INTERNATIONAL EDITION
January 2014

Tunnels AND TUNNELLING

FROZEN EARTH

New applications for ground freezing

North America • Rock classification • Coen Tunnel

MYSTERIES OF THE DEEP

CHRISTMAS IN Italy was dogged by the unrelenting threat of collapse of the capital. Unconventionally for Rome, this threatened collapse was not political but physical. That might be a little over dramatic but nevertheless a large network of ancient Roman tunnels, formally part of quarries, has been causing collapses across the city.

A team of geologists from George Mason University, Washington, and Centre for Speleoarchaeological Research, Sotterranei di Roma is exploring the network and mapping the tunnels.

As the new city of Rome has grown it has covered the infrastructure that supported the ancient city. Over time these aquaducts, buried streets and quarries have weathered and weakened.

When the weathering reaches a critical point the ground above has collapsed.

Using 3D laser scanning the team are looking for weaknesses in known tunnels and if it is safe to do so they enter the tunnels and see where it leads, adding to the map.

Knowing the ground you are building on or working in is the first point for all civil engineers. But for the tunneller this understanding is more difficult and more crucial.

There is no shortage of projects that ran into trouble because the ground was not fully understood before the project began, but there is a limit to what is achievable.

Rome's efforts to start mapping this ancient tunnel network is a kin to Finnish capital Helsinki's efforts to map its entire underground infrastructure and Sydney, Australia's further step to load maps of underground services and obstructions into augmented reality software to aid underground engineers and contractors.

Geotechnical investigation can help engineers understand the obstacles that naturally exist, and will always be hindered by the unpredictability of geology.

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What do you think? Send your views to the editor and join the debate

Jon Young
Editor

Man-made obstacles, however, are totally predictable and any project should be able to start with a complete understanding of what lies ahead.

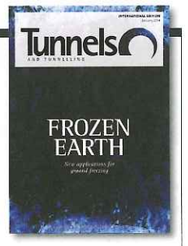
In London, contractors working on the upgrade of one of the Tube's busiest stations Tottenham Court Road were faced with plans of the original construction that were so incomplete they were not entirely sure whether or not they would encounter a buried shield.

In Rome, mapping the ancient tunnels should just be the beginning of the project, creating a complete map of the underground world would greatly ease development in the city.

Towards the end of last year a team of amateur cavers mapped a vast network of passages built by emperor Tivoli to keep his slaves. It is thought the network covers a 250 hectare (2,500,000m²) site.

The costs of such a project in Rome might prove too much, but in newer cities there is a much greater opportunity to get this right early on and as we develop our underground network there is an ever increasing urgency for accurate data

Cover
A technical look at groundfreezing is provided this month by US-based Moretrench



Next issue
In the next month, *Tunnels* looks at an Indian tunnelling industry truly advancing from necessity as the roads of its capital city become ever more congested, and links to it's far flung regions enter the public mind. Also next issue, Drill Rigs are examined

This month...

20 YEARS AGO

What is reported to have been the world's earliest carriage tunnel has been discovered in north China's Shaanxi Province. Built in 66AD, the tunnel measures 15.86m long, 3.6m high and 4.2m wide. Called 'Shimen' meaning stone gate, it was claimed to be the third wonder of the world. The tunnel was excavated by heating the stone with firewood then applying cold water to cause cracking at the face.
Tunnels and Tunnelling, January 1994, p.12

40 YEARS AGO

The first experimental tunnel in the world to gather data for use elsewhere has been driven at Chinnor in Oxfordshire, UK. Myles O'Reilly, head of the Tunnels Division at the Transport and Road Research Laboratory (TRRL) says, "There is good reason to believe tunnelling could reap the same benefits as bridge technology from research, where technical improvements resulted in cost savings of 30 per cent over a period of 20 years." According to the TRRL deputy director R. S. Millard, although actual construction costs have not been falling thus far, the increasing land costs in cities have narrowed the price gap between tunnelling and other routing methods. O'Reilly says that with all the tunnelling work in the world, he predicts tunnelling speed to double over the next decade, and estimates that a 25 per cent increase could drop costs by up to 10 per cent.
Tunnels and Tunnelling, January 1974, p.9

