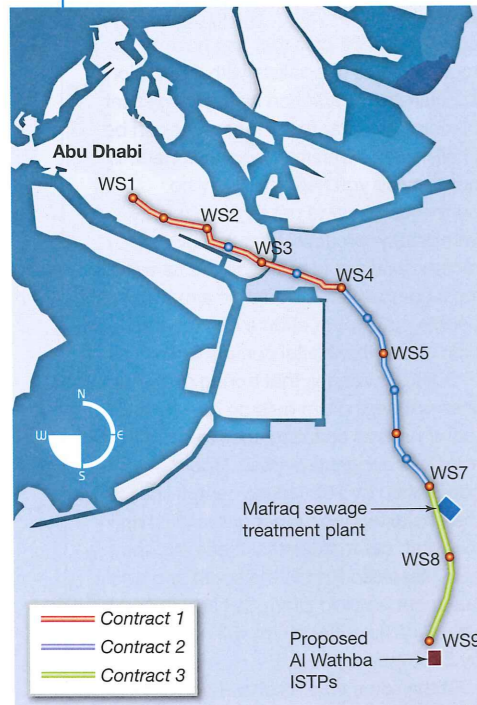
connection that will link the New Doha International Airport with central Doha while at the same time running through the business districts, into the huge Lusail real estate project and then on to Al Shamal in the north. "It will be the heaviest used. It links all of the high population density parts of Doha. The green and golden lines link into the suburbs and the blue line creates an orbital railway that links all the rest of it together."

A total of 110km or 31 per cent of the metro is set to be tunnelled and in order to meet the public transport criteria laid out by the FIFA World Cup Committee, QRC must complete the first phase of the metro by 2020. "That means about 12 contracts worth up to USD 1.5bn going on at the same time in the middle of a highly populated city. That is at least 12 TBMs. No one has ever attempted to run 12 TBMs at the same time in the city so that will be a big challenge," says Mee. "If we haven't finished phase One by 2020 we will not have time to commission it, test it, put it into public service and get people used to using it."

This sets a challenging timescale for the project and procurement is now underway.

Right: Figure 2, planned Qatari metro





Above: Figure 1, Abu Dhabi's 40km-long deep tunnel sewer system was divided into three contracts

underground people mover beneath the existing main business district of West Bay. This will link into the red line of the metro and according to QRC will enable passengers to have a completely air conditioned journey from home to the office. The people mover is a key development for the busy business district which is facing huge parking problems. Estimates show that if the current area was to expand by more than 40 per cent, the city would face gridlock. In terms of construction the people mover will require 10km of single bore tunnel with an external diameter of 10.5m. There will be 19 stations and QRC estimate 143,000 boardings per day.

Rail projects are not the only Qatari infrastructure requiring tunnelling. Plans for a crossing of the Doha Bay are set to include a 12km tunnel section. The route of the crossing is yet to be finalised but it will run north/south across the bay bypassing the busy city centre and enabling commuters to travel directly from the airport to the residential areas north of Doha. This section must be buried underground due to its proximity to the airport. However for the remaining sections of the crossing design competitions have been held to find an iconic bridge. Saad Khodr, senior transportation engineer, at the Ministry of Municipality and Urban Planning was also presenting at the MEED

conference. "The concept was originally to have a 12km tunnel, broken up with an Island then some kind of a bridge. We also planned for a link to the Pearl," he says. The Pearl is a residential area created offshore to the north east of Doha. "This was presented to his Highness but he didn't like any of this. He wanted something special. He said go and do a competition."

This led to the completion of four new concepts created by teams made up of both architects and engineers. The plans varied from a number of small bridges to a huge iconic crossing. These were once again presented to the Emir Hamad bin Khalifa al Thani who was still not convinced by the options shown. "His Highness said unless you bring something special that adds something to the Bay then I want it all to be a tunnel," says Khodr.

As a result another consultant has been commissioned to develop another solution, but the plans have not yet been revealed. For the tunnelling sector though the Doha Bay Crossing will certainly need a tunnelled section linking it to the airport.

In the water sector Doha is also expected to build its own sewer tunnel project akin to the STEP project (Strategic Tunnel Enhancement Programme) in nearby Abu Dhabi. Details on the Qatari project are yet to emerge.

Good progress in Abu Dhabi

In Abu Dhabi the 41km sewer tunnel scheme is gathering pace as all three major tunnelling packages have been awarded with a combined value of over USD 700M.

The first contract for 15km of 5m internal diameter tunnel was awarded to Italy's Impregilo in September 2009. This is for the central section of the sewer and also involves construction of three 16.2m internal diameter work shafts (WS5, WS6 and WS7) up to 60m deep and 110m of access passages. Three Herrenknecht EPBMs will be used for the bore which began in April 2011. By mid-July the first machine had progressed 333m between WS5 and WS4. The second machine was launched at the end of June and by mid-July had bored 16m between WS5 and WS6. The final TBM launch is imminent.

Impregilo was also successful in securing the second contract to be let, for 9.7km of 5.5m internal diameter tunnel that forms the end section of the sewer. This was awarded in November 2010 and also requires the construction of two 16.9m internal diameter work shafts (WS8 and WS9), up to 87m deep; two 6.9m id access shafts, a 60m connecting tunnel from WS9 to the pumping station and two 7m long adits from the

access shafts to the bored tunnel. Site preparation is underway and construction of the work shafts is progressing with the diaphragm walls for WS8 now complete and those for WS9 underway.

A third contract for 16.1km of 4m internal diameter tunnel was awarded to Samsung C&T in February 2011. This forms the first part of the sewer and as such the five work shafts (WS1, WS2, WS3, WS3.1, WS4) are much shallower at between 25 and 36m. Their diameters vary between 13 and 17m. Work shaft three will form the main drive site. Shaft work is underway and Samsung C&T says it will complete its work by 2014.

The project manager CH2MHill tells T&T that the successful launch of the first TBM in April 2011 has been the biggest achievement on the project to date, along with the swift installation of the next two machines in their launch shafts in May and June 2011. Key future milestones are the award of the link sewer contracts and the pumping station contracts which are yet to be awarded, along with the arrival of TBMs for the remaining tunnel sections.

Two contracts for link sewer packages are needed to create a 50km network of pipelines from 0.4 to 3m in diameter that will collect sewage and feed it in to the new sewer tunnel. Part of the rationale behind structuring the main tunnel and connection sewers in separate contracts is to enable both local and international firms to participate in the scheme. It is envisaged that local firms will be involved in link sewer construction. A sixth contract for a new deep pumping station at Al Wathba sewage treatment works is also yet to be awarded.

The scheme as a whole is designed to increase the sewage capacity of the fast growing emirate and replace the existing myriad of pumped mains with a gravity sewer and single pumping station.

Past president of the International Tunnelling Association Martin Knights expects that this is just the beginning for underground construction in Abu Dhabi and the wider Gulf. "You don't necessarily think of Abu Dhabi as a tunnelling centre, we know about Tehran and Cairo but Abu Dhabi is really embracing the third dimension," he says. "In Abu Dhabi the Department of Transport were originally planning a series of bridges to connect to the mainland. I said this is like Holland, it is perfect for immersed tube tunnels. So we did a workshop for them and they are now looking at immersed tubes."

"Who would have thought that 20 years ago the region would be embracing underground technology at the rate that it is now. It is a booming centre," he says.

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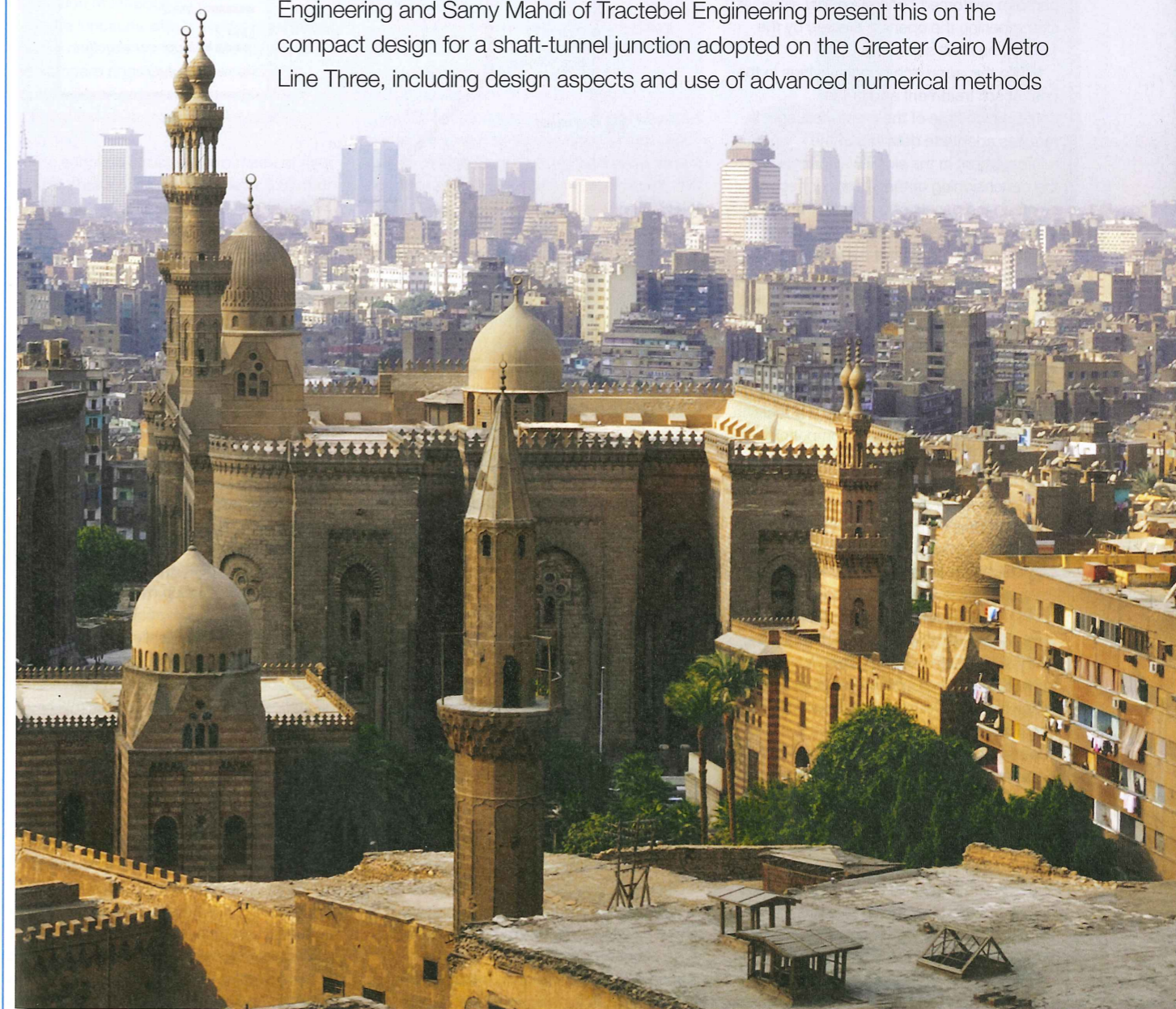
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Cutting into the shaft

Sylvie Giuliani-Leonardi of Vinci Construction, Dr. Olivier Gastbled of Tractebel Engineering and Samy Mahdi of Tractebel Engineering present this on the compact design for a shaft-tunnel junction adopted on the Greater Cairo Metro Line Three, including design aspects and use of advanced numerical methods





The design of shaft-tunnel junctions on the Greater Cairo metro system has evolved over time. Initially for Line Two, the junction between rectangular shafts and the bored tunnel is achieved by excavating the cross-passages in artificially frozen ground. Later for the new line three, the technique of artificial freezing is replaced by a ground improvement approach using plastic concrete.

More recently, a new concept has been introduced in which no ground improvement and no connecting galleries are necessary. The principle lies in driving the TBM to partially intercept an unexcavated circular slurry wall. The shaft can then be excavated in several stages, allowing for the construction of the upper part and the lower part of a reinforced concrete portal aimed at strengthening the opening created by the TBM in the shaft slurry wall.

While this approach brings savings in the cost of soil treatment and in the construction time of the cross-passage, it requires adequate detailing of the reinforcement in the slurry wall panels and the dimensioning of the shear connectors between the panels of the shaft, the segmental lining of the tunnel and the concrete elements of the portal.

Advanced three dimensional numerical modelling is thus used to assess structural forces on which the detailing is based. It is only recently that finite element software with sufficient capabilities and user-friendliness are available to model such a three dimensional configuration in a realistic way and within a timeframe compatible with project requirements. This example illustrates how advances in construction methods can be stimulated through improvements in the analytical tools.

In tunnelling works, annex structure construction is always a challenging part of the project. As opposed to standard tunnel boring which is a repetitive mechanised work, annex structures are singular points: firstly, they are generally excavated by the conventional method in unstable ground which requires preliminary soil treatments; secondly, bored tunnel lining needs to be supported prior to opening; finally, the excavation of the connecting gallery induces an increase of the forces in the neighbouring structures – in the shaft walls, for instance.

The design adopted for the annexed structures in phase two of the construction of Cairo metro Line Three, as developed by the site and the design managing team based on the experience gained during the construction of previous metro lines in Cairo, reduces significantly the difficulties of



Above: Figure 1, map showing the Line Three expansion of the Cairo Metro

existing techniques. The principle of this concept lies in driving the TBM to partially intercept an unexcavated circular slurry wall. The main advantage of this method is that no ground improvement and no connecting galleries are then necessary.

Advanced three dimensional numerical modelling was very helpful firstly to validate the feasibility of such a concept and secondly to assess structural forces in all components of this complex geometry.

Project phase two

The new Line Three is split in four phases. As T&T goes to print, phase one is close to completion and phase two is in progress. The other phases, three and four, are in planning.

Tunnelling for phase two will be excavated by TBM. The tunnel is circular in shape with an internal diameter of 8.35m.

The alignment passes under the densely built city of Cairo and sometimes passes under existing structures. This results in several challenges: deep foundations of some bridges at immediate proximity of the tunnel, buildings up to six floors high

just above or at close proximity of the tunnel, sewage pipes passing close to tunnel crown.

The particularity of phase two of the Line Three is that two different TBMs are used to complete the excavation mainly due to the changes in hydrological conditions along the tunnel route: the tunnel starts at Abbasiya station crossing saturated sands and clay below water table, then from Cairo Fair station the water table level is lower and the tunnel crosses partially to totally dry sands and clays.

The boring starts between Abbasiya station and Cairo Fair station with a Herrenknecht slurry TBM then continues with an NFM EPBM. The tunnel face is supported by a total slurry pressure, varying from 60 to 180kPa (0.6 to 1.8 bars) at crown, and mostly above 120kPa (1.2 bars). The tunnel face is supported by a total pressure varying from 50 to 150kPa (0.5 to 1.5 bars) at crown, and mostly below 100kPa (1 bar). Face support pressures

have been adjusted not only to ensure stability of the face but also to control induced settlements when passing below existing buildings and surface structures. Both TBMs have an excavation diameter of 9.41m.

The tunnel lining has an inner diameter of 8.35m. The lining segments are 0.4m thick and are made of concrete with a cube strength of 42.5MPa. The lining is made of tapered precast segments, of 1.5m mean width. Concrete faces are equipped with bolted connections: two bolts of 25/22 diameter are installed per segment face between ring and between segments. For watertightness, segments are equipped with a sealing gasket at extrados plus a hydrophilic gasket placed in addition at intrados.

At the junctions with annexed structures, special rings are used: they are similar to the standard rings but each ring face is equipped with polyamide dowels, which increase the shear capacity between each ring.

The annexed structures are made of near circular shafts of internal diameter 8.87m or 10.27m. The slurry wall panels are 0.8m or 1m thick. The temporary and also final shaft lining is made of 14 adjacent slurry wall panels. These panels are not structurally connected between each other.

Slurry panels are reinforced in order to support earth and water pressures and also any forces induced by the bored tunnel intersection. Reinforcement is achieved by glass fibre reinforced polymer bars in the part that will be intersected by the TBM.

Slurry wall panels have varying depths depending on bored tunnel levels and have various embedment lengths depending on encountered water conditions.

Design of annexed structures

Experience gained with the annexed structures of phase one revealed the difficulties pertaining to the construction of connecting galleries of very limited length (1-1.5m long) to be excavated from a shaft of very limited dimensions (3m wide) in which space was further reduced by a massive strutting system.

Moreover, excavation in sand below water required expensive soil improvement (soil freezing was adopted for Line Two and plastic concrete substitution was adopted for the Line Three phase one).

The choice to drive the TBM to partially intercept the unexcavated shaft wall implies that no ground improvement and no connecting gallery are necessary. This meant that no manual underground excavation works were required.

Top right: Figure 2, bending moments in the longitudinal direction of the panels in a case of continuous shell modelling (left) or sliding joint modelling (right)
Centre right: Figure 3, displacement norm on deformed shape in case of shell or sliding joint modelling (left, right)
Bottom right: Figure 4, Tensile zones in the portal structure

Structure 17A

The geology consists of a fill layer overlaying sand intermixed locally with gravel, silt and an interlayer of clay with a limited thickness. A decrease of the presence of thick hard clay band is observed. The sand formation is more frequent than other tunnel drives. Water table is at about rail level.

The final open space in the connecting gallery is rectangular with a height of 3.84m and a width of 4.5m (for other annex structures, the width can reach 6m).

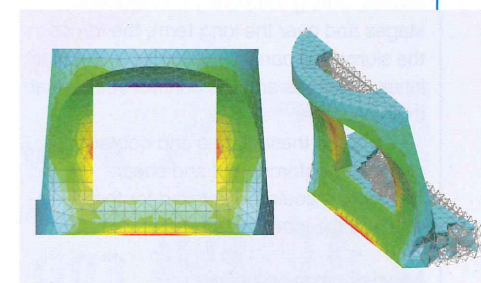
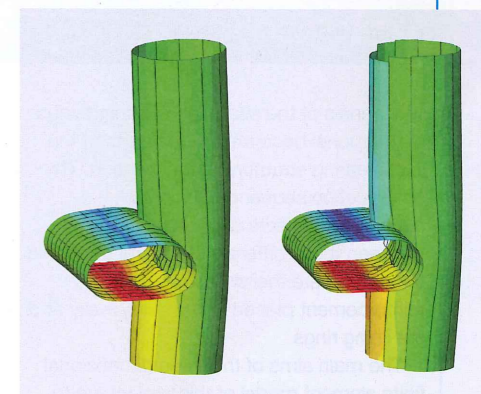
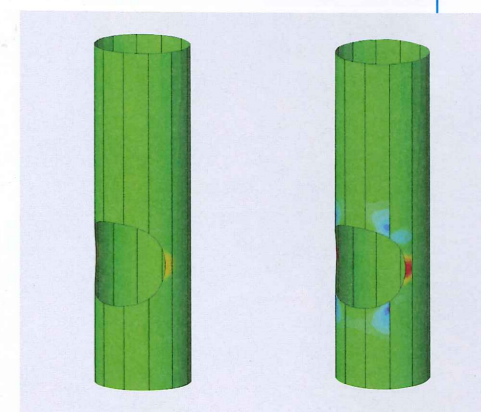
At the junction, the stability of the bored tunnel lining during construction stages as well as in final stage is ensured thanks to a concrete portal located in the shaft and made of an upper beam located at the top of the intersection between the tunnel lining and the slurry-walls, a lower beam located at the bottom of the intersection between the tunnel lining and the slurry-walls and two side walls connecting the two elements previously mentioned.