Above, left: Seattle U-Link, p.23

Above, middle: Second Coen Tunnel, p.41

Above, right: Rock classification, p.49

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Contributors

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Joe Sopko
Joe graduated from Michigan State University in 1980 with a BS in civil engineering, earning his Masters in 1983 and doctorate in 1990. He joined Moretrench in 2010 as regional manager for its Midwest operations. He has over 30 years of experience in geotechnical construction, particularly for frozen earth excavation support

Robert R. Chamberland
Robert is a Project Engineer at Moretrench American Corporation. He has assisted Dr. Joseph Sopko on numerous freeze jobs throughout North America since 1997. In this issue the two work together again on a paper discussing new applications of ground freezing in underground construction

Leighton John Holland awarded Thomson Line contract

Singapore Leighton Asia, India and Offshore (LAIO), in a JV with John Holland, has been awarded a contract worth AUD 329M (USD 309.1M) from the Singapore Land Transport Authority (LTA) for the Thomson Line project, it was announced last month.

The contract requires the JV to construct spring leaf station and 2km of of twin-bored tunnel as part of the 30km Thomson line railway consisting of 22 stations and six interchange stations. When completed, the Thomson Line is expected to provide greater accessibility, significantly reducing travel time for commuters.

Ian Edwards, the managing director of Leighton Asia, India and Offshore said: "We have developed a strong working relationship with LTA and the award is indicative of our proven track record for delivering projects to the highest standard."

Edwards added that, "With over 30 years' experience in rail infrastructure in Hong Kong, the project award supports our strategy of exporting our core competencies across the Asia region."

Construction works will commence immediately and is expected to be completed by 2020.

SWEEPING CHANGES FOR LU SPARK RAIL UNION FURY

Great Britain Transport for London (TfL) laid out a set of changes for the operation of the London Underground (LU) this morning. Notable among these are 24-hour services planned across several lines on Fridays and Saturdays, and the closure of every ticket office in the network by 2015, reportedly costing 750 jobs.

The National Union of Rail, Maritime and Transport Workers (RMT) called an immediate strike ballot in response to what it called a "lethal" and "savage" programme of cuts. TfL revealed earlier this year that it would be required to make GBP 80M (USD 130M) of cuts over the next two years, despite some of the highest fares in the world and swelling passenger numbers.

An RMT spokesman said, "RMT deplores LU's announcement today that it plans to close every ticket office [and] reorganise station staffing including the removal of station supervisors at some stations. This is a catastrophic attack on London Underground's passengers and staff. It is not aimed at improving our Tube but at saving millions of pounds following the government's 12.5 per cent cut to TfL's funding."

RMT general secretary Bob Crow added, "Throwing in the plan for night time operation at the weekends is just a smokescreen to try and camouflage the real issue which is a savage cuts to jobs, access and safety. Any move to run through the night would require huge additional capacity and staffing and wholesale changes to fleet and infrastructure maintenance that would require the agreement of the tube unions and the issue has only been flagged up today as a diversion from the massive cuts agenda."

Mike Brown, managing director of London Underground, said: "People are at the heart of this vision - our customers and staff. My commitment to London is that all Tube stations will continue to be staffed and controlled in future, with more staff visible and available to help customers buy the right ticket, plan their journey and keep them safe and secure. We will continue to make the Tube more accessible and provide assistance at stations for all our customers who need it.

Other changes include: Wi-Fi coverage in all underground stations; contactless bank card payments; better disabled access; a further 30 per cent reduction in delays by 2015 relative to 2008/09; more ticket machines, and the extensive station upgrades.

Illegal Asia Pacific gold tunnel caves in

Philippines Rescuers recovered on the bodies of six miners buried alive in a tunnel that collapsed in Magpet Town in North Cotabato, Philippines last month.

The miners were digging for gold when the tunnel in Barangay Village collapsed over the weekend.

Reports said the victims had no permit from the local government unit.

Barangay community leader Yolly Bernabero said they learned of the victims' plight from their companion, who managed to dig his way out of the tunnel.

The municipal government of the Magpet region has ordered the immediate closure of the illegal mining site in Barangay to prevent a repeat of the incident.

The national government has been putting pressure on illegal and dangerous mining operations.

Local media previously reported that one result of this has been unemployment and poverty.