All these elements are connected to the slurry walls while only the upper and lower beams are connected to the bored tunnel lining through sealed reinforced bars. Invert slabs bring an additional stiffness to the supporting system, while other structures are present to support the internal equipments.

Construction methods and technology

Construction stages are presented below:

- First the slurry walls of the shaft are installed in the ground
- Then the TBM passes and cuts the slurry walls in the shape of two cylinders partially intersected
- Temporary support is placed
- The excavation of the shaft can proceed from surface level down to the bottom level of the upper beam
- When the excavation reaches this level, connecting bars between the upper beam and the tunnel lining and between the upper beam and the slurry walls are sealed; then the beam can be concreted, thus creating the first support for the tunnel lining
- Excavation of the shaft can continue



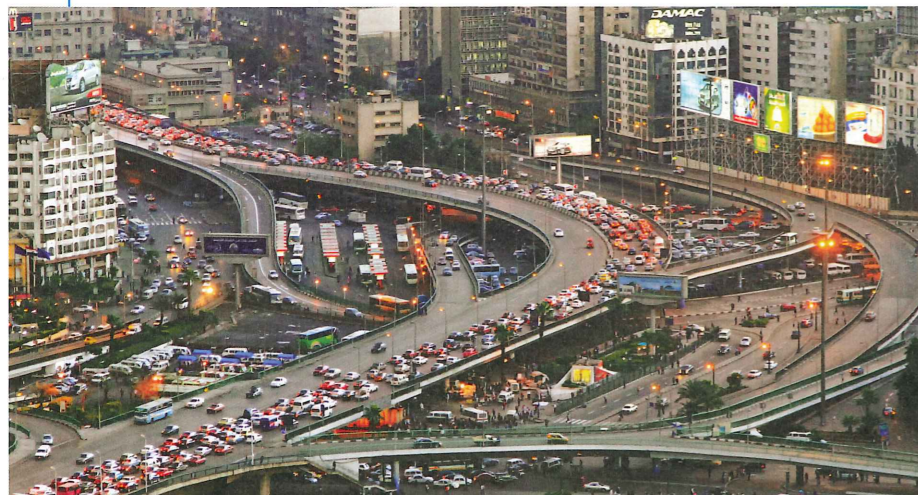
down to the bottom level of the lower beam; at this point, connecting bars between the lower beam and the tunnel lining are sealed as well as the connecting bars between the lower beam/side walls and the slurry walls; then the side walls and the lower beam are concreted, thus completing the temporary and final support for the tunnel lining

- Excavation is completed down to invert level; then the invert slab, the invert wall and slab at tunnel level are concreted
- The tunnel lining is fully supported and can be opened to create the final passage from shaft to tunnel

Three dimensional numerical analysis

An important consequence of adopting such a compact design is that the slurry





wall panels of the shaft and the lining rings of the tunnel become integral parts of the load bearing structure at the junction. The construction sequence, the three dimensional effects and the interactions between these different structural parts and the ground are therefore key to the reinforcement placed in the slurry walls and the lining rings.

The main aims of the three dimensional finite element model of this project are to assess, during temporary construction stages and over the long term, the forces in the slurry wall panels, the forces in the shaft inner structures and the contact stresses at their interface.

Based on these forces and contact stresses, reinforcement and shear connectors could be detailed for the slurry wall and the inner structures.

Model presentation

The ground layers, the tunnel lining, the slurry wall and the inner structures of the shaft were modelled in three dimensions in a single finite element model using the software Midas GTS, which is dedicated to geotechnical and tunnel engineering analysis. Seven horizontal ground layers made of fill, sand or clay are modelled with thicknesses ranging from 1.5m to 10m. The overall dimensions of the model are 100m x 100m in plane and 80m in depth. The ground layers are meshed with tetrahedron elements, which allow easy mesh refinement where necessary, and mesh coarsening towards the model boundaries.

The material model adopted for all ground layers is Mohr-Coulomb perfect plasticity. The ground water table is assumed to intercept the tunnel close to its invert. The sand and fill layers are assumed to behave in a drained way. The clay layers

are assumed to behave in an undrained way during the construction stages. For the long term computation stage, the clay layers are assumed to become drained.

The insitu stresses are determined based on the equilibrium under self-weight and on normally consolidated K_0 ratios deduced from Jaky formula ($K_0 = 1 - \sin \phi$).

The tunnel lining is modelled with triangular plate elements. Interface elements are inserted between the lining and the ground to model sliding and debonding. Since the model is primarily aimed at detailing the shaft structures, the exact geometry of the lining segments is not represented and the lining is assumed to behave as a continuous linear elastic shell.

The exact geometry of each slurry wall panel is modelled. The panels are meshed with triangular plate elements. Dedicated line interface elements are inserted between each panel to allow relative sliding, hinging and debonding.

The slurry wall panels are assumed to behave linear elastically.

Two analysis cases are considered with varying assumption on the behaviour of the panel joints. In the first analysis case, the joints are assumed perfectly sticking (continuous shell modelling). In the second analysis case, the joints are assumed perfectly sliding (no cohesion or friction) and with zero tensile strength. The variability of the actual properties of the inter-panel joints and the difficulty to anticipate which case will be the most adverse for the detailing of the panels led us to consider the two bounding cases and carry out the reinforcement detailing of the panels based on the combination of both results.

The non-linear analysis is carried out in seven stages including stress initialisation,

Left: Cairo gridlock shows metro need

shaft excavation stages, stages for the construction of elements of the inner structure, opening of the tunnel lining and eventually the long term behaviour including water level rise above the clay layer and uplift pressure applied on the raft.

Results and detailing

The model provides the distribution of axial and shear forces and of bending moments in the slurry wall panels for all construction stages, see for instance the bending moments in the last computation stage, figure 2. At any one point of the panels, the required reinforcement area is determined in each construction stage, for the short term and for the long term, for the continuous shell assumption and for the sliding joint assumption. Planned reinforcement detailing of the slurry wall panels is checked against the most adverse case.

The tunnel ovalisation induces the global 'bending' of the shaft around the tunnel. With the modelling of sliding along panel joints, tunnel boring induces relative displacement of some of the panels of around 2-3mm. However, once shaft excavation proceeds, no additional sliding appears as the hoop forces developing in the circular wall increase the shear capacity at the joints.

The distributions of tensile stresses are obtained in the upper beam and in the portal elements. The values and the cross-sectional areas covered by these tensile stresses are used to assess the required reinforcement area to be implemented in the inner structure.

The contact between the inner structures and the slurry wall or the tunnel lining is modelled as fully bonded. The tensile contact stresses and the shear contact stresses are used to assess the required area of anchor bars to be implemented to ensure full connection between these different structural elements.

Conclusions

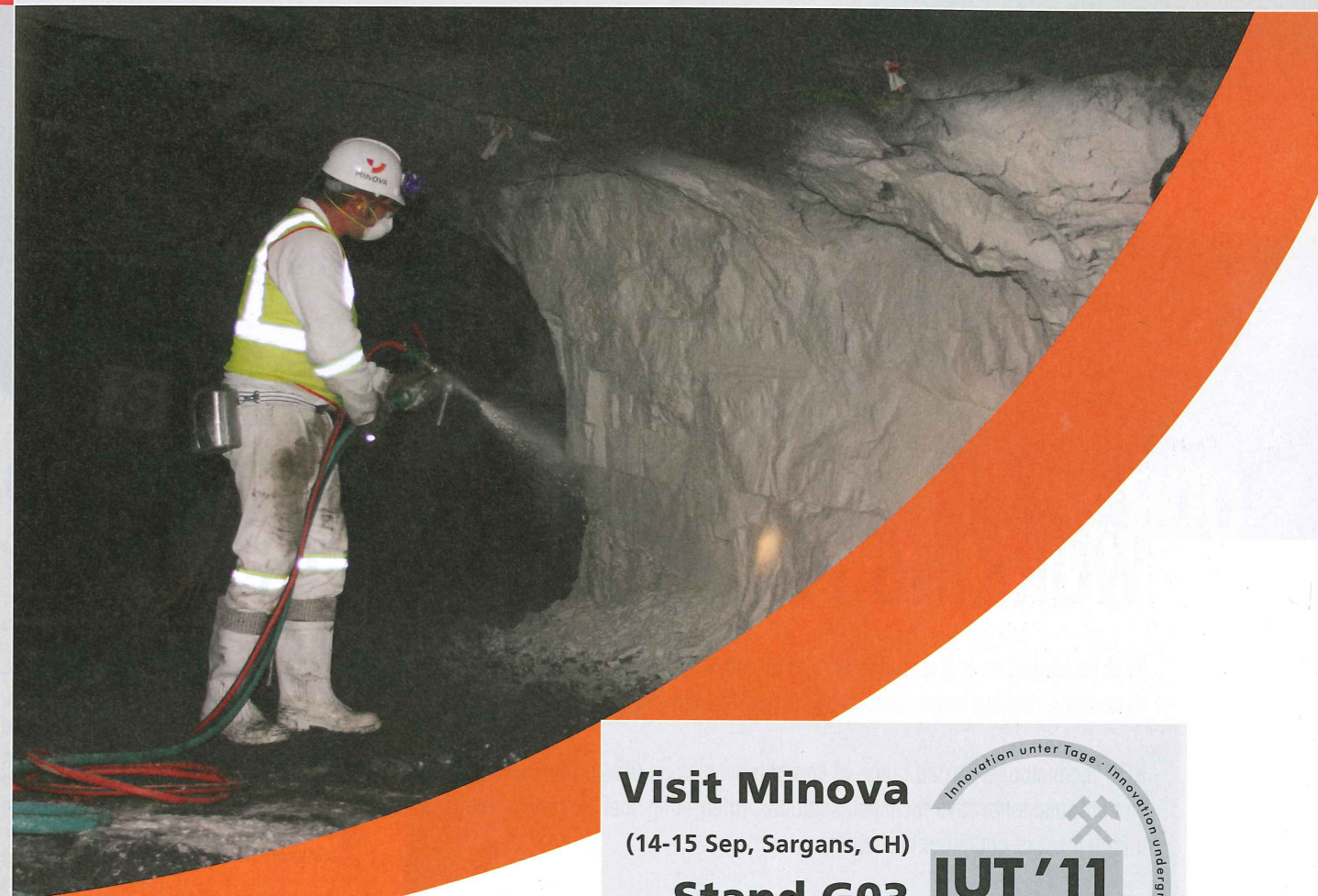
A new concept for shaft/tunnel junction is introduced whereby no ground improvement and no connecting galleries are necessary.

Three dimensional finite element analysis is successfully used to validate the feasibility of such a concept and to assess the structural forces of this complex geometry, which allows detailing of the reinforcement and shear connectors. Induced displacements in the shaft and lining are shown to stay admissible. ■



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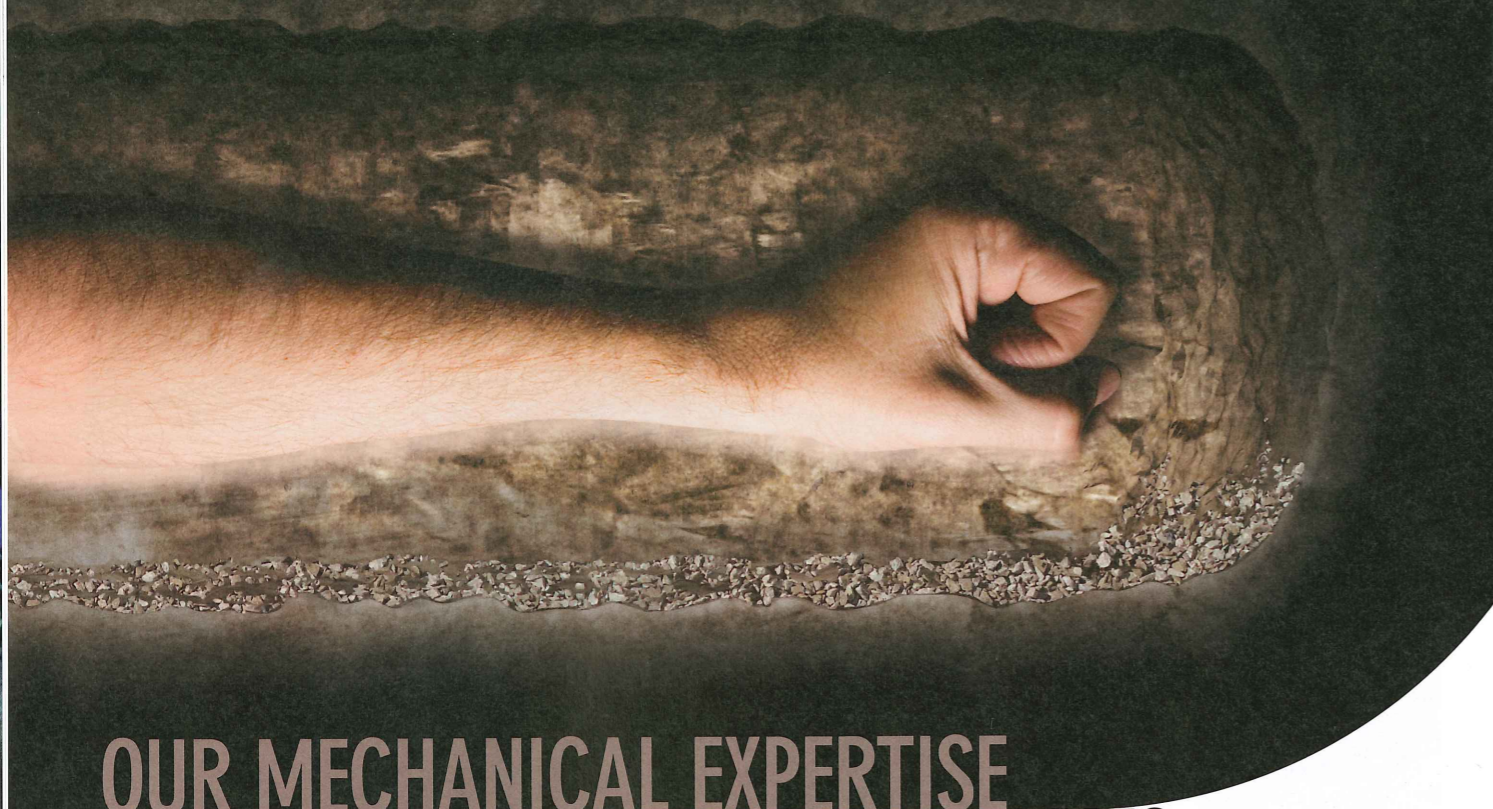


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Collapse and recovery in Abu Dhabi

Contract one - Al Salam Street Tunnel on Al Salam Street in the centre of Abu Dhabi, UAE, is constructed using a top down construction method with a total length of 3.6km. The tunnel is located within a highly developed urban setting with numerous underground utilities.

The formation level of the tunnel is 13m below ground level and the temporary shaft support comprises an 18m-deep diaphragm wall. To allow for excavation within the temporary support, a system of dewatering wells is installed and then the base slab cast in the dry.

Two ground investigations are completed prior to construction. These do not show any abnormalities.

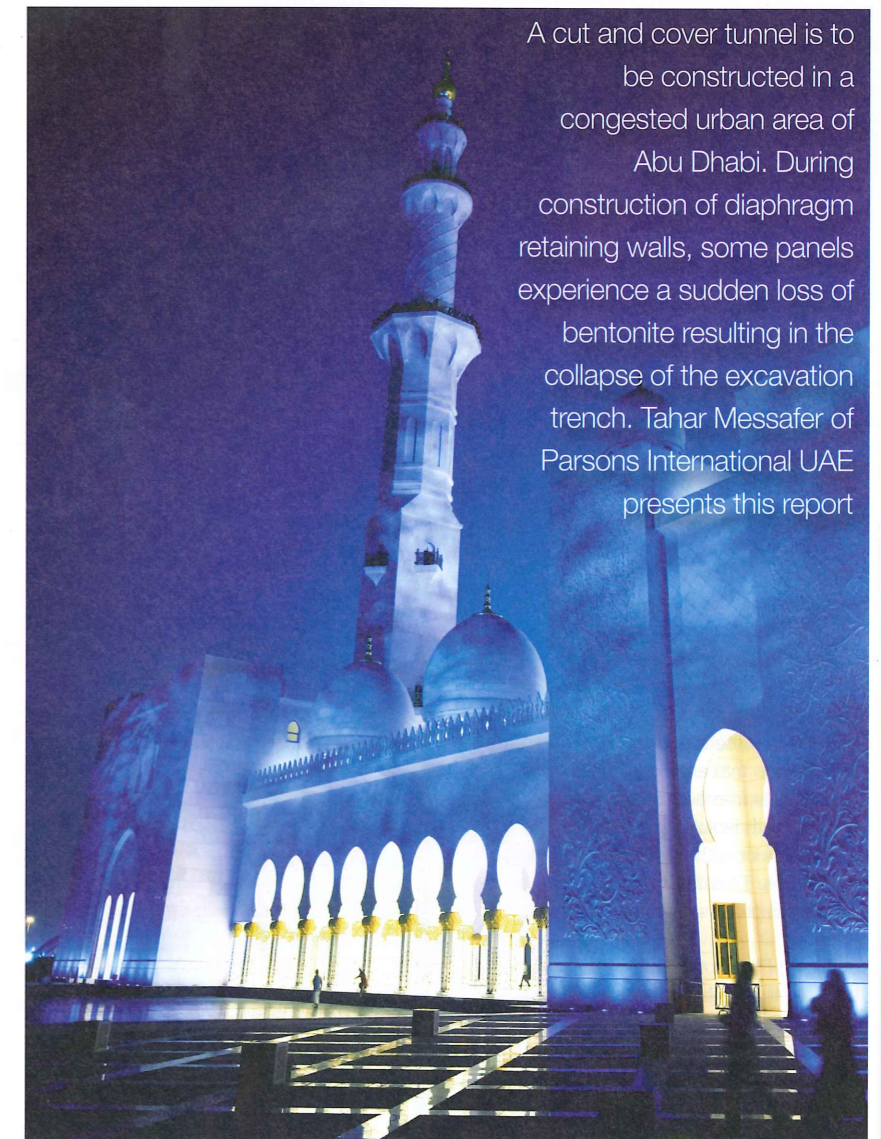
The temporary support and tunnel foundation are designed based on the findings. The wall is a conventionally anchored diaphragm wall and the base slab is a piled raft foundation. However in one area along the line of the tunnel, ground conditions are discovered to be very different during wall construction. Bentonite slurry supporting the sides of the wall excavations disappears completely and the sides collapse.

This results in a complete rethink of the design and construction of the walls and base foundation of the tunnel.

Geological conditions leading to wall failure

Two ground investigations were carried out. One designed and managed by the consultant prior to tender and the other by the main contractor after winning the contract. A geological cross section shows the ground model comprises calcarenite

A cut and cover tunnel is to be constructed in a congested urban area of Abu Dhabi. During construction of diaphragm retaining walls, some panels experience a sudden loss of bentonite resulting in the collapse of the excavation trench. Tahar Messafer of Parsons International UAE presents this report





and calcareous sandstone below the dune sand deposit of approximately 8m thick.

The temporary support system comprises mainly diaphragm walls along both sides of the tunnel. The walls are 800mm thick and 18m long. A series of geotechnical instruments are installed in the ground to monitor movement and pore water pressures.

In one area in particular, 30m long diaphragm wall works can not continue because the trench collapses at about 10m depth. To investigate the problem additional ground investigation is undertaken by the main contractor, a Samsung and Saif Bin Darwish JV.

The investigation comprises 17 boreholes each 30m deep. Figure 2 shows the location of the boreholes and the geological cross section indicates the presence of cavities up to 1m thick within the calcarenite and sandstone layers. These new findings are surprising because there is a risk of high settlement to the tunnel and adjacent structures to the tunnel. In order to quantify this risk, a damage classification assessment is carried out.

Buildings Risk Assessment

When assessing the severity of damage for an existing structure, the control of damage should be based on multiple factors such as crack widths, total settlement, differential settlement and angular distortion of the foundation. Relying on only one parameter can be misleading.

The damage classification proposed by Rankin (ref 1) was used to determine the control parameters to the buildings that are applicable to framed buildings with isolated foundations or with pile foundations. This uses two control parameters –

Top right: Figure 1, shape of the collapse and slurry flow

Right: Figure 2, an investigation of the collapse with borehole and geological profiles

distortion and settlement – to classify the damage level.

This classification is updated to take into account the vulnerability index of the building likely to be affected by the tunnel construction (ref 2).

This index is evaluated for each building using its structural behavior, foundation type, use of the building, state of conservation and its orientation. For each building a building condition survey is compiled containing all of the information, and a vulnerability index for each building is determined.

The results of Rankin classification and the risk categories through a vulnerability index evaluation are summarised opposite in figures 3 and 4 (right).

Investigation and Analysis of Tunnel Movement

Geophysical investigation

A geophysical survey by multichannel analysis of surface waves (MASW) is carried out to determine the extent of the cavities. The technique provides shear wave velocity distribution as two-

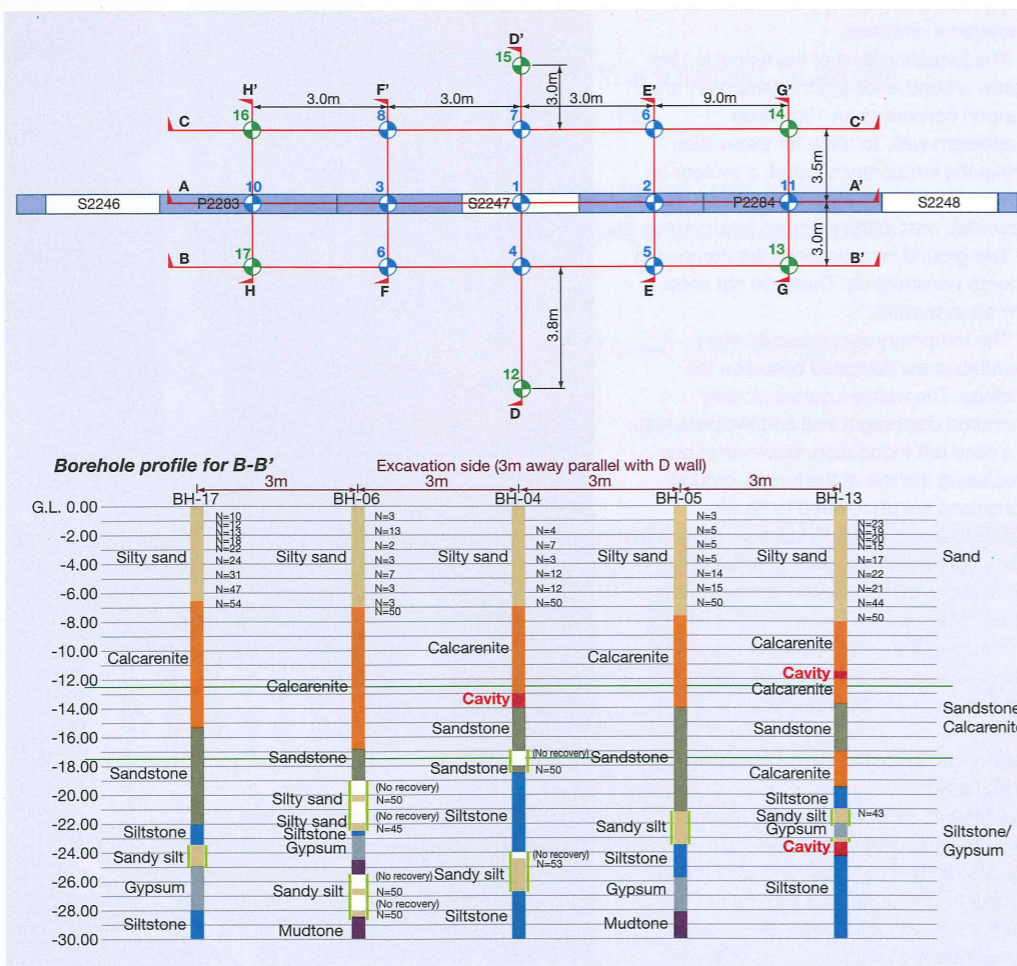
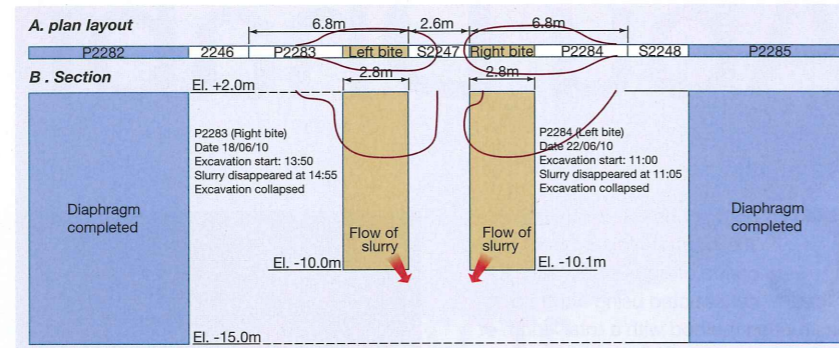


Figure 3: Risk damage classification adjusted by the vulnerability index Iv

Category of Damage	Control Parameter									
	Negligible 0 < Iv < 20		Low 20 < Iv < 40		Slight 40 < Iv < 60		Medium 60 < Iv < 80		High 80 < Iv < 100	
	Smax (mm)	βmax	Smax	βmax	Smax	βmax	Smax	βmax	Smax	βmax
1	<10	<1/500	<8	<1/625	<6.7	<1/750	<5.7	<1/875	<5	<1/1000
2	10-50	1/500-1/200	8-40	1/625-1/250	6.7-33	1/750-1/300	5.7-28.5	1/875-1/350	5-25	1/1000-1/400
3	50-75	1/200-1/50	40-60	1/250-1/63	33-50	1/300-1/75	28.5-43	1/350-1/88	25-37.5	1/400-1/100
4	>75	>1/50	>60	>1/63	>50	>1/75	>43	>1/84	>37.5	>1/100

dimensional profiles or a series of depth slices. These shear waves were generated by an impact at ground surface. Shear waves are proportional to shear modulus.

The MASW is carried out along 25 lines, which include 13 in east-west direction, and 12 lines in north-south direction. The fieldwork includes the use of 24 low frequency geophones separated 1m from each other. Also an 8kg sledgehammer (shot) fired at 2m centres was used to create the waves and a seismograph recorded the shear wave data.

The data is processed and then plotted in two-dimensions along 25 lines with a depth of penetration limited to 20m. The data is also presented as a series of geological cross sections. Two regions are defined as follows.

The first has shear waves between 200 and 600m/s and is found to be limited at shallow depth less than 9m below ground level, i.e. above base slab level.

The second region has shear waves greater than 600m/s and locally less than 400m/s and is found at depths greater than 10m, i.e. below base slab level. Low velocities indicate weak strata or a cavity.

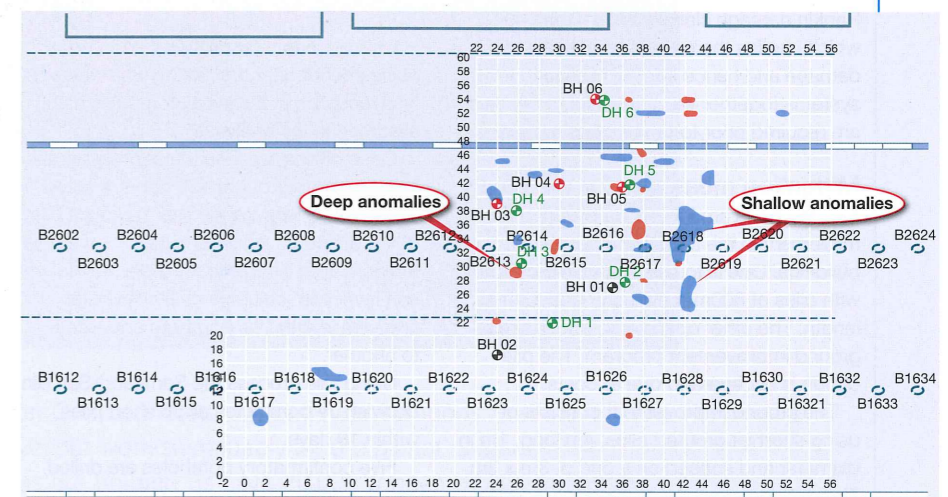
The low velocity zones shown on the two dimensional sections and depth slices are summarised in figure 5 (right) as anomalies. This shows some localised deep anomalies and large areas of shallow anomalies (ref 3). The shallow weak ground is not a concern as it is located above the base slab and therefore will be excavated, but the deep anomalies are another matter.

Borehole investigation

A program of investigation is carried out to confirm the presence and extent of the deep anomalies recorded in the geophysical investigation comprising six boreholes and six diagraphy holes to 30m depth. To maximise core recovery, a double tube core barrel with a nominal diameter of 90mm with hard liner on short core runs of 0.5-1.5m is used (reference 4). The

Figure 4: Actions related to damage and risk categories in the building

Actions	Description	Risk Category
Type A	Special monitoring system and consolidation measures before the passage of the TBM	3-4
Type B	Special monitoring system and consolidation measures to be executed before the passage of the TBM in case the monitoring confirms the necessity	2
Type C	Buildings that require a light monitoring system and any consolidation measures	1



investigation includes a series of SPT and pressuremeter tests to determine the elasticity modulus of the various strata.

Diagraphy profile (DH) results correlate well with the boreholes, so where diagraphy profiles show high penetration rates, standard penetration test results are almost zero at the adjacent boreholes.

Ground model and analysis

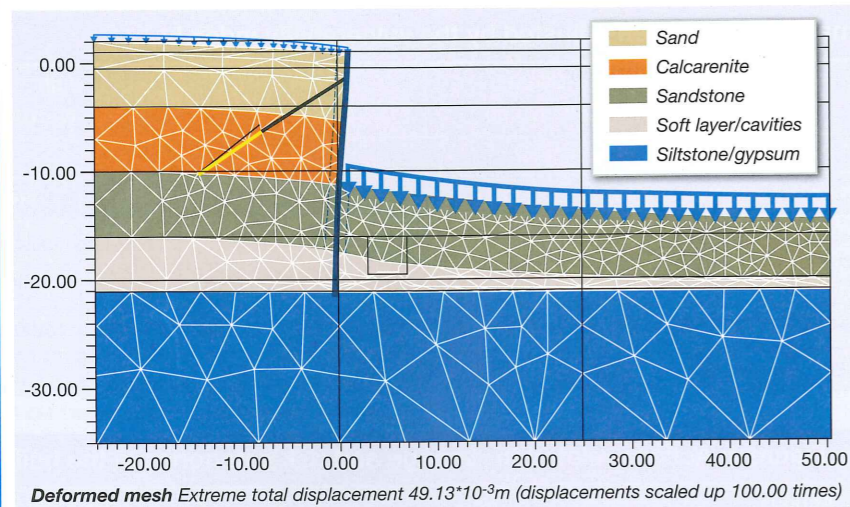
The ground model from the exploratory holes is shown in figure 6 (page 26). This shows the presence of a soft layer 3m to 4m thick and cavities at 18m, some 5m below the proposed base slab formation.

The presence of the soft layer can induce

Above: Figure 5, anomaly plan and confirmatory borehole locations

very high movements in the tunnel. The magnitude of these movements is predicted by a two dimensional finite element analysis using Plaxis (ref 5).

The various stages of construction are analysed, including excavation to install ground anchors, excavation to form the tunnel structure and applying surcharge behind the wall. Then the weights of the base slab and tunnel structure are applied, and are predicted to experience maximum movements of 31 and 49mm respectively. The effect of constructing the tunnel also



Above: Figure 6, predicted ground movement as deformed mesh and geology location

induces high levels of movement on the adjacent structures.

These movements are excessive and therefore the category of damage is quantified to be three and four according to Rankin damage classification (figure 4) which implies there is a high risk of damage and hence special monitoring systems together with mitigation measures are required prior to tunnel construction.

Mitigation measures for the cavity

Two solutions are investigated to control movement in the tunnel and adjacent buildings. One is to use a raft piled option with piles of 800mm diameter and 13m in length. The other option is to undertake a ground improvement program. The pile option is disregarded due to costs.

The ground improvement consists of using short jet grouted piles, 4m long, 1m in diameter and spaced on a grid of 3m x 3m. The spacing would be reduced to a tighter grid of 1.5m x 1.5m if a cavity is encountered during improvement works.

This program of improvement is to be followed by confirmatory boreholes to prove the remediation was successful.

A Klemm Bohrtechnik KR-805 is used and this is equipped with sophisticated programmable recording and controlling system installed on the operating panel for quality control of the jetting process. The panel has the capability to produce continuous logging of drilling parameters such as penetration speed, thrust, rotation speed and injection pressure of drilling fluid. This allows for the identification of soft areas. In addition where a sudden drop of the drilling rod or loss of drilling fluid are

recorded then this would indicate the presence of cavities.

After the first few holes a criteria for determining thickness of ground to be improved is set as follows:

- ▶ Less than 100m/h the rock is hard
- ▶ Between 100 and 200m/h the rock is very weak
- ▶ Greater 200m/h rock/soil is soft

Drilling parameter profiles for the 96 holes confirm that the soft layer is where it was recorded in the initial boreholes and assumed in the analyses.

Once drilling reaches the stronger strata, high-pressure grout of 400 bar is injected as the rod is withdrawn. This creates a pile of 1m diameter which terminates 1m above the soft layer. This process replaces the soft layer with columns of 1m diameter and with lengths varying from one location to another.

Using this process the Samsung-Saif Bin Darwish JV completes all 96 short piles within 10 days.

Five confirmatory boreholes are drilled and the drilling parameter profiles confirm that the soft layer has been replaced by grout and therefore the remediation has been successful. Subsequent surveys of the tunnel structure show very little movement at this location.

Instrumentation and monitoring

As a consequence of the high category of damage, an instrumentation program is implemented. Its objective is to confirm the remedial works are satisfactory and in addition monitor the tunnel and adjacent structures to ensure movements are below control levels.

As well as the existing instrumentation for the tunnel an additional series of instrumentation is installed in this

problematic area to monitor movements in the walls, soil behind the wall and adjacent buildings. This includes five inclinometers in the piles, three prism targets installed on the capping beam of the piles, three extensometer and six piezometers installed in the soil behind the piles.

Ground settlement markers are installed in a grid pattern between the walls and adjacent buildings.

On the buildings themselves a series of prism targets, tilt meters, settlement pins and crack meters are also installed. Two load cells to monitor the loads in each of the ground anchors on the tunnel walls are also installed.

Conclusion

The construction of a tunnel using the cut and cover technique is eventually successfully completed in an area that had complex and extremely weak ground conditions with cavities.

A damage risk assessment together with investigation, assessment and analysis is presented. All deep excavation works are successfully completed without any damage to the tunnel or adjacent buildings and structures.

This confirms that the ground improvement work was the key factor contributing in minimising ground movement, and that remedial measures together with extensive instrumentation and monitoring were essential contributors to a successful completion of the project. ▶

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GRANDS PROJETS

Grouting supports tunnelling market

The principles of grouting to improve the stability of ground around underground excavations has been known for a long time, but greater attention to the basic questions of 'where?' and 'when?' has led to grouting operations that are much more sophisticated than pumping mortar into the ground more in hope than judgement. Maurice Jones explores some of the more advanced grouting techniques now being used and how they help make more tunnelling projects possible or easier

Modern grouting now demands skilled, probably specialist, practitioners that know the best way of using the many techniques now available. The expanding range of grouting techniques has made tunnelling more practical in situations where it has been nearly impossible; whether through mixed and broken geology in mountainous areas for base tunnels or in increasingly crowded urban underground space to prevent damage to adjacent structures.

Grouting can be used as a preventative measure, perhaps as part of the designed geotechnical structure, or as a rescue measure. The latter is legitimate if truly unexpected poor grounds conditions are encountered that have to be rectified, such as an undiscovered underground fault.

However adequate site investigation should reduce the chances of such grouting being necessary. Rescue grouting often halts other tunnelling activities, increasing the project time. Grouting operations that can be carried out before or elsewhere, simultaneous with tunnelling, should not delay the project as long. In the latter case they should be carried out with sensitivity to their possible effects on tunnelling.

It should be pointed out that this article does not concern itself with grouting solely to prevent groundwater movement.

However, particularly in soft ground, this can well have a structural component.

Traditional injection 'permeation' grouting fills naturally occurring voids with suitable grout to consolidate ground. There are now several extensions of this basic technique by which ground can be compacted or slightly moved, as examples. The advent of



Above: Excavating a tunnel previously strengthened with Sireg Durglass continuous glass-fibre and polymer elements including grouting tubes

additives to modify the properties of cement-based grouts, colloidal grouts as silica gels, and the polymer, or 'chemical' grouts has broadened the range of ground types that can be treated as well as the reach of grouting. The more advanced artificial grouts however are relatively expensive and usually reserved for where there are substantial water problems or emergency requirements.

Despite the exclusion and support expectations of the performance of TBMs, grouting seems to be increasingly practiced concurrently with TBM operation to the extent that, on some critical projects such as the Gotthard base tunnel, drilling and injection grouting equipment is designed into the TBM complex. This may be an

obvious necessity or a requirement of the client or its design engineer requiring greater assurance. For example, in many circumstances in the construction of the Madrid southern metro network extensions injection grouting was used, especially in crossing sensitive surface structures, despite efficient use of the EPB TBMs.

On the other hand, insufficient grouting capacity, for whatever reason, to meet the ground conditions actually encountered can lead to greater problems, whether technical, as reduced project progress or financial matters. For example, in preparation for the boring of the Port of Miami tunnel, Florida, the client has rejected a request for extra funding for grouting limestone that is more permeable

than anticipated by the contractor.

An extension of injection/permeation grouting in this context is 'compaction' grouting in which grout is injected into loose soils to form layers or 'bulbs', compacting the surrounding ground into denser material with 'engineered' properties. The technique has been widely used by Hayward Baker, part of the Keller Group in North America, with its Denver System chiefly to correct building settlement, but also for treating rubble or loose fills, and liquefiable soils.