News briefs

SOUTH AFRICA

Six people died and six others were injured when a platform in a tunnel collapsed at an Eskom construction site near Ladysmith, South Africa, local press reported recently. The incident happened at Eskom's Ingula pumped storage construction site in late October. A detailed investigation has been launched.

VIETNAM

A truck moving at high speed lost control and overturned in the Saigon river tunnel last month. No casualties were reported. This is the second such incident to occur in Southeast Asia's largest underwater tunnel since it was opened in November 2011.

USA

Sound Transit will open the University Link light rail extension by March, 2016, some six months earlier than previously scheduled. Tunnelling has finished on the USD 1.95bn project and contractors are currently installing rail in the twin tunnels and continuing construction at the two new stations on Capitol Hill and at University of Washington. A Sound Transit spokesman said, "The University of Washington Station is about 80 percent complete and the Capitol Hill Station is about 25 percent complete. Opening early will require continued close coordination among the contractors building the stations and the follow-on systems contractors installing the power, communications and fire/life/safety systems necessary to operate the system. Staff will report in late 2014 or early 2015 with a specific opening day.

MAKKAH METRO PLANS AFOOT

Saudi Arabia Two metro systems will be established in the city of Makkah in the first phase of a SAR 62bn (USD 16.5bn) public transport project.

Makkah Governor Prince Khaled Al-Faisal has given the green light to implement the project's strategic plans, Makkah Mayor Osama Al-Bar said on 10 November.

The first project, an 11km metro line that begins in the Jamrat region in Mina, will move westward and run along the northern side of the Grand Mosque, King Abdul Aziz Road and Haramain Railway's main station in Rusaifa, ending its course on the Makkah-Jeddah Expressway. This line will have seven stations, he said.

The second metro will set off from Madinah Road, north of Taneem Mosque, and move southward to reach the western side of the Grand Mosque. It will pass by King Abdulaziz Towers and Azizia Street before turning to Taif-Karr Road to reach Umm Al-Qura University. This 33km line will have 15 stations.

Saad Al-Qadi, CEO of Makkah Trains Company, said three contracts would be awarded to carry out the first phase, which involves signing contracts for undertaking civil work, implementing control and signal systems and importing trains and carriages.

"We will begin procedures this week for the qualification of contractors to award contracts in the first quarter of 2014," Al-Qadi said.

Most of the first metro line and part of the second line will operate through underground tunnels.

Higher authorities have already approved the Makkah transport project, which includes four metro lines spanning 114km with 88 stations and a fast-track bus service network. These projects are projected to drastically improve pilgrim transportation around the city.

Al-Bar said the first phase, which costs around SAR 25.5bn (USD 6.8bn), will begin by the middle of next year and would take three years to complete.

Al-Balad Al-Ameen, a company owned by the Makkah Mayoralty, conducted a technical study on the metro system, which would be implemented by the Makkah Trains Company.

Systra, a French consultancy firm, and BW Engineers from Germany, are also involved in the project.

The bus service will be integrated with the metro system, Al-Bar said, adding that a speedy bus service would link various parts of the city, covering 60 km with 60 stations. There will be a local bus service provided to areas not covered by the metro and speed bus network.

In addition, there will be feeder bus services for the metro system. The huge transport project is to be completed within 10 years in three phases.

Dartford Crossing reaches golden milestone

Great Britain A golden milestone was reached last month with the 50th anniversary of the opening of the first tunnel at the Dartford Crossing, the Highways Agency (HA), an executive agency of the Department for Transport announced last month.

The opening of the first bore at midday on 18 November 1963 paved the way for what is today the busiest links on the national motorway network, HA stated.

From the initial estimates of two million vehicles crossing each year it is now used annually by some 50 million.

Robert Goodwill, roads minister, said: "The Dartford Crossing has proved to be a vital link on the M25 and a great investment in the economy, helping nearly 1.5bn vehicles cross the river Thames over the past 50 years.

"It continues to bring huge benefits to the economy and with these benefits comes demand. The Government is committed to doing all we can to ease traffic flow and improve journeys for the future."

Simon Jones, Highways Agency regional director added: "With tens of thousands of drivers relying on the crossing every day, it is vital that we keep the tunnels and bridge flowing. We understand the importance this route has for the local and national economy and have a team of operators and traffic officers who work around the clock to keep traffic moving."

Today's crossing was designed to handle 135,000 vehicles per day but it is not unusual for 160,000 to occur, HA stated. In October 2014 a different, remote payment system will come into operation to reduce congestion and ease traffic flow.

Drill rigs chosen for Finnish road tunnel

Finland Finnish-based infrastructure construction company, Lemminkäinen, has chosen Sandvik DT1131i tunnelling jumbos for the excavation of a road tunnel in Tampere, Finland, Sandvik announced last month.

The machines will excavate the 2.3km long bypass tunnel, a part of highway 12, between Santalahti and Naistenlahti areas. The Sandvik DT1131i is a computer-controlled three-boom tunnelling jumbo designed for the excavation of 20 - 183m2 mechanised long-hole drilling.

Construction work has begun and the tunnel is scheduled to open for public in 2017. The budget for the project is EUR 180M (USD 243.3M).

The Rantaväylä, "Lakeside Route", tunnel project aims at developing the central areas of the city of Tampere. The tunnel aims to decrease the common urban problems caused by the transfer traffic as well as enable the expansion of the city centre and residential areas by the lake Näsijärvi.

The Lakeside Route Tunnel is a part of the highway 12 in Finland. It will consist of two separate tunnels, each of which has two one-way traffic lanes. The tunnel access will be 14m in width and 7.5m in height. The total length of the tunnel will be 2.3km, of which 2.22km will be rock excavation. The remaining part will be concrete construction.

An alliance of the developer, the contractor and the designers will be responsible for the construction of the tunnel; the parties have signed a common agreement for the target costs and other key performance indicators as well as sharing of the risks in the project.

Southland Mole to build Honolulu sewer

Hawaii The City and County of Honolulu awarded some USD 175M in contracts for the Kaneohe-Kailua gravity sewer tunnel project to the joint venture group of Southland Contracting, Inc. and Mole Construction, Inc. (Southland Mole JV) and local construction management firm Bowers + Kubota.

The Kaneohe-Kailua Gravity Sewer Tunnel Project is an approximately 3mi (4.82km) long tunnel from Kaneohe Wastewater Pre-Treatment Facility (WWPTF) to Kailua Regional Wastewater Treatment Plant (WWTP) that will be constructed by TBM about 15ft (4.6m) in diameter.

A 10ft (3m) internal diameter pipe will be installed into the bored tunnel. The alignment starts at a depth of approximately 35ft (10.68m) below ground level at the Kaneohe WWPTF, and ends approximately 62ft below ground level at the Kailua Regional WWTP.

The sewer tunnel will fulfill a portion of the First Amended Consent Decree mandated by the U.S. Environmental Protection Agency (EPA) and the Hawaii Department of Health (DOH).

To do so it will implement several remediation projects on the island of Oahu over the next 25 to 28 years, focusing on the wastewater collection system and wastewater treatment plants (WWTP).

Crossrail cross passages scooped by Manchester heavy engineer

Great Britain Manchester-based Eaves Machining, a specialist in bespoke heavy engineering solutions, announced last month that it had secured a tunnelling contract worth GBP 1.2M (USD 1.96M) with Spanish contractor Dragados.
The contract, to be completed within the next eight weeks, emerged following the completion of the main tunnel drive on the Crossrail Contract 305 earlier this year.

An Eaves Machining spokesman said, "We have eight weeks to design, manufacture, machine, finish and supply tunnel linings for four cross passages, which will be placed on the latest section of the Crossrail project in London.

"Following the development of a bespoke erector plate, Eaves Machining has significantly reduced the overall time of the machining process, allowing the work to be completed within such stringent time scales and providing the client millions of pounds in cost savings."

British contractors securing more work on previous year

Great Britain A third-quarter workload report from the UK's Civil Engineering Contractors Association (CECA) has revealed that 58 per cent of firms secured more work in the last 12 months than the same period a year ago.

The report added that 40 per cent of contractors expect these positive conditions to continue, saying they expect to have more work in a year's time. Only 14 per cent reported falling workload.

Alasdair Reisner, the CECA director of external affairs, said: "After the challenges of recent years it is encouraging to see some real growth in workload for the UK's civil engineering contractors.