TAMs

Although tube-a-manchette devices, the sleeved grouting pipes also known as TAMs, have been available for many years, they have been important in allowing grouting operations to be more selective and better controlled. The effects are still being felt in such operations as compensation grouting (see below), aided by the development of new grouts. The advantages of TAMs include:

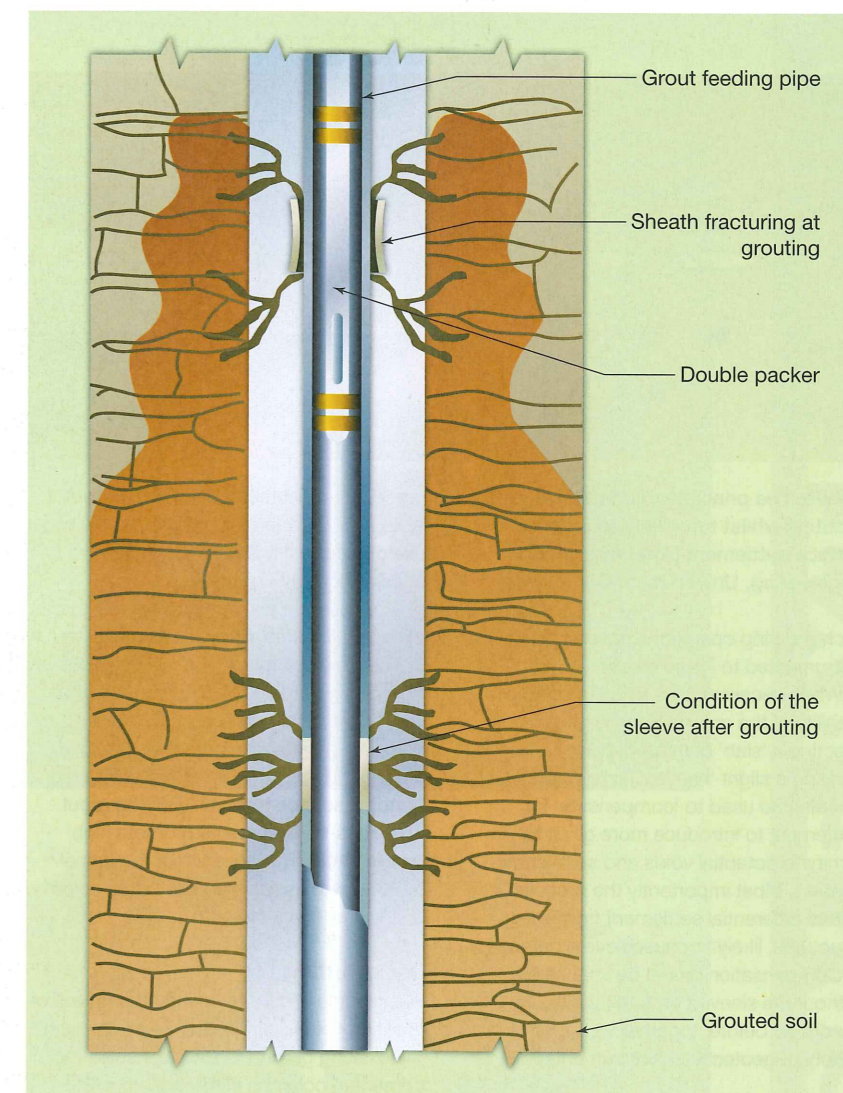
- Grout injection can be carried out in various stages.
- Different mixtures can be injected for each grouting stage, in order to treat the ground in the most suitable way.
- The treatment of the ground is carried out in a very accurate way using the sleeves mounted on the pipes to meet client requirements on location.
- Injections may be repeated at later stages through the pipe installation.

The Durvinil and Durvitech devices available from Sireg include sleeved grouting pipes in plastics and fitted with Dur-O-Ring rubber valve sleeves on the extrados or within the wall of the sleeve, operating at a specific 'bursting' pressure. The tube is installed in a bored hole filled with a cementitious grout to form a 'sleeve'. This is broken through during grouting, allowing the grout to pass through and into the ground to be treated.

Compensation

Since its first major application on London's Jubilee Line Extension (JLE) metro project under Waterloo mainline terminus, and then elsewhere on the JLE project, compensation (also 'fracture' in North America) grouting has gained growing acceptance for the stabilisation of surface structures possibly affected by settlement due to tunnelling, or to 'compensate' for any actual movement detected by an array of instrumentation on the surface.

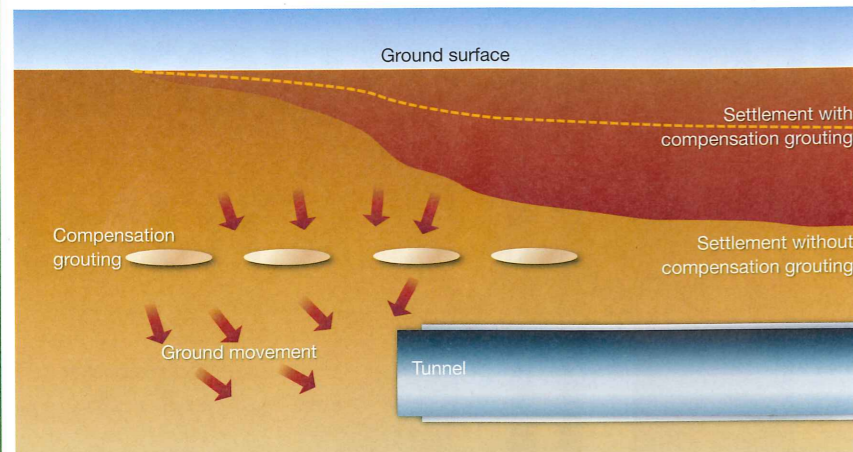
It should be noted that the injection of dense grout under high pressure in order to support or lift the structures above, then



there could well be a reaction on the structure(s) below, especially the new tunnel support lining. This type of situation has been the subject of research at Cambridge University. This affirms that

Above: Operation of a sleeved grouting pipe - tube-a-manchette - in situ using a Sireg grouting tube Below: At the control panel of Atlas Copco's Unigrout truck-mounted grouting system





Above: The principle of compensation grouting whilst tunnelling to reduce surface settlement [After Dept of Civil Engineering, University of Cambridge]

such grouting operations have to be widely instrumented to judge reactions.

When necessary it is usual to optimise stability of the ground prior to tunnelling by injecting a 'slab' of treated, perhaps creating a slight 'heave'. The grout holes can also be used to 'compensate' for settlement to introduce more grout to eliminate potential voids and so maintain support. Most importantly the process deters differential settlement from tilting structures, likely to cause severe damage.

Compensation would be impossible without the sleeved grouting pipes, as described before, together with a wide variety of geotechnical instrumentation.

Preconfinement

Grouting plays an important part in the

Below: Use of Sireg glass-fibre and polymer elements, including a grouting tube, in anchors installed in a tunnel portal face. Below right: Using jet grouting semi-horizontally, as developed by Rocksoil, to form a canopy around the excavated tunnel using a special rig



preconfinement method within Rocksoil's ADECO-RS system. In addition to the wider use of face and advance ground stabilisation with injection grouting, preconfinement also employs glass-fibre elements in holes also used for grouting.

The Durglass range of such elements from Sireg including various profiles and bars, sometimes with grouting tubes, composed of continuous glass fibres embedded in a polymer matrix with a high bonding surface to key in with the grout. The glass-fibre elements promote high tensile strength in advance of the tunnel face, as well as allowing easy excavation due to low shear strength.

Jet grouting

Having little in common with other forms of grouting, jet grouting relies on mixing with the existing ground to form consolidated, cemented columns in the ground with known structural properties. These can be linked to form a wall around an excavation in a similar way to piling or diaphragm walling. There may also be multiple rows of columns to treat greater areas.

More recently, inclined or horizontal jet grouting has been employed from either the surface or underground to form a canopy over the tunnel excavation.

Jet grouting can only be used in softer deposits or soils since the grout jet has to break up the existing structure and mix it

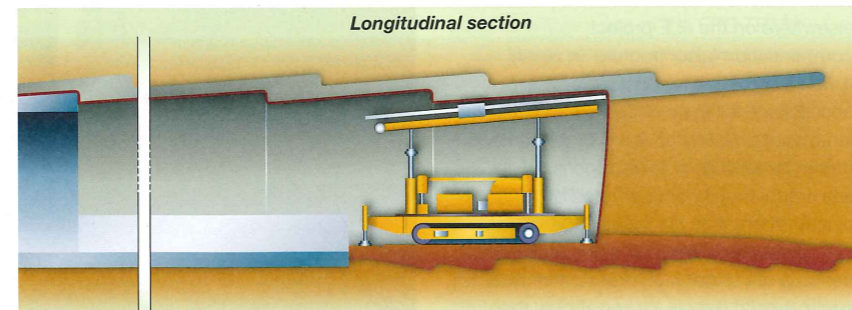
with the grout to form a new structure on curing. The boring and jetting drill string can carry one to three jetting heads that are rotated on withdrawal from the bottom of the borehole to the surface in a carefully controlled and monitored procedure.

Use of jet grouting associated with tunnelling has increased rapidly and is now being used in London for the first time on London Underground's Victoria metro station upgrading by Keller UK for the Vinci-BAM Nuttall contracting joint venture.

Control and monitoring

In the more specified and reported environment of modern tunnelling it is important that there is a good system of feedback on grouting and its effects. In traditional grouting, if the necessarily permeable ground could 'take' the injected grout, then excavation and support would be greatly improved. However, not all ground can accept grout. Indeed some ground could be made worse if the ground is friable as well as impervious, or the grout pressures and hence delivered volumes are too high, causing ground heave.

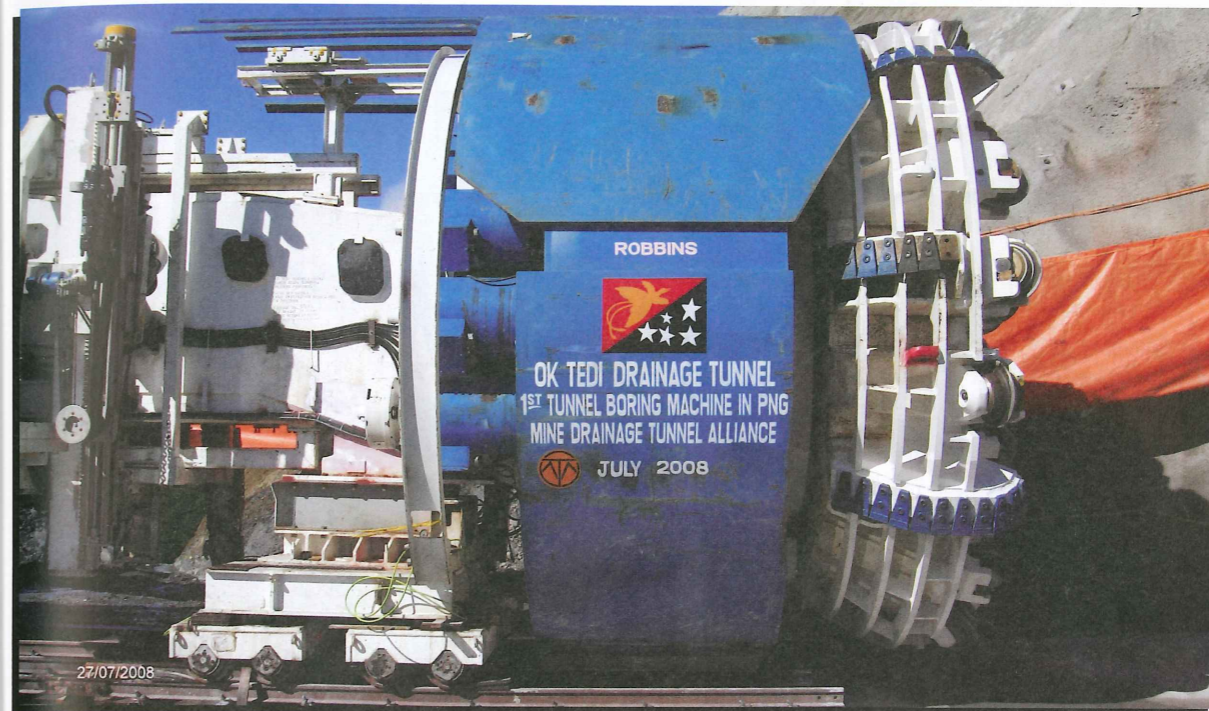
Therefore the nature of the ground being treated should be understood, with sampling and testing, before grouting. And then the correct volumes and applied pressures of grout can be decided to achieve the required results. So instrumentation is essential, with automatic reporting usually required. A wide variety of instrumentation is now available for accurate and reportable grouting. Soletanche Bachy's in-house control systems is called Spice handles data including borehole geometry and volumes of grout required at the set-up stage, injection settings, monitoring of the grout plant including pumps, flowrate and injection pressure, and tracking of grouting quality and production. It works in conjunction with programmes such as Caster, which groups together all the exploration data and establishes the location of grout holes, and Sphinx, to assemble actual grouting data and presents them graphically.



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Standards set for pre-grout drilling

Anders Ostberg of contractor Veidekke and Gunnar Nord of equipment manufacturer Atlas Copco explore the use of a four-boom drill rig for structural grouting on the Swedish Hede-Alvängen tunnel

Pre-grouting works have a large impact on all tunnelling in Scandinavia. Almost no civil tunnel work is performed without the pre-grouting component. This is still not the case in most other parts of the world and therefore a brief explanation should be given.

The bedrock in Scandinavia is 80 per cent of crystalline character and of Precambrian age. It is in general of good quality for construction as it is stable and durable. Almost no conventionally excavated tunnels are given a secondary concrete lining. The permanent support is normally based on grouted bolts and sprayed shotcrete.

The drilling and pre-grouting work is carried out rapidly and to a high standard. The sealing work constitutes a large share of the total tunnelling time. The drilling of grout holes at the Hede - Alvängen rail tunnel in Sweden is carried out with a newly developed drill rig specially designed to deal with pre-grouting operations. With the project's quality and capacity achievements, it is suitable for presentation of the drilling technique.

The project

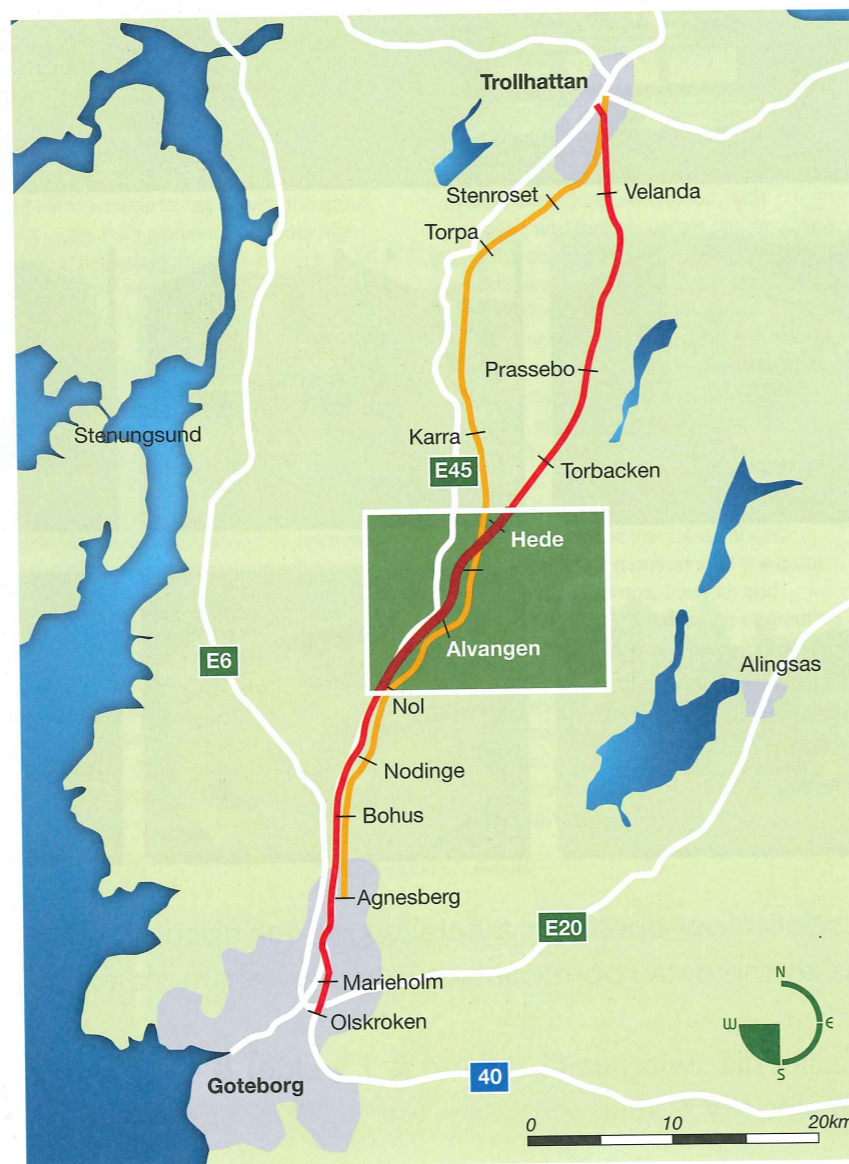
The 130m² tunnel is part of an upgrading of the railway line between Gothenburg and Trollhattan. It is a 1.1km dual track high speed rail tunnel. An emergency escape tunnel of 35m² runs parallel for 0.6km. To speed up the excavation but also to provide access to the emergency tunnel a 500m long additional tunnel has been constructed.

The Swedish division of the Norwegian company Veidekke is subcontractor to Sweden-based Peab, which has been

Right: Figure 1, location of the Hede-Alvängen tunnel project in southwest Sweden

given a larger share of the upgraded railway line. All tunnel works including permanent support are due to be completed within 21

months. The excavation itself is expected to take 18 months. Of these 18 months, roughly six months are typically allocated for sealing of the tunnel against water



Above: The Boomer XE4C rig at the tunnel face of Hede-Alvängen

seepage by use of pre-grouting.

Three major joint sets have been identified and the recorded rock quality designation values are generally very high. In the portal areas the rock cover will go down to 4m, which is low for the 15m span.

Drilling for pre-grouting

The most common drilling method is to drill in a funnel shape along the periphery of the tunnel face. In this case the number of holes is 38. The number of holes will vary depending on the ground conditions and the demand on the sealing effect. The target of the sealing is specified as 'litres of water inflow over 100m of tunnel and minute'. The accepted maximum ranges normally from 0.5 to 10. In this case the target is 8l/100m/min. The procedure has for many years been to start with a moderate number of grout holes and monitor the result by use of water loss measurements in a number of additionally drilled holes, a relation between the water loss measurement results and the expected inflow is then established. New means to

monitor the ground conditions makes it possible to pinpoint the number of holes needed to ensure that the maximum allowed inflow of water is not exceeded.

The long grout holes require drilling with extension rods. That means a number of joints and decouplings are performed for every hole. This has until a few years ago been performed manually by tunnellers standing on the service platform of the rig. The safety regulations state that no drilling is permitted when people are in front of the drill rig. As the application of the regulations becomes strict, the drilling procedure becomes much more time consuming and the tunnelling more costly. These facts pushed for the development of the fully mechanised handling and jointing of the drill rods.

The standard procedure for drilling grout holes is to have two or three boom rigs in the heavier range equipped with strong and stiff booms to rods. The storage should be large enough to hold a drill string with a length of 25 to 30m. The rig will be used for regular blast hole and bolt drilling.

This standard drilling procedure applied on a set of grout holes will take some 10 hours. In addition to this, the time for grouting and hardening of the grout will consume another 10 hours. This means that a full day is spent on the sealing work. Now some 18m of tunnel can be excavated. Normally 18m requires three (3 x 6m) rounds, with the time for one round is some 12 hours for a tunnel the size of Hede - Alvängen. This means that the time for grouting takes about 35 per cent of the total time for tunnelling for a tunnel of this character and the time for drilling is roughly 17 per cent.