"We recognise that this growth has been supported by the actions of Government, which has worked with industry to unlock vital infrastructure investment projects across the country.

"However, it is essential that as the wider economy returns to growth, there is no loss of focus on the continuing need to invest in our national transport and utility networks.

"A booming economy does not remove the need to tackle congestion and energy security – in fact it makes tackling these issues even more critical."

Thames Water awards London sewage upgrade

Great Britain Thames Water has confirmed Aecom and Murphy Kier (AMK) as the successful contractor for a GBP 177M (USD 290.4M) rebuild of one of London's largest sewage works.

AMK was due to start work as *Tunnels* went to press, and a full planning application is expected to be submitted in summer 2014.

The upgrade aims to meet tighter environmental standards, improve the water quality of London's River Lee and reduce odour.

The works will be updated to meet strict new Environment Agency sewage treatment standards that will apply from March 2017. The project will also increase capacity to allow for future rises in population, and significantly reduce the frequency and intensity of odour on site.

TORONTO AWARDS SECOND EGLINTON CONTRACT

Canada Metrolinx's board of directors approved the award of the Eglinton Crosstown East Tunnel construction contract, from Yonge Street to just east of Brentcliffe Road, to an Aecon-Dragados joint venture.

The CAD 177M (USD 165M) contract is the second of the two tunneling contract packages for the Crosstown Project, and the JV will start work later this year to construction approximately 3.25km of twin tunnels using two TBMs and precast concrete tunnel lining segments supplied by Metrolinx.

"Approval to award this contract means Metrolinx and the Province of Ontario can keep moving forward to deliver public transit that will transform the way residents travel across the region," said Metrolinx president and CEO, Bruce McCuaig. "The Crosstown project is a priority for Metrolinx and regional transit, making it easier for people to choose transit."

The twin tunnels are to be constructed as a single pair of drives from a launch shaft located east of Brentcliffe Road to an extraction shaft located east of Yonge Street. In addition to the twin tunnels the contract also includes the construction of the launch and extraction shafts, headwalls associated with future stations, two emergency exit buildings, three cross passages, required utility relocations, traffic staging, ground and building settlement monitoring and site restoration.Metrolinx received a total of three bid submissions on September 12 out of seven pre-qualified bidders. Tender prices ranged from a low of CAD 176,663,700 to a high of CAD 224,699,345 exclusive of HST.

Tunnelling from the west launch shaft area near Black Creek Drive to Yonge-Eglinton station began in June, under a contract awarded by the Metrolinx Board last year to Crosstown Transit Constructors, a joint venture of Obayashi Canada, Kenny Construction, Kenaidan Contracting and Technicore Underground.

The Eglinton Crosstown is a light rail transit line that will run along Eglinton Avenue between Mount Dennis (Weston Road) and Kennedy station. This 19km corridor will include a 10km underground portion, between Keele Street and Laird Drive.

The Crosstown is a CAD 4.9bn investment from the Government of Ontario to expand transit in Toronto. It is the largest transit expansion in the history of Toronto.

NPBCL KICKS OFF WORK ON NEPAL HIGHWAY TUNNEL

Nepal Construction works on Kathmandu-Kulekhani-Hetauda Tunnel (KKHT) Highway began on 11 November 2013.

Issuing a statement to the media, developer Nepal Purbadhar Bikas Company Limited (NPBCL) said construction works would begin from Bhimphedi in Makwanpur district.

"We have the responsibility of starting the project within the time mentioned in the agreement with the Nepal government. We are happy that we are starting construction works within the timeframe announced earlier," said Kush Kumar Joshi, president of NPBCL.

Joshi added that NPBCL wouldn't be holding any formal program to begin construction works as most of the people are busy due to the upcoming Constituent Assembly (CA) election.

The company claimed that the 58km tunnel highway will shorten travel distance between Kathmandu and Hetauda to just an hour from around six hours.

The project is estimated to cost around NPR 35bn (USD 350M) and expected to complete by December 2016.

TBM ready for Evergreen Line

Canada The TBM for Vancouver's Evergreen Line LRT project has been shipped from the Cat factory in Ontario, Transport Canada announced November 7.

As part of the LRT project, the 9.86m diameter EPBM will construct a 2km tunnel west of Barnet Highway in Port Moody to south of Kemsley Avenue in Coquitlam. Contractor EGRT Construction, a consortium led by SNC-Lavalin, has the project's design build and finance contract.

The TBM is being shipped from Ontario in pieces and will be assembled at the launch site in Port Moody, with tunnel excavation expected to start in February. The entire TBM is 85m long and the mixed face cutterhead weighs 130t.

Estimates call for an average progress of 8m per day through the alignment's geology comprising tills, glacial outwash, glaciomarine and ice contact deposits, as well as boulders with maximum UCS of 350MPa.

The machine is designed to operate under six bar of pressure and run on a six per cent gradient tunnel, Cat said. Tunnelling is expected to take one year.

"The many benefits of the Evergreen Line for British Columbians include jobs and new transportation choices for families and communities," said Transportation and Infrastructure Minister Todd Stone. "A comprehensive community relations program is in place, and the public will continue to be informed of traffic changes and construction activities until completion of the line in the summer of 2016."

Funding for the Evergreen Line is a partnership between the Government of Canada, the Government of British Columbia and TransLink.

The estimated project cost is CAD 1.43bn.

Metro system mulled for Madina

Saudi Arabia The city of Madina will have a smart mass transit system of metro trains and fast bus services within eight years.

This was revealed at the weekly Cabinet meeting chaired by Crown Prince Salman, deputy premier and minister of defense, on 4 November 2013.

The Cabinet ordered a higher committee for the mass transit project to be set up under the chairmanship of Madina Governor Prince Faisal bin Salman, who is also head of the Madina Development Authority. Committee members include ministers of municipal and rural affairs, finance and transport.

"The higher committee will supervise the implementation of the project and will set up an executive committee to be headed by the Madina mayor. The mass transit project should be completed in eight years," Culture and Information Minister Abdul Aziz Khoja said in a statement.

Contractor blocks Lowari tunnel due to paucity of funds

Pakistan Hundreds of people, including Japanese tourists, are stranded at 10,500ft (3,200m) high Lowari Top in Pakistan due to the blockade of Lowari Tunnel.

A group of 10 Japanese tourists has been stranded at Lowari Top since the tunnel was blocked by Korean construction company Sambo and National Highway Authority (NHA) in early November 2013. Officials cite lack of funds as the reason behind the closure.

Local elders of Chitral district demanded the provincial government to pay the amount to Sambo through NHA facilities so they would reopen the tunnel to facilitate the residents of Chitral.

The entire district has been cut off from the rest of Pakistan, while the tourists are also stranded.

Local elders said due to the blockade, residents of the district are providing security to the tourists, whose visas will soon expire. They added despite pleading to the officials, the foreigners were not allowed to use the tunnel. They also said locals went with some of the tourists via 12,500ft (3,810m) Shandur Pass to enter Gilgit and then find a way to reach Islamabad.

They said if the government has decided not to open the tunnel, then they should provide an alternate route for the 0.6 million population of the district. Most Chitralis term the blockade of Lowari Tunnel a hand-in-glove situation of Sambo and NHA to extract funds from the government.

Latest Thomson Line contracts awarded

Singapore The Land Transport Authority (LTA) has awarded two further civil contracts for the Thomson Line. Contracts T202 and T217 have been awarded to Penta-Ocean Construction Co and Sinohydro Corporation respectively.

Contract T202 for the construction of Woodlands North station and its associated tunnels has been awarded at a contract sum of SGD 337M (USD 268.9M). Contract T217 for the construction of Napier station and its associated tunnels has been awarded at a contract sum of SGD 189M (USD 150.8M). Construction works should start in Q1 2014. T202 is scheduled to complete in 2019, and T217 in 2021.