The Veidekke concept

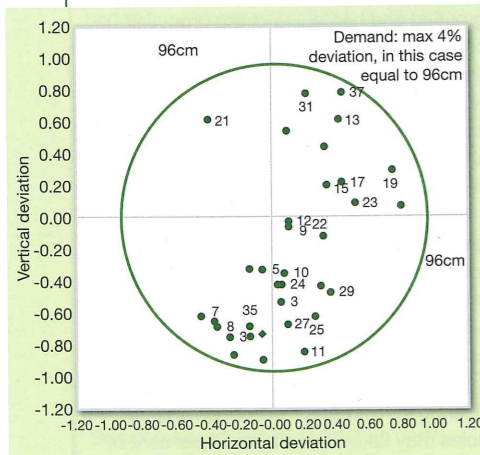
Bearing in mind that the drilling for grout holes may take as much as 17 per cent of the total tunnelling time it is not a stretch to think of the option to add more rock-drills to the rig. A doubling of the rock drilling capacity would theoretically reduce the

construction time by 9 per cent.

Assuming a tunnelling cost where one rig is involved of SEK 150M (USD 23.69M) the time related costs will roughly be SEK 100M (USD 15.79M). The nine per cent (17 per cent over two) would mean a saving of SEK 9M (1.42M) for one project only. Certainly there are additional costs involved and the reduction of time may be less but the idea to go for more rock-drills on the rig still seems viable. These ideas brought the Veidekke Company to form a kind of joint venture with Atlas Copco in Orebro to design and build a four-boom rig equipped with high capacity rock drills all suited for the drilling of long grout holes.

The rig was supposed to be used for all types of drilling that will occur in drill and blast tunnelling. The rig was given four equal booms and a capability to cover a cross-section of 200m². The feeds are 21ft (6.4m)-long and all are equipped with a rod handling system (RHS) with capacity to drill 30m-long holes using T45 rods suitable for 64mm bits of retract type. The rock-drills are of type Cop 3038. The rig control system (RCS) is such that it should be possible for one man to operate it. It is based on the ABC total system where the rig performs all the pre-programmed working sequences with the option for the operator to interfere if needed.

On this new rig-concept the operator has been given a more active role. He is given the tool to alter the design of the drill holes and drill settings of the rig. This feature has been designated 'active operator design'. That means the operator will play a more important role, providing a better sealing result. As well as a more precise location of the grout holes, the drilling is faster.



Above: Figure 2, deviation at the bottom of the 24m long grout holes from one round of holes

In order to get as accurate positioning of the rig as possible it is given the 'total station' navigation. That means that the rig position can be established with an accuracy of 10mm.

The rod handling is automatic. This system has been given the name 'Auto RHS'.

The specification used for the rig makes it suitable for the Hede - Alvangen project. The project is designed with continuous pre-grouting and a fairly short construction time. The threshold for accepted water leakage is far from the lowest as it set to 8l/min and 100m. The accepted deviation of the grout holes was up to four per cent and that means that the bottom of the 24m-long grout holes must not deviate more than 1m from the planned position.

Four-boom rig performance

The accuracy of the grout-hole drilling is continuously monitored and the result from one round of holes is given in figure 2. All the holes fall within the stipulated tolerance of 960mm. There are rounds where one or two holes have an unacceptable deviation. This might be explained by structural changes in the rock-mass. Sets of weakness planes crossed by the drill bit is known to have a great impact on the hole deviation. Typical weakness planes are joint sets of somewhat higher frequency, foliations and bedding planes when dealing with sedimentary rock.

The percussion rates in the grout hole drilling are in line with what can be expected from a 30kW rock drill and a 64mm bit when drilling in this type of ground. The penetration rate varies between 1.5 and 2m/min. For the 48mm blast hole the penetration rate is doubled.

Already at this early stage the expected speed improvements have been realised. For blast hole drilling some may dispute the time saving when going from three to four rock-drills on the boomer. Theoretically, when disregarding mobilisation and demobilisation time and losses, due to the higher complexity to coordinate when the number drilling units is increased the capacity cannot be increased by 33 per cent ($4/4=1.33$). Experience indicates that a more correct capacity increase should be $3.4/2.7 = 1.27$ or an increase of 27 per cent.

This figure matches the results achieved at this site compared to another site with very similar conditions using the XE3C rig with the rock drill Cop 3038.

Concerning the capacity increase for grout hole drilling when going from two to four rock drills on the boomer no algorithm

has been established to evaluate such an alteration. It is however easy to apply the formula for blast hole drilling and the result is an increase by 80 per cent. The result is close to reality.

Manning and rig safety

In this Hede-Alvangen case one man operates the four-boom rig. He is dealing with the whole process from transport up to the tunnel face, hook up of services, navigation and drilling. This is considered a very safe way to work, as there can be no miscommunication. Furthermore there is no labour working from the service-platform as the rod-handling system makes that activity obsolete. So far the anticipated improvements of the safety have come true. The number of accumulated man-hours at the rig is still too small to confirm that the safety has definitely improved.

The economy linked the four-boom rig

A quick look at the effect of time saving indicates the following:

The blast hole drilling typically covers some 20 per cent of total time at face. A 20 per cent reduction of the drilling time, which will be the case when going from three to four booms, would mean a four per cent reduction of the total excavation time or 2.7 per cent of tunnelling time. The time related cost for this project that can be related to this rig is given above and was estimated at SEK 100M (15.8M). The savings will then be SEK 2.7M (USD 0.4M). The discussion on savings as performed above for the grouting work ended at SEK 9M (USD 1.4M). What it means to cut down on the number of operators is probably another two million for a project of this nature. That means that savings in the range of SEK 14M (USD 2.2M) can be identified.

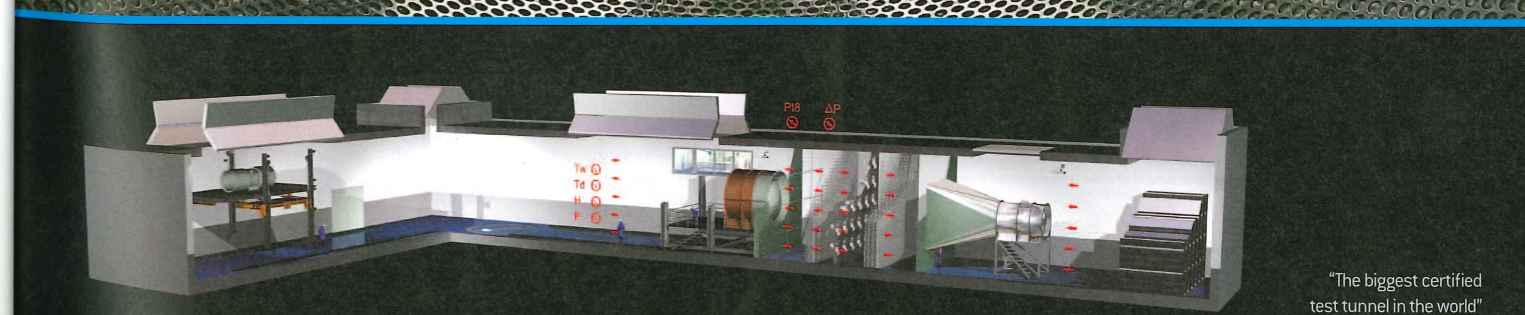
Conclusions

The driving force behind the development of this rig was a strong request from contractor Veidekke to the drill-rig manufacturer Atlas Copco. It should be a rig capable of performing all the drilling tasks asked for in tunnelling but with a competitive edge to grout-hole drilling.

The rig was manufactured and delivered mid 2010 and in autumn the same year performed as expected. The rig concept developed at an early stage and there was plenty of time for sending ideas back and forth and also to make proper checks. The project started with very ambitious plan, which were beneficial in the long run.



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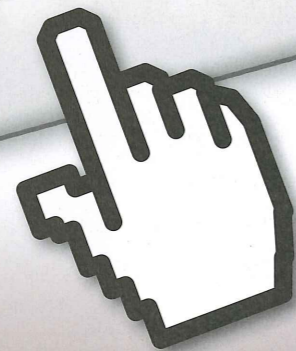
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Forecasting tunnelling behaviour

Most rock characterisation and ground behaviour prediction has concentrated on TBM drives, but the authors of this paper go into forecasting tunnel behaviour for feasibility and planning purposes when using conventional tunnelling methods, using new methodology from Spain. Prof Richard Z T Bieniawski of US-based Bieniawski Design Enterprises, David Aguado and Benjamin Celada of Geocontrol and Alejandro Rodriguez CDIAM (both companies in Spain) present the argument

In the process of designing a tunnel, knowledge of a foreseen length of advance as a function of rock mass conditions, tunnel size and shape and a method of excavation has received much attention in recent years, particularly for tunnels excavated by mechanical means, such as TBMs. For tunnels excavated by conventional methods an early prediction, for feasibility and planning purposes, is also important with respect to achieving the desired progress.

In this respect, the selection of tunnel support depends not only on rock mass quality but also on other factors, such as the depth below surface and method of excavation.

In this article, a new methodology from Spain is presented for forecasting the behaviour of tunnels constructed by conventional methods based on an evaluation, combining theoretical and empirical approaches, of the degree of tunnel stability.

Elastic behaviour

To evaluate the elastic behaviour of an underground excavation, one may recall the classic equations of Kirsch, dating back to 1898.

For the purposes of this discussion, the Kirsch solution for stresses at the perimeter of a circular excavation subjected to uniaxial compression provides two expressions for the maximum tangential stress σ_t :

Table 1: Designation of stress-deformation behaviour of a tunnel section as a function of the Index of Elastic Behaviour ICE

ICE	Stress-deformation behaviour
>130	Completely elastic
70-130	Elastic with incipient yielding
40-69	Moderate yielding
15-39	Intensive yielding
<15	Mostly yielding

$$\text{for } K_0 \leq 1: \sigma_{\theta \text{MAX}} = (3 - K_0) \sigma_0$$

$$\text{for } K_0 \geq 1: \sigma_{\theta \text{MAX}} = (1 + K_0) \sigma_0$$

where K_0 is the ratio of the horizontal to the vertical applied stresses, and the vertical principal stress $\sigma_0 = \gamma H$.

Hence, assuming an elastic behaviour, and in terms of effective stresses, one obtains:

$$\text{if } K_0 \leq 1: \sigma_{CM} \geq (3 - K_0) \cdot \gamma \cdot H$$

$$\text{or } \frac{\sigma_{CM}}{(3 - K_0) \cdot \gamma \cdot H} > 1$$

$$\text{if } K_0 \geq 1: \sigma_{CM} \geq (1 + K_0) \cdot \gamma \cdot H$$

$$\text{or } \frac{\sigma_{CM}}{(1 + K_0) \cdot \gamma \cdot H} > 1$$

where σ_{CM} is the uniaxial compressive

strength of rock mass.

Now we introduce an index of elastic behaviour (ICE - Índice de Comportamiento Elástico) (ref 1) by the following expressions:

$$\text{for } K_0 \leq 1 \text{ ICE} = \frac{100 \sigma_{CM}}{(3 - K_0) \cdot \gamma \cdot H}$$

$$\text{for } K_0 \geq 1 \text{ ICE} = \frac{100 \sigma_{CM}}{(3 - K_0) \cdot \gamma \cdot H}$$

considering a specific average value of: $\gamma = 0.027 \text{ MN/m}^3$ and adopting the Kalamaras-Bieniawski relationship (ref 2) of:

$$\sigma_{CM} = \sigma_{ci} \cdot e^{\frac{\text{RMR}-100}{24}}$$

where σ_{ci} is the uniaxial compressive strength of intact rock, the following expressions for ICE are obtained:

Qatar Integrated Railway Project ("QIRP") Requests for Expression of Interest - Metro

1. Major Underground Design-Build Works
2. Major Elevated Design-Build Works
3. Enabling Works



Brief Description of the Project

QIRP comprises 4 Metro lines along with Long Distance passenger services and a Freight system. The current focus is placed on six urgent underground Design-Build packages that include 22 km of underground tunnels as well as 15 underground stations.

Invitation to Express Interest

Qatar Railway Company (QRail) is following on the Industry Awareness Events held in May & July 2011 by inviting Consortia to express their interest in:

- Major Underground Design-Build Works (tunnels, MEP, stations, shafts...etc)
- Major Elevated Design-Build Works (viaduct, stations)
- Enabling Works (roads and utilities diversions)

Consortia comprising local, regional and international companies are invited to showcase their capacity and experience in the design and construction in some or all of the fields mentioned above.

Process for the Expression of Interest

Consortia wanting to express their interest are invited to send an email to info@qrc.com.qa and mention which types of projects or activities they are interested in. QRail will email back the Expression of Interest Form(s) and Schedule(s) providing all detailed requirements for the submission(s).

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$$\text{for } K_0 \leq 1: \text{ICE} = \frac{3704 \sigma_{ci} \cdot e^{\frac{\text{RMR}-100}{24}}}{(3-K_0) \cdot H}$$

$$\text{for } K_0 \geq 1: \text{ICE} = \frac{3704 \sigma_{ci} \cdot e^{\frac{\text{RMR}-100}{24}}}{(1+K_0) \cdot H}$$

Since the equations of Kirsch are only applicable to circular tunnels, for non-circular excavations a factor of correlation, F , is introduced.

To quantify the values of F , calculations were performed using the program FLAC 3D, including a plastic behaviour and four types of underground excavations:

1. Circular tunnel 6m in diameter;
2. Circular tunnel 10m in diameter;
3. Conventional oval tunnel 14m wide; and
4. Chambers 25m wide and 60m high.

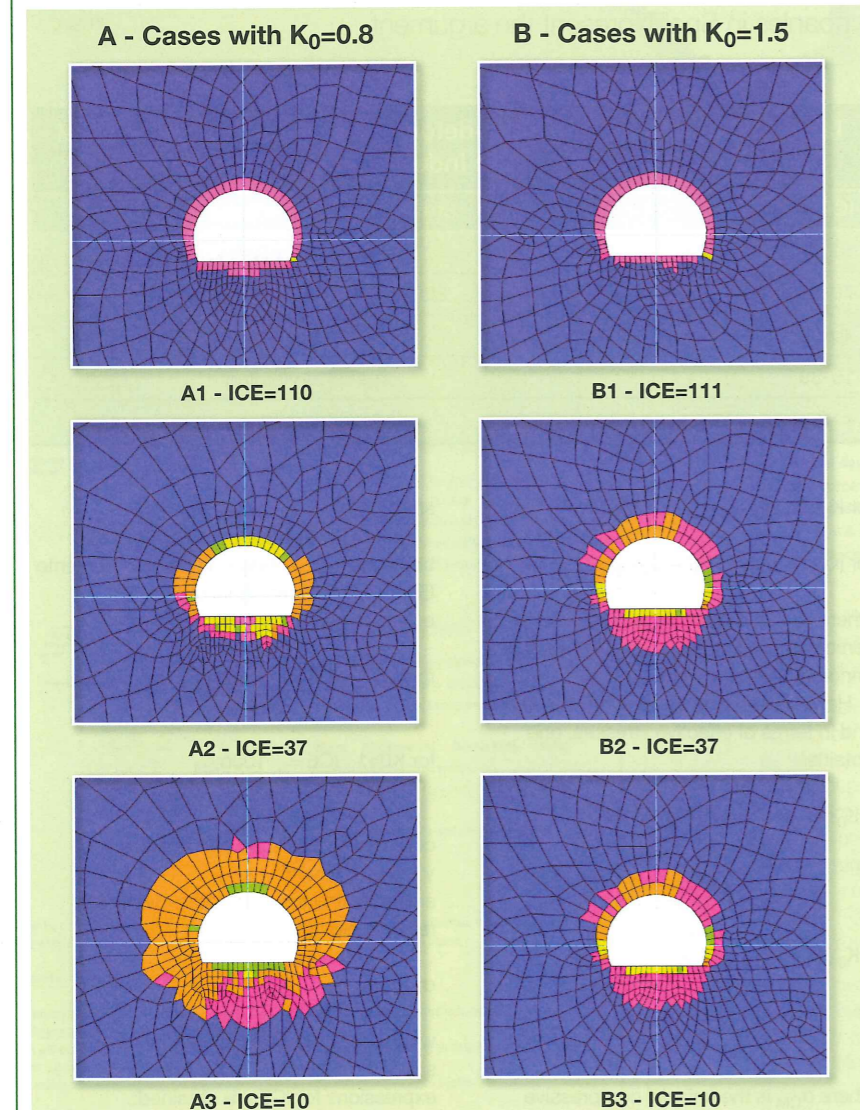
For each case of these 288 calculations were performed combining the following

values of the variables in the index ICE: $H = 100 \text{ m}; 200 \text{ m}; \text{ and } 400 \text{ m}.$
 $\sigma_{ci} = 30; 50; 70 \text{ and } 100 \text{ MPa}.$
 $\text{RMR} = 20; 30; 50 \text{ and } 70.$
 $K_0 = 0.6; 0.8; 1.0; 1.5; 2.0; 2.5.$

For each of the 1152 problems solved with the program FLAC 3D, the values of ICE were calculated and compared with the thickness of the plastic zone around each excavation.

Figure 1 shows the yielding zone around a conventional tunnel, 14m wide with six ICE values for $K_0=0.8$ and 1.5. From the results of these calculations, factor F was determined as follows:

1. Circular tunnel, diameter $\varnothing = 6 \text{ m}$
 $F = 1.3$
2. Circular tunnel, diameter $\varnothing = 10 \text{ m}$
 $F = 1.0$
3. Conventional tunnel diameter $\varnothing = 14 \text{ m}$
 $F = 0.75$
4. Chambers 25m wide x 60m high
 $F = 0.55$



Incorporating factor F , the final expressions of the index ICE are:

$$\text{for } K_0 \leq 1: \text{ICE} = \frac{3704 \sigma_{ci} \cdot e^{\frac{\text{RMR}-100}{24}} \cdot F}{(3-K_0) \cdot H}$$

$$\text{for } K_0 \geq 1: \text{ICE} = \frac{3704 \sigma_{ci} \cdot e^{\frac{\text{RMR}-100}{24}} \cdot F}{(1+K_0) \cdot H}$$

On the basis of the completed calculations, it was found (ref 3) that the ICE index provides sufficiently realistic estimates of the stress-deformation behaviour of a section of a tunnel using the criteria presented in Table 1.

Determining rate of advance

A development reported in *T&T* in 2007 (ref 4) proposed an index of Rock Mass Excavability (RME) on the basis of the experience gained during the construction of the tunnels of Guadarrama, Abdalajis and San Pedro; all in Spain. This index is determined using five parameters as follows:

1. Uniaxial compressive strength of the intact rock material: 0 - 25 points;
2. Drilling Rate Index (DRI): 0 - 15 points;
3. Effect of discontinuities at the front of the excavation: 0 - 30 points;
4. Stand up time of unsupported rock mass: 0 - 25 points;
5. Influence of water at the front of the excavation: 0 - 5 points.

A recent publication (ref 3) provides a convenient way of determining the above parameters.

While the RME was first directed at tunnelling with TBMs, the process of tunnel construction using conventional methods, such as drilling and blasting, is based on repetition of a cycle of operations. This involves the activities of excavation, loading the volume of rock to be removed and introducing support for reinforcement around the perimeter of the excavated tunnel. The length of a tunnel section excavated during each cycle of operation defines the round of advance; it is usually between 0.5m and 6.0m, and affects the overall performance of a tunnel project.

In the case of tunnels excavated in ground characterised by elastic behaviour, various operational factors play a decisive role in the resulting round of advance; bearing in mind the construction of tunnels is organised into two to three shifts every

Fig 1: Typical yielding zones for various values of the Index of Elastic Behaviour ICE and K_0 .