What do you think? Send your views to the editor and join the debate

editor@tunnelsonline.info

Share tracker

Company	October	November	Change (%)
Aecom (NYSE: ACM)	30.95	28.96	▼ 1.99 (6.43)
Atkins (LSE: ATK)	1,139	1,251	▲ 112 (9.83)
Balfour Beatty (LSE: BBY)	268.7	274.5	▲ 5.8 (2.16)
BASF Global (XETRA: BAS)	71.46	76.09	▲ 4.63 (6.47)
Bekaert (BSE: BEKB)	26.86	29.47	▲ 2.61 (9.72)
Bilfinger Berger (DUS: GBF)	79.25	81.56	▲ 2.31 (2.91)
Costain Group (LSE: COST)	260.5	294	▲ 33.5 (12.86)
Ferrovial (MCE: FER)	13.3	13.99	▲ 0.69 (5.19)
Hindustan Construction Company (BOM: HCC)	11.85	13.6	▲ 1.75 (14.77)
Hochtief (XETRA: HOT)	64	66.02	▲ 2.02 (3.16)
Leighton Holdings (ASX:LEI)	17.49	17.62	▲ 0.13 (0.74)
Morgan Sindall (LSE: MGNS)	820	839.5	▲ 19.5 (2.38)
Sandvik (STO: SAND)	91.25	90.75	▼ 0.50 (0.56)
Shanghai Tunnel Engineering (SHA: 600820)	9.19	8.45	▼ 0.74 (8.05)
Strabag (LSE: STR)	17.86	20.96	▲ 3.10 (17.36)
URS Corporation (NYSE: URS)	52.86	51.56	▼ 1.30 (2.46)
Vinci (EPA: DG)	45	46.88	▲ 1.88 (4.18)

Prices are taken on the 12th of each month. NYSE is in USD. LSE is in GBP. STO is in SEK. BSE, EPA, MCE, STR and XETRA are in EUR. BOM is in INR. SHA is in CNY. ASX is in AUD.

Central bank rates

	Rate (%)
AUD	2.50
BRL	10.00
CAD	1.00
CHF	0.25
CNY	6.00
EUR	0.25
GBP	0.50
INR	7.50
JPY	0.10
NZD	2.50
USD	0.25

Rates are taken on the 12th of each month.

Aecom appoints Flaherty as new UK managing director

Great Britain Patrick Flaherty will be joining Aecom as managing director for the UK and Ireland from early January, the company announced last month.

Working with the CEO, Europe, Steve Morriss, Flaherty will have full management responsibility for the UK and Ireland business and will be responsible for driving growth across the region.

Flaherty joins Aecom from Fluor, having at various times been managing director for their UK business and led their infrastructure business.

In the UK, Flaherty led Fluor's pursuit and delivery of PPP projects with London Underground for the Connect Telecommunications Project and the UK Highways Agency National Roads Telecommunications Project.

"We have built a world-class team, which is performing really well," Morriss said. "Patrick brings strong leadership and a huge depth of experience to the team, particularly in the infrastructure and industrial markets. His work on public-private partnership projects internationally will provide real value to our clients, many of whom are increasingly seeking opportunities in this arena at home and abroad."

Flaherty added: "I chose Aecom because of the challenge and the opportunity. I have had a high regard for the company since my first interaction with them over 10 years ago in the US and this has grown as I learned more about the projects and clients Aecom has worked with. The areas the company has targeted for growth fits very well with my previous experience and provides great opportunity for continued success. I look forward to working with our clients and the Aecom team."

Aker Solutions sells German mining and construction assets

Germany Aker Solutions agreed to sell its German Aker Wirth tunnel-boring and its shaft-boring technology to China Railway Tunneling Equipment (CRTE), as part of a plan to divest assets that do not fit with its main offshore-services strategy.

The company made the announcement last month.

CRTE will acquire technological intellectual property rights.

It will also gain the right to use the Wirth brand name on tunnel boring and shaft boring products that are based on the acquired technology.

The transaction does not involve the transfer of any Aker Solutions employees and the manufacturing facility in Erkelenz, Germany, will remain part of the company's drilling technologies business unit.

The involved parties agreed not to disclose the value of the transaction, which was set to be completed in December 2013 as *Tunnels* went to press.

Aker Solutions has said that the transaction will have a limited financial impact on the company.

Oil price

110.7 October 2013

106.3 November 2013

Values are taken on 12th of each month.

INDUSTRIAL RUMBLES

Union movements in the UK sparked during wider public inquiries into industrial action

NOVEMBER SAW political and union posturing across several UK industries. Relevant to civil engineering, the Union of Construction, Allied Trades and Technicians (Ucatt) announced it would commence legal action, and demonstrate, against 10 UK-based companies involved with the Consulting Association, which the unions claim operated a 'blacklist' of workers involved in union activity. Ucatt said it has employed the services of Mark Warby QC, a leading expert on privacy law, to take the cases on behalf of its members.