No.	Tunnel	Locality	Purpose	Length (m)	Excavated cross section (m ²)	Number of rounds of advance studied
1	Castro	Pontevedra	High speed railways	380	110	6
2	Reboredo			650	110	8
3	Ardilleiro			570	110	11
4	Curro			750	110	8
5	Prado			260	98	9
6	Bascuas			320	98	2
7	Portiño			478	110	6
8	Caldelás			510	110	5
9	A Pena			815	110	48
10	Vilar Do Xestal			1215	110	9
11	Bendoiro			400	110	8
12	Anzo			545	110	19
13	Archidona	Málaga	Road	1110	140	33
14	Candelaria	Canaria		500	94	5
15	Mogán	Island		600	94	36
Total number of rounds of advance studied						213

day. In essence, the question arises whether a full cycle can be completed in one shift or is it preferable to adopt a longer round of advance, which would make it necessary to complete the cycle over a few shifts.

In such cases the round of advance is dependent on downtimes at the face, on the capacity to transport the excavated rock, and on the difficulties that the ground might offer for drilling and blasting. In tunnels with a total length of less than 2.5 km, which represent most of those constructed by conventional methods, the downtimes at the face are similar due to the operations of transport vehicles. In essence, in the case of modern large highway tunnels or long railroad tunnels constructed by conventional methods, the round advance is dictated by rock mass excavability if an excavation behaves elastically, so that the tunnel sections have sufficient stand-up time without support throughout their length. In such cases, the RME index can be used to decide the advance round.

When an excavation does not behave elastically and loosening takes place, the round of advance will be governed by the degree of stability of the rock mass and, in this case, one should utilise the RMR classification (ref 4) or the Q-system.

Data collection

To carry out the present investigation, a comprehensive program of data collection from tunnels during construction was undertaken. In each case, data were obtained including the RME and RMR of the rock mass, as well as other data related to the process of construction.

Recent research showed (ref 3) that the RME was equally applicable to tunnels constructed with TBMs as well as with conventional methods.

To prove this finding in the course of this investigation, beginning in the second half of 2009, extensive data collection was carried out from 15 tunnels which were part of the high speed train network in Spain, as well as others from highway tunnels, as depicted in Table 2.

In total, 213 rounds of advance were analysed; 129 of them – representing 60 per cent of the total – were excavated with explosives and the remaining 40 per cent by mechanical means. It is believed that the tunnels studied contain a sufficient number of cases, including a wide variation in rock mass conditions.

Analysis

The data obtained from the collection of 213 tunnel sections were analysed statistically to develop representative

correlations between the round advance (RA) and indices RME, RMR and ICE.

The best correlation relating the three indices with the round advance (RA) was found to be in the form of a hypersurface having this equation:

$$\left(\frac{\text{RME}}{86}\right)^2 + \left(\frac{\text{RMR}-50}{44}\right)^2 + \left(\frac{\text{RA}-3.31}{4}\right)^2 + \left(\frac{\text{LogICE}-2}{4}\right)^2 = 1$$

The coefficient of correlation $r^2 = 0.896$ is considered very high.

Once this correlation was established, the next step was to identify the ranges of physical meaning of the round of advance RA. The first two ranges were characterised by $\text{ICE} < 130$ and $\text{ICE} > 130$, corresponding to plastic ground and that of elastic behaviour respectively. Following these delineations, these were the correlations obtained:

For plastic behaviour ($\text{ICE} < 130$):

$$\text{RA (m)} = 3 - 3 \cdot \sqrt{1 - \frac{\text{RMR}}{50}}$$

The coefficient of correlation $R^2 = 0.87$ is very high. In this case the length of tunnel advance would be between 0 and 3 m; such that the yielding condition of the terrain would not allow any stand-up time without support for a tunnel length greater than 3m.

Table 3: Tentative recommendations for tunnels 14m wide, based on ICE values

ICE	Excavation behaviour	Excavation size	Support	Special elements of support	Advance length	Tunnel lining
>130	Completely elastic	Full face ↑ ↓ Top heading and bench ↓	Rock bolts L=4.5m Sp=2-2.5 m Shotcrete: 5cm	None	By RME	Cast concrete. No invert.
70-130	Elastic with incipient yielding		Rock bolts L=4.5m Sp=2m Shotcrete: 10cm	None		
40-69	Moderate yielding		Rock bolts L=4.5m Sp=1.5m Shotcrete: 15cm	None	By RMR and Q	Cast concrete and invert (0.1 x excavation width)
15-39	Intensive yielding		TH-29 Steel arches 1m spacing	Elephant foot, heavy forepoling umbrellas and grouting under elephant foot		Cast concrete and invert (0.2 x excavation width)
<15	Mostly yielding		HEB-180 Steel arches 1m spacing	As above plus face bolted		Steel reinforced concrete in circular cross section

In the case of a tunnel section excavated in ground characterised by elastic behaviour, better correlations were obtained when this region was subdivided into two conditions: RMR > 50 and RMR < 50. The correlations in both cases are as follows:
For ground with elastic behaviour (ICE > 130) with RMR > 50:

$$RA (m) = 3 + 4.4 \cdot \sqrt{1 - \frac{RME - (RMR-50)^2}{90 \cdot 55}}$$

The coefficient of correlation was obtained as $r^2 = 0.77$ which is reasonably good.

In this case, the expected round of advance would range between 3.5 and 5.5m.

For ground with elastic behaviour (ICE > 130) with RMR < 50:

$$RA (m) = 3 - 5 \cdot \sqrt{1 - \frac{RME - (RMR-50)^2}{90 \cdot 42}}$$

The coefficient of correlation is $r^2=0.79$, which is again, reasonably good.

Selecting temporary support

One of the applications of the ICE concept is to provide recommendations for primary tunnel support for the tunnel sections when the value of ICE remains practically constant, as this index includes the RMR of the rock mass, the depth below surface and the length of advance.

On the basis of the experience of the authors, acquired over many years from 337 tunnels of various types, tentative recommendations on tunnel support are proposed in Table 3 for an example of excavations 14 m in width.

These recommendations include guidelines for conventional excavation involving primary support as well as final lining, subject to measurements of the magnitude of tunnel convergence and monitoring the stability of the tunnel during construction.

Conclusions

Based on the equations developed by Kirsch and supported by 288 calculations of stress-strain analyses using the software FLAC 3D, an index ICE (Índice de Comportamiento Elástico - Index of Elastic Behaviour) was developed. This approach proved useful for assessing stress-strain

The authors

The research presented in this article was performed in Spain under the initiative of Geocontrol, a civil engineering company established in Spain in 1982 and with branches in Chile, Colombia and Brazil.

Initially specialising in applied rock mechanics, since 1987 the company has been oriented towards design and construction of tunnels.

Prof Bieniawski, the principal of Bieniawski Design Enterprises, has been associated with research and consulting with Geocontrol since 1987.

Dr Benjamin Celada, former professor and chair of underground rock engineering at the Technical University of Madrid, leads the company as its president and technical director.

behaviour of tunnels constructed by conventional methods.

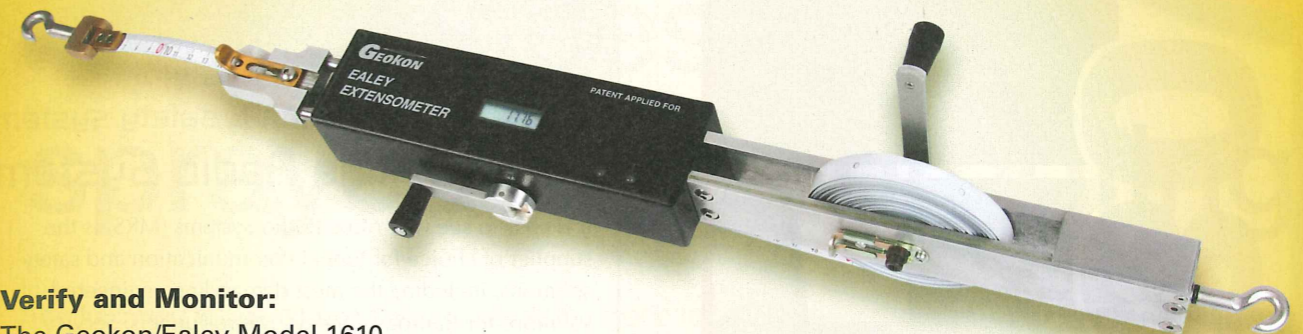
In addition, several tunnels under construction were analysed, providing correlations between the length of advance and the values of the RME (Rock Mass Excavability) and the RMR (Rock Mass Rating), distinguishing between tunnels behaving elastically and those involving a degree of yielding behaviour.

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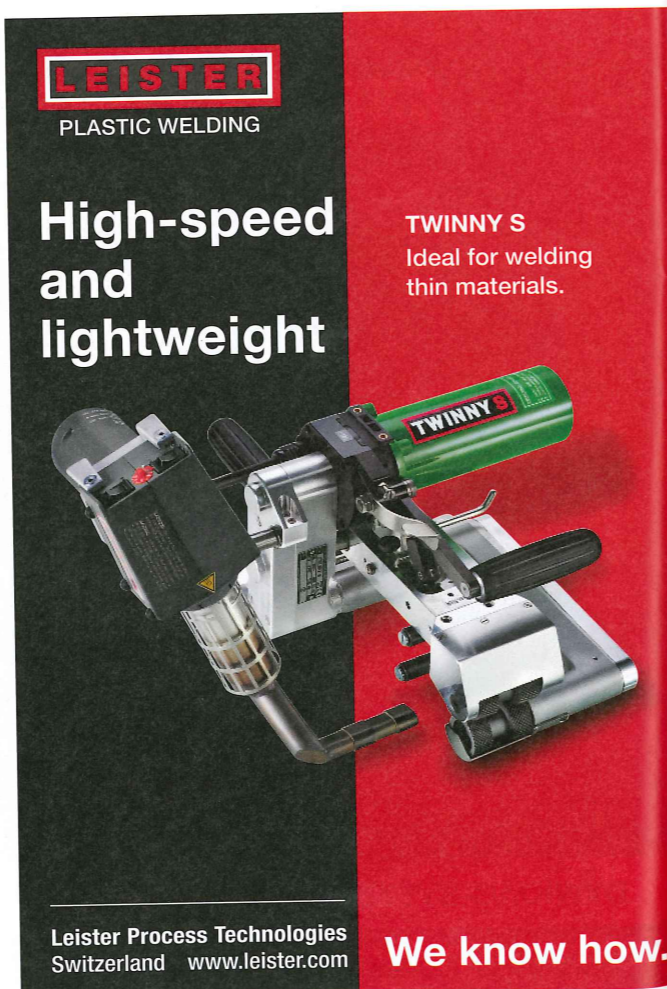


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Experiences with sprayed waterproofing

The following article is based on a presentation made to the 'Underground Construction' conference in June in London and is based on the experiences of three tunnel engineers on projects utilising sprayed waterproof membranes. The authors are David Naylor, Petr Salak and Simon Stephenson, at the time all of Mott MacDonald consulting engineers

The use of waterproof membranes for underground construction is becoming more and more common, with a range of products now available on the market. Spray applied membranes can offer a range of benefits compared to the sheet membrane alternatives, but with any product there are key points to note for its successful application and lessons to be learnt to improve future membrane systems and applications.

The following is based on experiences obtained from both the design and site supervision of three tunnelling projects in the UK. These projects illustrate the range of applications of a sprayed waterproof system, covering large shafts, small-scale

tunnelling schemes, as well as major infrastructure projects.

The experience gained on these projects is documented and lessons learnt put forward to try and assist the industry in successful use of sprayed waterproof membranes in the future.

Projects

The Hampton Pump Out Shaft (HPOS), south-west London, is a 40m-deep, 15m-diameter shaft and constructed between 2007 and 2009 using a combination of precast concrete segments and sprayed concrete. The initial section of the shaft was constructed using precast concrete segments using underpinning techniques until the shaft was within London Clay.

For the second half of the shaft a permanent primary and secondary sprayed concrete lining (SCL) was constructed utilising a sprayed waterproof membrane. A waterproof membrane was required for the scheme, despite the relative impermeability of the ground, in order to provide the client the assurance that the end product would be waterproof for the entire design life.

The Dorchester Service Link, London, consists of two 12m-deep, 3.7m-diameter shafts and one 117m-long connection tunnel. The two shafts were excavated within the existing basements of 45 Park Lane and the Dorchester Hotel.

The primary lining of the shafts utilised a combination of steel liner plates and SCL with a 200mm thick cast in situ concrete secondary lining. The tunnel primary lining was designed as 150mm-thick SCL without any reinforcement. A 200mm-thick, cast in situ concrete secondary lining completed the tunnel lining. The client's requirement was for a leak-free, undrained scheme that minimises the influence on the water table. A sprayed waterproof membrane system was chosen to fulfil this requirement as it was accepted by all parties within the scheme and was seen to be a simple and swift solution for the waterproofing issues present in a challenging construction environment.

The A3 Hindhead road improvement scheme comprises 6.7km of new dual carriageway in Surrey, south-east England. Of this, 1.8km is twin tunnel bores constructed during 2008-2009 using SCL. The tunnel alignment was



Left: Applying BASF Meyco Masterseal in Hindhead Tunnel using standard robotic spraying equipment



Above: Connecting tunnel for the Dorchester Hotel service link

through the Hythe Beds, which comprise highly interbedded sandstone with sand lenses, and was kept above the water table at all times.

Both primary and secondary linings at Hindhead included fibre reinforcement. The primary sprayed concrete lining was designed to be permanent and was applied direct to the exposed material by robotic spraying equipment.

Spray-applied waterproofing was placed using the same equipment as the



primary lining. Secondary lining walls were cast using single-sided shutters and finally the newly sprayed secondary crown was installed.

The spray-applied waterproofing system at Hindhead was chosen for a number of reasons:

- The primary linings were mostly dry during excavation due to the alignment being above the water table.
- The limited reinforcement in the secondary linings prevented the need for many penetrations through the sprayed membrane.
- The system offers great construction flexibility by removing the need for large installation staging.
- A spray-applied crown could be used which removes the need for large shuttering, again improving construction flexibility.

Flexibility

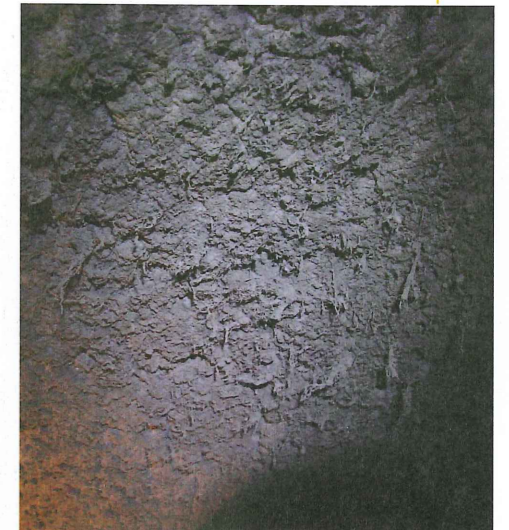
A distinct advantage of the sprayed waterproof membrane system is the ease and flexibility of its application through robotic application. This gave particular

Left: Examining the sprayed membrane applied in the Hampton pump-out shaft

benefits to the schemes at Hindhead and Hampton. For the Hampton HPOS, robotic application of the SCL and membrane was proposed utilising the same robot throughout the project. While the plant is more expensive than 'hand' spraying, the use of a robot allows the operator to be away from the face of the excavation and provides more control over the thickness of the sprayed concrete applied with less rebound (thereby saving material costs). The robot used at Hampton proved its flexibility and was used without problems for both the 15m-id shaft as well as the 3.7m-id SCL connection tunnel required from the HPOS. In practice the robot swiftly managed to apply the membrane due to its large operating reach and certainly proved its worth in terms of quality, safety and programme benefits.

Preparation

For the successful application of any construction product, preparation is key. Preparation must begin with the training of the staff that will be applying the membrane. From all three project experiences, successful application of waterproof membranes was related to the

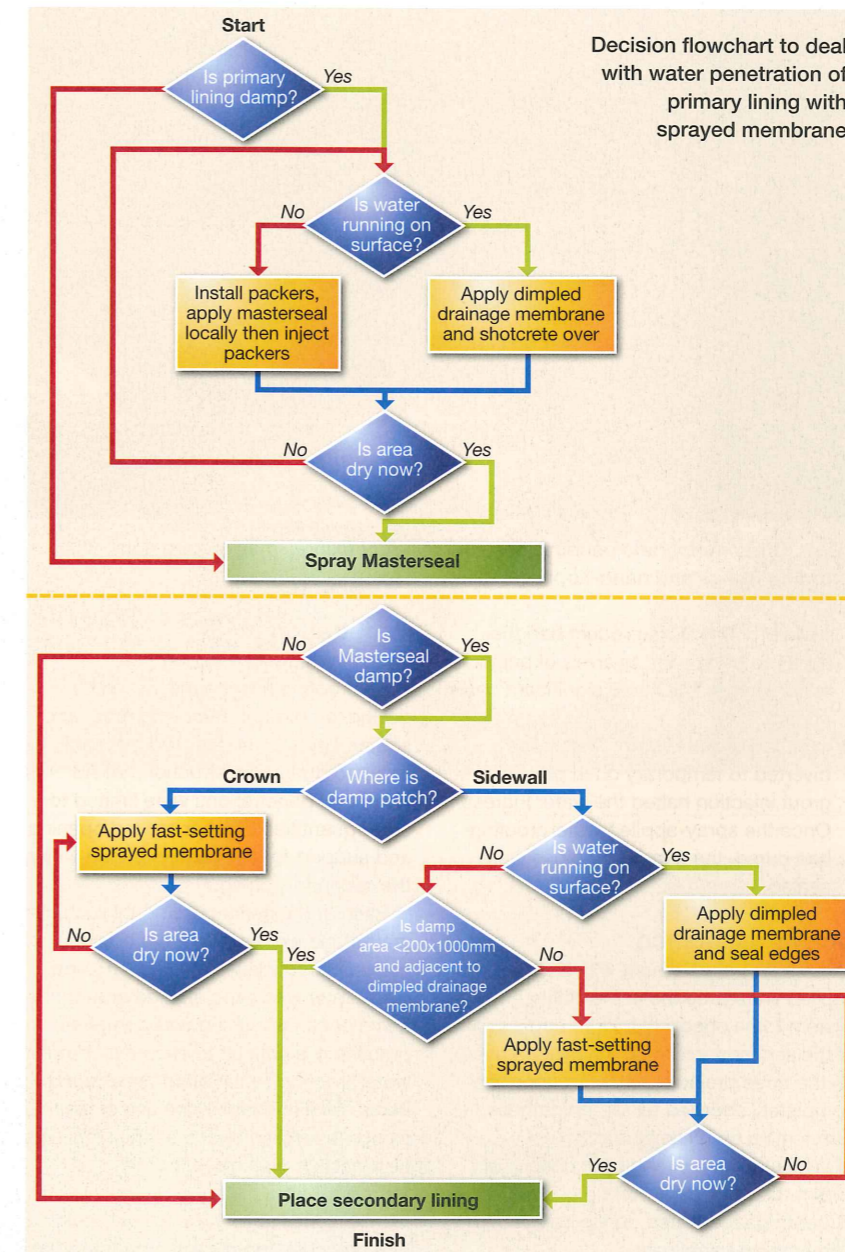


Above: Uneven substrates such as this can cause problems in applying sprayed membrane

waterproof membrane for the HPOS was applied in the shaft while being exposed to the elements, which presented some additional challenges. The success of the curing of a waterproof membrane can be affected by both low temperature and large temperature ranges. For the HPOS project it was required for the membrane to be applied in a particularly harsh winter month. In order to cope with the low temperature, space heaters were used to ensure that ambient temperatures were kept to acceptable levels, but had mixed results. While the extent and duration of British winters have been difficult to predict in recent years, from the work undertaken at Hampton it would be recommended for any future projects that application of waterproof membranes should be undertaken in summer months if at all possible within construction programming.

Managing water

Active water ingress (eg dripping) prevents the currently available spray-applied membranes from curing. Proactive water management may therefore be required in order to provide a dry substrate during the curing process. Unlike the other projects described in this article, the application of the waterproof membrane for the HPOS was applied in the shaft while being exposed to the elements. In order to prevent water flow down the surface of the curing membrane, local guttering at the transition of the segmental and SCL sections of the shaft was used to ensure



learning curve of the site labour. Consequently it is strongly recommended that for future projects a significant length of time is allocated for trial spraying of any membrane with testing of the consistency of the membrane mix to ensure that it is suitable for the application proposed.

Going beyond the preparation of the site team, good preparation of the concrete substrate is vital for effective application of a sprayed waterproof membrane. All of the projects mentioned either benefitted or would have benefitted from the use of a smoothing layer. Through the use of a smoothing layer all large uneven parts of the substrate can be

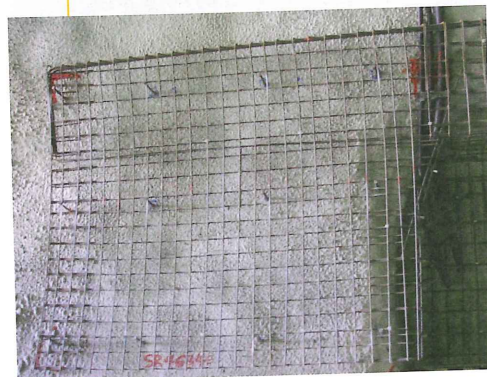
overcome as well as preventing any protrusions caused by fibres in the substrate that could jeopardise the membrane performance. For the Hampton scheme, the absence of a smoothing layer led to a substrate that was insufficiently smooth in certain areas for successful membrane application and therefore required respraying.

Given the large difference in the cost of a smoothing layer compound versus the waterproof membrane, it would be recommended that smoothing layers are specified for SCL substrates to minimise material wastage.

Unlike the other projects described in this article, the application of the



Above: Proximity of reinforcement wire etc to the membrane may result in accidental penetration; **Below:** Some planned penetration of the membrane can be allowed if sealed as with reinforcing mesh



water ingress down the surface of the shaft could be controlled and managed. These measures are quite simple but provided an additional set of activities to be undertaken which could have impacted upon the scheme programme.

At the A3 Hindhead project, water ingress was prevented through by a number of means (see flow-chart):

- Application of natural cement: This fast curing product could be placed over active water ingress, and provided a dry substrate for a short time (allowing the spray-applied waterproofing to cure). In practice this solution reduced the flexibility of spray-applied waterproofing because of the short timescale required to apply the waterproofing over the cement.
- Application of dimpled drainage membrane: This was fixed to the spray-applied waterproofing, as a water-path for permanent drainage. Care is required to ensure sealing of the product to the substrate in order to prevent side leakage (particularly if not installed vertically). A second coat of spray-applied waterproofing was applied over the product.
- Application of fast-curing spray-applied



Above: Other membrane penetrations such as duct fixings may require non-corroding fixings and hand-applied sealing

waterproofing: This product had the ability to be applied to areas of active water ingress but had a significant cost impact.

- Injection of water path: Water was diverted to temporary drain pipes whilst grout injection halted the water ingress. Once the spray-applied waterproofing had cured, the temporary pipes were sealed.

Quality assurance

An area for improvement with spray-applied waterproofing is the ability of the system to be checked prior to application of the secondary lining. The system used on the three projects featured cannot be completely checked for watertightness, with testing being limited to:

- visual inspection and spot checks of film thickness and bond,
- depth gauges used during sprayed membrane application ,
- removing 50mm x 50mm patch off the membrane from the SCL surface, to check for the required minimum 3mm thickness.

While these measures are simple to undertake on site, they offer little assurance of the integrity of the membrane composite for the entirety of the application. Consequently, whilst the bonding of the secondary lining to the waterproofing will minimise water ingress, it is not possible for the construction team to guarantee the quality and integrity of the installed system. With remedial work after installation of the secondary lining being costly, a solution to allow checking of the waterproofing would be welcomed.

Penetration

Whilst penetrations through the waterproofing may be minimised by design (eg through removing rebar and equipment fixings), they will inevitably be required during construction. At A3 Hindhead penetrations were limited to small quantities of rebar around openings and support for duct banks buried within the secondary lining.

Each of the items passing through the membrane were specified to be non-corroding (stainless steel or GRP) and membrane was hand applied around the items once installation was complete. In practice it is difficult to ensure a complete waterproofing seal around penetrating items. As a mitigation, the use of resin fixings is recommended as the resin acts as a backup waterproof barrier.

Conclusions

The preceding points are brought to the industry's attention with the intention of improving the use and design of future sprayed waterproof membrane systems and products.

By improving the usage and design of waterproof membranes it is hoped that they can be successfully used in many future UK and worldwide schemes.

It is worth noting additionally that the successful use of these products is also down to growing client acceptance of sprayed waterproof systems and contractors appreciating the benefits that they can offer.

All the authors thank the contractors and clients of the schemes willing to accept the benefits of a sprayed waterproof membrane solution. ■

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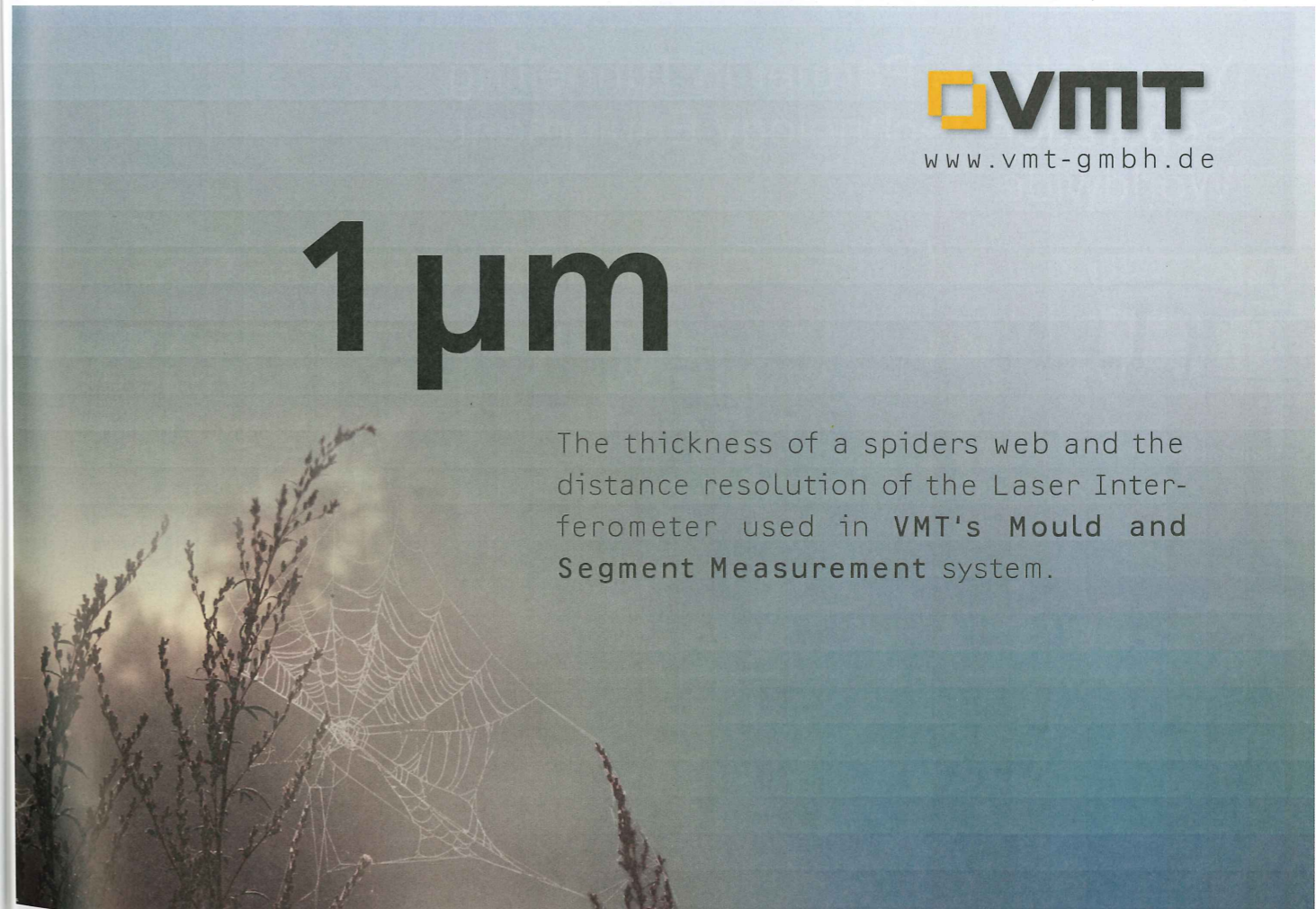


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Predicted and encountered deformations

Andreas Feiersinger of Dr. Sauer Company was the runner up in the British Tunnelling Society 2011 Harding Prize for this paper comparing deformations predicted using 3D Finite Element Analysis with those encountered on the Green Park station upgrade in London

Green Park Tube Station is a London Underground (LU) station situated on the north side of Green Park in central London. The station serves as an interchange between the Piccadilly, Victoria and Jubilee Lines.

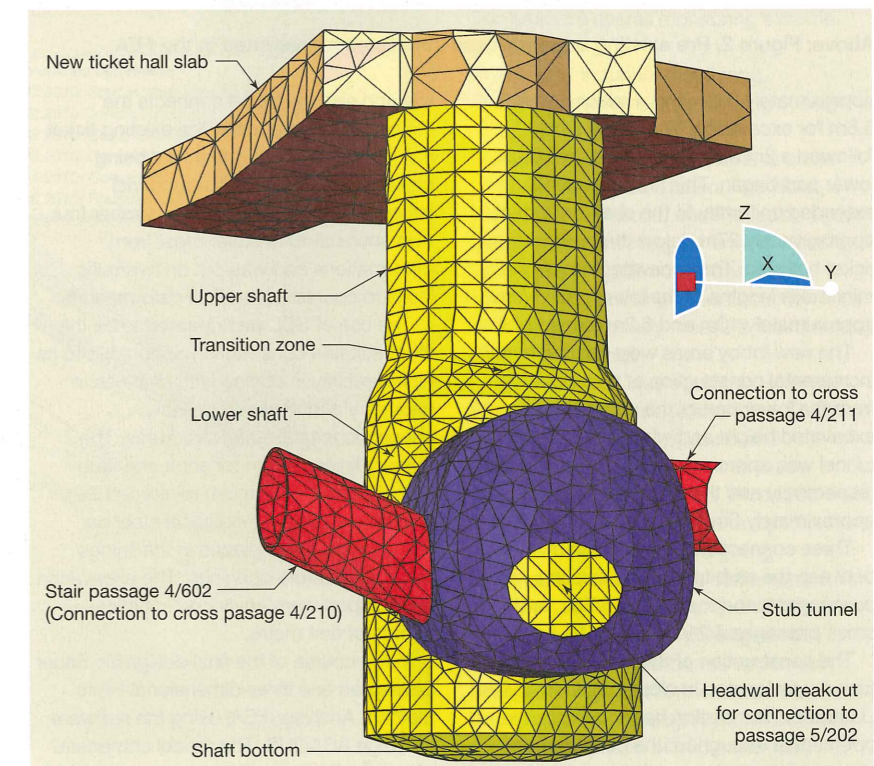
The purpose of the project at Green Park is to provide the station with step-free access (SFA) between street level and all operational platforms via a new ticket hall extension and lift system. The station, used by circa 60 million people annually, will thus become accessible for Tube passengers with disabilities and passengers with reduced mobility.

Project overview

The works for the excavation and construction of the lift shaft at Green Park were let as a design build contract by main contractor Tube Lines. The winning tender was presented by the contractor, Joseph Gallagher (JGL), with Capita Symonds as the lead design organisation. The specialist sub-consultant for the shaft and tunnel works was Dr. G. Sauer Company. Dr. Sauer was responsible for the design of the sprayed concrete lining (SCL) primary support and for providing construction support services.

The contract was awarded in February 2009 at which point a six-month design phase commenced. The SFA is due to be completed in time for the start of the Olympics in 2012.

The value of the civils contract was GBP 9M (USD 14.57M), excluding the architectural, mechanical and electrical fit-



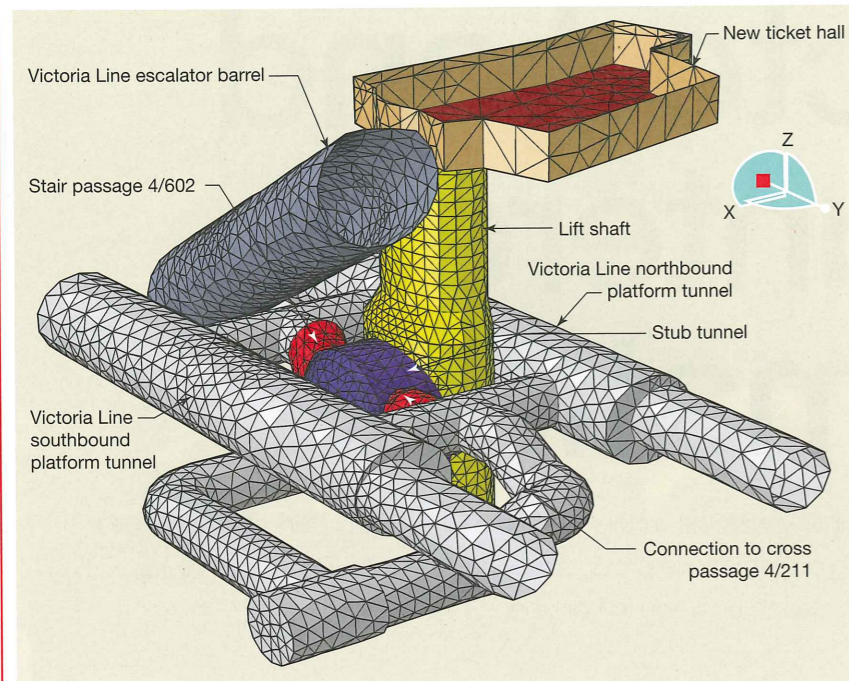
Above: Figure 1, Proposed structures for the Green Park lift shaft and stub tunnel

out works.

The shaft and tunnel works involved the design and construction of a SCL ellipsoid shaft, stub tunnel and stair passage tunnel (see Figure 1, above). The shaft will house two 19-person Machine Room Less lifts which will take Tube passengers from the new subsurface ticket hall extension to the Victoria line and the Piccadilly and Jubilee

line interchange passageway. The stub tunnel will provide lobby areas to each lift landing and connection to existing circulation and passageway assets.

The ellipsoid shaft consisted of a smaller upper part, which is belled out for the larger lower part. The upper part extends to approximately 10m below the base of the new ticket hall slab with a major axis of



Above: Figure 2, Pre existing and proposed structures represented in the FEA

approximately 8.6m and a minor axis of 5.6m for excavation. The upper shaft followed a 2m transition before the larger lower part began. This cross section extended uniformly to the shaft bottom at approximately 27m below the base of the ticket hall slab. The excavated major and minor axis lengths of the lower shaft were approximately 10m and 6.2m respectively.

The new lobby areas were formed by the incremental construction of a stub tunnel from the lower part of the shaft. The excavated height and width of the stub tunnel was approximately 11.2m and 9.6m respectively and the total length approximately 6m.

Three connections were required between the stub tunnel and existing passenger tunnels; passage 5/202, and cross passages 4/210 and 4/211.

The construction of the shaft and stub tunnel was located in close proximity to live LU assets. The station had to remain operational throughout the construction phase necessitating continuous monitoring of the existing structures.

Design

The design of the shaft and tunnel works comprised sprayed concrete primary linings (SCL), cast in place secondary linings and sheet waterproofing membranes.

During the design the impact of construction onto the existing Victoria line escalator barrel was a major issue. Containing three escalators (numbers four,

five and six), the barrel connects the Victoria line platforms to the existing ticket hall with escalator number four being closest to the shaft and stub tunnel excavation. Hence, escalator number four was anticipated to suffer most from deformations and was put on hydraulic jacks to counteract vertical deformations.

The use of SCL was deemed to be the most suitable construction option due to its high flexibility in coping with changes in geometry and its ability to allow connections to existing structures. The primary lining design for shaft and stub tunnel consisted of mesh reinforced SCL with lattice girders. Additional steel bar reinforcement was placed in the linings around the future openings. The excavation and support were advanced in typical rounds of one metre.

In the course of the final design Dr. Sauer developed one three dimensional Finite Element Analysis (FEA) using the software package ABAQUS. The model comprised of pre existing cast iron structures and the new sprayed concrete lined structures (Figure 2, above). The model also included the new ticket hall excavation and a concrete collar surrounding the top section of the escalator barrel at its connection to the ticket hall and upper machine chamber.

The model represented an underground volume of 100m x 100m x 42m and comprised approximately 160,000 three-dimensional continuum elements. The elements were kept small particularly at the

location of excavations and in close proximity to cast iron structures with characteristic minimum edge lengths of 0.5m. Precise mesh quality checks were conducted during the modelling process to prevent potential numerical instabilities.

The entire structure was located within London Clay except for the uppermost two to three metres which were within made ground. This was removed during excavation of the new ticket hall.

London Clay was modelled following an elastic plastic constitutive material model. The linear elastic material was characterised by a depth dependent Young's Modulus, linearly increasing with depth and directly proportional to the linear increase of the undrained shear strength. The Mohr Coulomb failure criterion was used to model soil plasticity in undrained soil conditions. To generate the initial stress state a lateral earth pressure coefficient of one was used for London Clay.

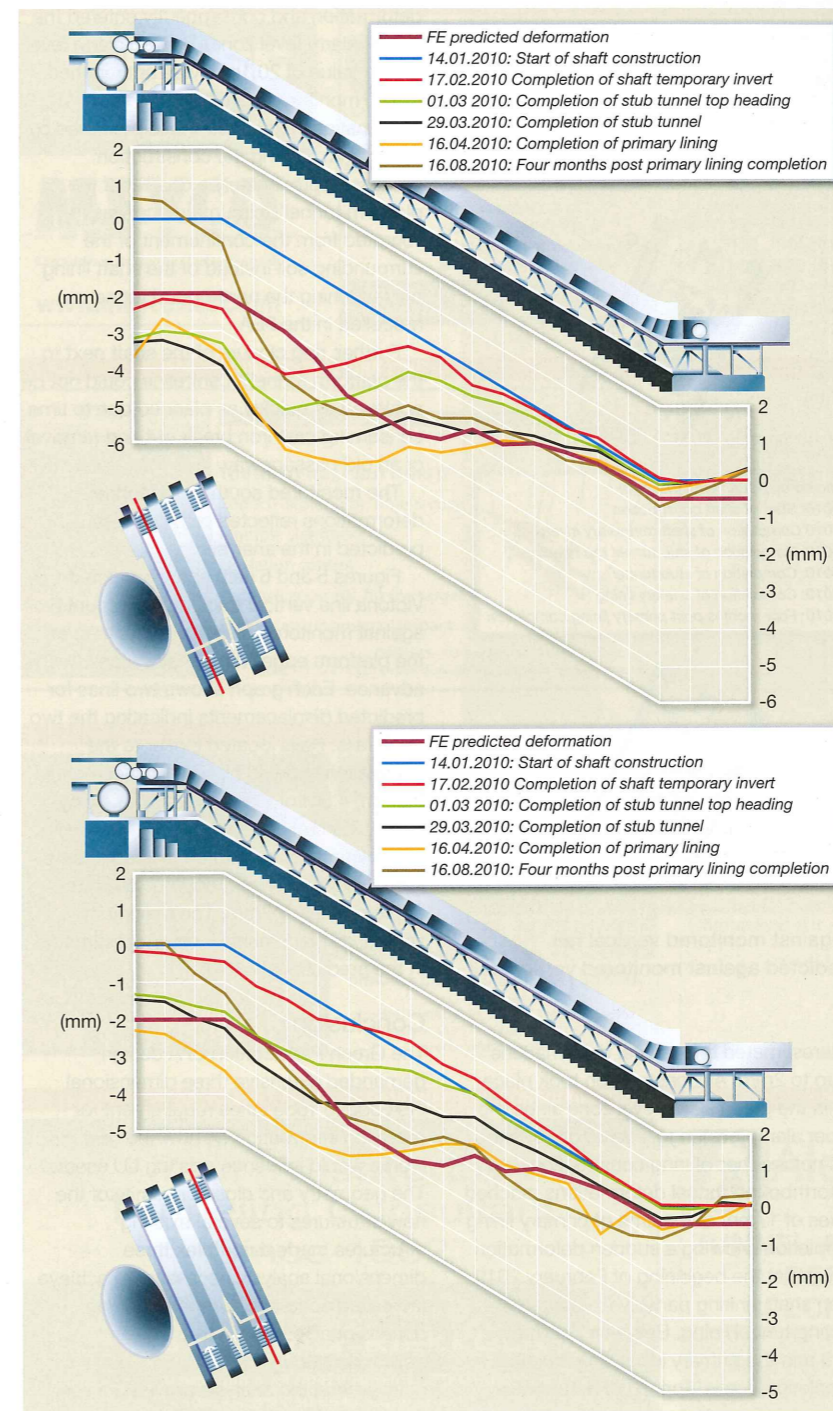
The stiffness of London Clay was modelled without direct dependence on the soil's micro strain or small strain stiffness. However, strain values and strain changes were observed in the model and the suitability of the used stiffness confirmed. The Young's Modulus used in the model corresponded well with the tested Young's Modulus at a strain level of approximately 0.1 percent.

Parametric studies of the Young's Modulus were undertaken in order to generate expected boundary values of deformation and for the evaluation of model sensitivities. The modulus was varied up to (+/-) 50 per cent with respect to the original design value.

The groundwater was omitted from the stress strain analysis of the soil and no pore water pressures and pore water pressure dissipations were modelled. However, groundwater pressures linearly increasing with depth were applied to the secondary lining for the assessment of lining thickness and required reinforcement.

The pre existing cast iron structures of the Victoria line tunnels and the concrete primary and secondary linings of the proposed structures were modelled using structural shell elements (two dimensional elements with a characteristic shell thickness).

Cast iron elements were characterised by the same cross sectional area (and hence same normal stiffness) as the cast iron segments installed at Green Park Station in the 1960s. This resulted in a uniform shell thickness of 0.05m with regard to the Victoria line platform tunnels. The cast iron was modelled to follow a



Left: Figure 3, escalator number four – predicted against monitored vertical deformations (monitoring values obtained from electrolevel readings below the escalator)
Figure 4, escalator number six – predicted against monitored vertical deformations (monitoring values obtained from electrolevel readings below the escalator)

was analytically investigated in the model and found to be minor. After discussions between Tube Lines and the design build team the pipe arch was discarded in favour of smooth metal spiles.

The FEA deformations taken for comparison in Section Five were 'best estimate' results based on the use of the proposed design soil properties. Results obtained from parametric studies deviated up to 30 percent from these results.

Construction

The project's overall monitoring scheme comprised:

- In shaft / in tunnel monitoring,
 - Ground movement monitoring through inclinometers and
 - Monitoring of existing assets such as Green Park Tube Station, Ritz Hotel, Devonshire House, and Piccadilly Street.
- The overall monitoring scheme of existing LU assets, the ground surface and neighbouring buildings was set up by Tube Lines to continuously measure movements, tilts and vibrations.

The Ritz Hotel was equipped with five tiltmeters on the facade and three vibration detectors (Room 121, Casino and Stairwell), and the Devonshire House facade with three tiltmeters. Piccadilly Street and the Green Park site compound were periodically surveyed giving information about surface settlement.

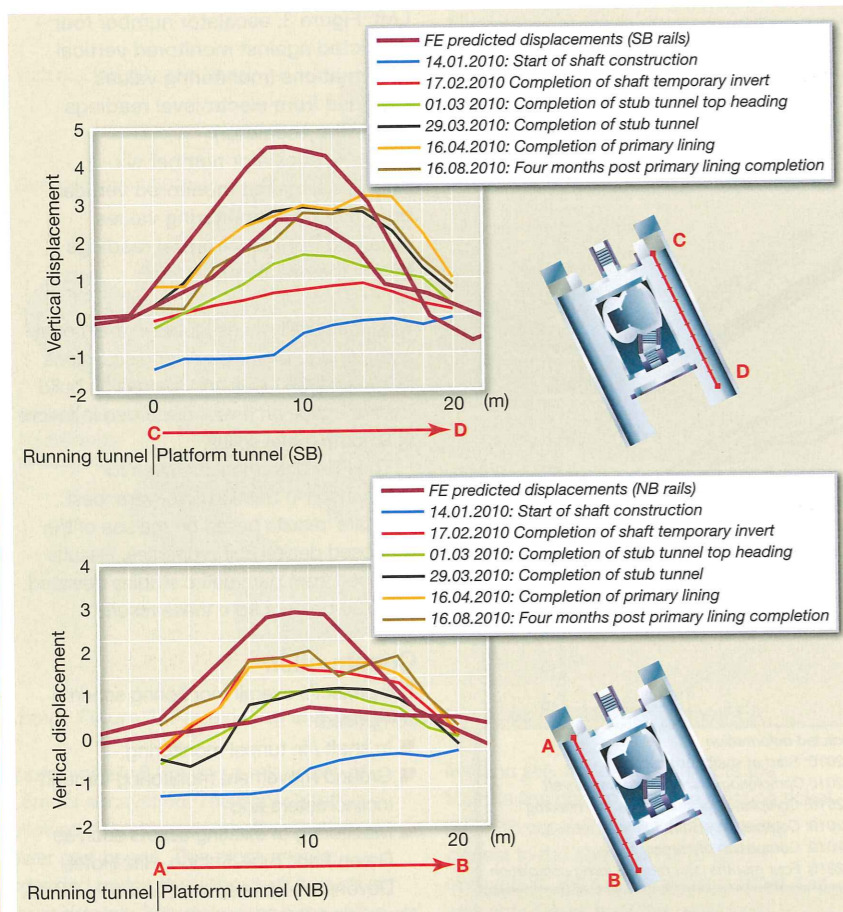
In the Tube station itself the Victoria line platform tunnels, cross passages, the Victoria line escalator barrel, upper and lower escalator machine chambers and the ticket hall were thoroughly monitored. The scheme comprised of 153 prisms, 50 tiltmeters, 88 electrolevels, 37 tape extensometer points and 32 track sensors. All prisms were automatically read from five robotic total stations on an hourly basis. Tiltmeters and electrolevels were read hourly from a data logger. Convergence measurements were performed weekly in the Victoria line cross passages and running tunnels using tape extensometers. Approximately 20m of all four rails located in the Victoria line platform tunnels were monitored with track sensors providing

linear elastic material behaviour ($E = 100\text{GPa}$, $\nu = 0.26$). Sprayed concrete primary ($E = 15\text{GPa}$, $\nu = 0.20$) and cast in place concrete secondary linings ($E = 26.5\text{GPa}$, $\nu = 0.20$) were modelled as elastic plastic materials.

The construction sequence was modelled according to the proposed excavation and support methods. This saw the shaft excavation advancing in one metre steps, starting after the simplified modelling of the construction of the pre

existing structures and the excavation of the new ticket hall. The stub tunnel, stair passage and connections were advanced continuously in one metre steps representing the designed sequence. In total the analysis comprised 130 individual analysis steps.

At the beginning of the design phase, the construction of a pipe arch over the stub tunnel was deemed necessary to protect the escalator barrel from excessive deformations. The benefit of the pipe arch



Above: Figure 5, Northbound track – Predicted against monitored vertical rail displacements; Figure 6, Southbound track – Predicted against monitored vertical rail displacements

hourly readings.

Except for the monitoring instruments installed in the Victoria line platform tunnels, all instruments were read from the beginning of August 2009. Hence, baseline readings were taken for approximately half a year prior to commencement of the shaft sinking works. The platform tunnel instruments were installed later with initial readings taken at the end of January 2010. Shaft sinking commenced one week before these readings were made.

The client specified four monitoring trigger values (green, amber, red and black) indicating to the contractor actions which had to be taken if the corresponding deformation values were reached.

Comparison of predicted and monitored deformations

Figure 3 shows the vertical deformation history of the escalator located closest to the shaft (escalator number four) and figure 4 of the escalator located remote from the shaft (escalator number six).

In general the predictions from the FEA

underestimated the vertical deformations by up to 2mm. All construction took place within the green alarm level zone since the amber alarm level trigger value of 10.1mm was not reached during construction.

Northbound tunnel deformations reached values of 17mm at the time of primary lining completion showing a sudden deformation increase at the beginning of February 2010 when shaft sinking partially excavated the existing tunnel lining. Between February 2010 and the primary lining construction completion in mid April 2010 deformation increased slowly but steadily. Readings taken four months afterwards in August 2010 showed a further slight increase in deformation to 18mm.

Southbound tunnel deformations reached values of 12mm at the time of primary lining completion. Generally the deformation increase was steadier compared to the northbound tunnel due to face subdivision and sequential excavation of the stub tunnel.

During construction some platform tunnel monitoring points exceeded 10.1mm

deformation and consequently entered the amber alarm level zone. The red alarm level trigger value of 20.1mm was not reached.

The monitored northbound tunnel deformations exceeded those predicted by up to 7mm. During the construction process approximately a quarter of the platform tunnel's circumference was liberated from the confinement of the surrounding soil instead of the shaft lining only touching the northbound tunnel as modelled in the FEA.

Further, ring closure of the shaft next to the platform tunnel's centreline could not be achieved as quickly as planned due to time consuming cast iron break out and removal of an old passageway.

The monitored southbound tunnel deformations reflected closely those predicted in the analysis.

Figures 5 and 6 (left) show predicted Victoria line vertical track displacements against monitored displacements read at the platform edge with construction advance. Each graph shows two lines for predicted displacements indicating the two track rails. Rails located closer to the excavation showed higher displacements (3.5mm; 4.5mm) than those further away (1mm; 2.5mm).

Deviations of monitored displacements from predicted ones amounted to approximately 12mm. The maximum vertical displacements were overestimated in the predictions.

Conclusion

The Green Park Station SFA design demanded extensive three dimensional FEA due to Tube Lines requirement for receiving information on how the new works would influence existing LU assets. The geometry and close proximity of the new structures to several existing structures made a complex three dimensional analysis necessary to achieve increased accuracy compared to two dimensional FEA and volume loss approximations.

In general the analysis provided a very good indication of locations where deformations were to be expected and corresponding magnitudes. Comparisons between predicted and monitored deformations typically showed a deviation of up to 2mm except for the NB platform tunnel indicating a deviation of approximately 7mm.

In summary, the performed FEA proved to be a good tool for anticipating expected deformations in London Clay and for dimensioning thicknesses of the concrete shaft and tunnel linings.

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12 - 15 SEPTEMBER 2011

15th European Conf on Soil Mechanics & Geotechnical Engineering, Athens, Greece

Organised by the Hellenic Soc for Soil Mechanics & Geotechnical Engineering on the theme 'Geotechnics of Hard Soils - Weak Rocks' at the megaron Athens Intl Conf Center. Registration and assistance from Triana Tours & Congress, tel.: +30 210 7499337 or +7499300, Email: efip@trianatours.gr or see www.trianatours.gr. For scientific activities e-mail the Secretary on athens2011ecsmge@hssmge.gr

12 - 16 SEPTEMBER 2011

6th International Symposium on Sprayed Concrete, Tromsø, Norway

Main themes will be the modern use of wet-mix sprayed concrete for underground support including design, construction and durability. The revision of Norwegian Concrete Association iPublication No. 7, Sprayed Concrete for Rock Support, will be debated during the symposium. Contact: Siri Engen Email: siri.engen@tekna.no Website: www.sprayedconcrete.no

14 - 15 SEPTEMBER 2011

IUT 2011, Sargans, Switzerland

Those involved in tunnelling will get together to exchange views and inform themselves about the latest trends and technologies. The traditional IUT Evening on the first day of the fair, being held in a VSH (Hagerbach Test Gallery) cavern, will be a highlight: here exhibitors and visitors will be able to exchange views against a relaxed background and experience an unforgettable evening. Contact: Deltacom Projektmanagement +49 (0)40 35 72 32 - 0 Email: info@deltacom-hamburg.de or see www.iut.ch

15-19 SEPTEMBER 2011

8th WBI-International Short Course on Advanced Rock Engineering

Led by Prof Dr-Ing Walter Wittke & Partners. Includes session on tunnels by NATM and TBM including design concepts with engineering versus classification, case studies and exercises. Other sessions on fundamentals, analyses, dam foundations and slopes. Total fee EUR 1190 inc VAT. Contact WBI on tel.: +49 241 88 98 7-0 or email: wbi@wbi-online.de

19-23 SEPTEMBER 2011

Hydropower Africa 2011, Johannesburg, South Africa

Hydropower Africa 2011 is a niche meeting forum where comprehensive presentations, panel discussions and

focused sessions will address the issues surrounding the financing and the implementation of hydropower projects in Africa. For further information, call: Nicolaas Loretz, Tel. +27 21 700 3555.

26-30 SEPTEMBER 2011

World Road Congress of the World Road Association (AIPCR/PIARC), Mexico City, Mexico

Includes a committee on road tunnel safety. For more information tel.: +52 (55) 5148 7500, Email: expo@aipcrmeexico2011.org or see www.aipcrmeexico2011.org

17 - 19 OCTOBER 2011

13th AFTES International Congress, Lyon, France

This 3-day congress is organised by the French Underground Tunnelling and Underground Space Association (AFTES), with partner associations in Italy, Belgium, Spain, Portugal and Switzerland. Along with technical sessions and an exhibition there are seven site visits planned for the congress focused on underground space. Contact AFTES for more information: 15 rue de la Fontaine au Roi, 75011 Paris, Tel : +33 (0) 1 44 58 27 43

26 - 27 OCTOBER 2011

Underground Infrastructure of Urban Areas, Wrocław, Poland

Organised by the Wrocław University of Technology's Institute of Civil Engineering, the Polish Society for Trenchless Technology and the ITA-AITESA Polish group, this will be a forum to develop an exchange of experiences and provoke a discussion on the topics related to building tunnels and underground infrastructure in cities. Contact Andrzej Kolonko, Tel. +48 71 320 2914 or email andrzej.kolonko@pwr.wroc.pl

6 - 8 DECEMBER 2011

STUVA Conference, Berlin

The 2011 biannual conference of non-profit research institute STUVA (the German Research Association for Underground Transportation Facilities) will focus on "Underground Construction for Sustainable Environmental and Climate Protection." New this year is a Youth Forum, an opportunity for young tunnel engineers to present. The winner of the STUVA young talent prize will be selected from the speakers, and awarded at the show. There is also an accompanying exhibition. More information available from www.stuva.de Email: info@stuva.de

8 DECEMBER 2011

T&T International Awards 2011, Berlin, Germany

Launch of this event that promises to champion the industry's best efforts, greatest achievements and most impressive recoveries. There are categories on overcoming adversity,

sustainability and innovation. For further information on entering and attendance e-mail: awards2011@tunnelsandtunnelling.com

14 - 16 MARCH 2012

ISTSS 2012, New York

The 5th International Symposium on Tunnel Safety and Security, organised by the SP Technical Research Institute of Sweden, will discuss themes of risk & security, human behaviour, construction, fire fighting and, ventilation. More info at www.istss.se

18-23 MAY 2012

World Tunnel Congress WTC 2012 & 38th General Assembly of the ITA, Bangkok, Thailand

Organised by the Thailand Underground & Tunnelling Group (TUTG) of the Engineering Institute of Thailand, the theme is 'Tunnelling & Underground Space for a Global Society'. ABSTRACT SUBMISSION DEADLINE 31 August. Congress Secretariat: Zaw Zaw Aye on tel.: +662 3192 410, Email: secretariat@wtc2012.com or see www.wtc2012.com

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15 SEPTEMBER 2011:

Crossrail

Status update. Latest developments on this major London project. Speaker: Andy Mitchell, Programme Director, Crossrail

20 OCTOBER 2011:

BTS / BGA Joint Event. Towards a Specification for the Ground - The use of Geotechnical Baseline Reports in the UK

Ground References Conditions. Details to follow. Speakers: Mike Black and Darren Page

17 NOVEMBER 2011:

Dulles Airport Rail Tunnel, Washington DC

Dulles Transit Partners is responsible for designing and constructing Phase 1 of the Dulles Corridor Metrorail Project. An 11.6 mile extension of the existing Washington Metro to Dulles International Airport. A central feature of the project is the Tysons Tunnel. The Tysons Tunnel is a twin-bore, two-track tunnel running at 762m in length between portals. The central 534m is being constructed by SCL. Speakers: Dominic Cerulli and Frank Jenkins of (Bechtel) Dulles Transit Partners and Vojtech Gall of Gall Zeidler Consultants

15 DECEMBER 2011:

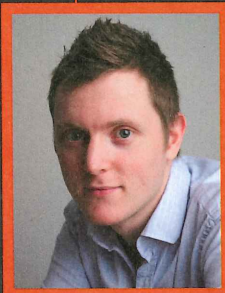
Cleaner Seas for Sussex

In order to treat the 95 million litres of wastewater generated each day by residents a new wastewater treatment works and 11km of new sewer were required. Now substantially complete find out how more than 11km of 1.8m and 2.4m diameter tunnels and associated shafts and pumping stations were completed. Speakers: Ben Green, Southern Water programme manager and Craig Reade, Costain project manager

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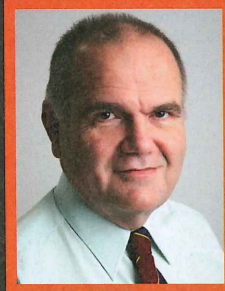
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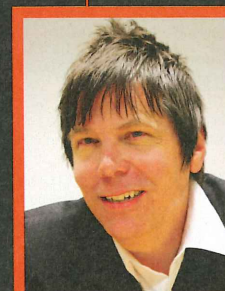
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Tunnels & Tunnelling International ISSN number 0041-414X is published monthly for US\$226 a year by World Market Intelligence Ltd (www.worldmarketintelligence.com), a Progressive Media Group company, John Carpenter House, 7 Carmelite Street, London

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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