Meanwhile UK Prime Minister David Cameron has launched an inquiry into trade union 'tactics' following a dispute that almost led to the closure of the Grangemouth petrochemical plant and "nearly brought the Scottish petrochemical industry to its knees" said Cameron.

Scottish First Minister Alex Salmond accused Cameron of merely "seeking electoral advantage". Unite the Union said it would not co-operate with the inquiry, calling it a "Tory stunt".

Deputy Prime Minister Nick Clegg said that the investigation can now be expected to include the alleged blacklisting of union activists following Ucatt allegations. Business Secretary Vince Cable supported such an investigation into blacklisting earlier this year only if evidence were provided.

A Ucatt spokesman said, "The companies that Ucatt is taking action against include: Balfour Beatty, Bam, CBEtl, Costain, Carillion, Laing O'Rourke, Lend Lease, Sir Robert McAlpine, [Skanska] and Vinci. In addition, and uniquely Ucatt are to commence legal action against an individual who held the position of chair of the Consulting Association and was a senior HR manager for a major blacklisting company."

Eight of the companies involved previously apologised for their relationship with the Consulting Association, and set up a fund for workers affected. They also denied any involvement in blacklisting. The companies' statement said, "Worker representatives have been invited to enter into a period of engagement to ensure that the proposed terms of the scheme are fair and attentive... The companies involved in the scheme would support the introduction of a code of conduct to ensure nothing like this can happen within the construction industry again."

A Bam spokesman said, "We are aware of the proposed Ucatt litigation and await further correspondence from their legal representatives. "

A Laing O'Rourke spokesman said, "Laing O'Rourke recognises and respects the rights of workers to observe a day of action... [We] regard positive engagement between our managers and employees as vital to maintaining a safe and productive workplace environment. In this regard, we totally accept and support the role of trade unions and the support they can supply to our employees and ourselves."

A Balfour Beatty spokesman said, "We have previously acknowledged using the services of the Consulting Association up until 2009 to carry out reference checks on employees in the construction industry. We have expressed regret over this. It should not have happened and we have apologised to the workers and families who may have been adversely affected over the years by this. Since 2009, our company Code of Conduct prohibits the checking of references for job applicants without first obtaining their consent and prohibits the use or support of databases of "blacklisted" people and the supply of information to such databases.

> "Unite said it would not co-operate with the inquiry, calling it a Tory stunt"

"For Balfour Beatty this is an historic issue. Following the receipt of the Information Commissioner's Enforcement Notices in 2009, we undertook steps to address the shortcomings revealed in our data protection practices which included the introduction of a data protection policy and a revised code of conduct."

Carillion issued a statement: "Along with other companies in the construction industry, over the past few years Carillion has been accused by campaigners of being involved in the illegal blacklisting of workers. This is not true... Carillion is a values-led organisation and we take real pride in our work. In particular, we take our commitment to transparency, openness, and safety extremely seriously. We wanted to put this information online to set the record straight. This is because others have been distorting the truth about Carillion and its involvement.

"Contrary to what has been claimed in public, Carillion is not anti-union and has never been part of any anti-union conspiracy. We have national recognition arrangements in place with a number of unions, including Unison, Unite, RMT, and the TSSA, and enjoy constructive working relationships with them.

"Carillion does not condone or engage in blacklisting and takes very seriously any accusation that it does so."

Steve Murphy, general secretary of Ucatt said: "Blacklisting companies destroyed the lives of workers and acted as though they were above the law. Our legal action will ensure victims [receive justice]."

Ucatt singled out Sir Robert McAlpine, and marked a TUC Day of Action against blacklisting by holding demonstrations outside of construction sites and offices operated by the company.

A Ucatt spokesman explained, "Sir Robert McAlpine was the company most closely involved with the Consulting Association. They provided the first and last chairman; they paid the Consulting Association's winding up costs and in the Consulting Association's final year of operation, they were the second highest user of its blacklisting service spending GBP 26,842.20 (~USD 42,000).

"Despite this... role in the Consulting Association blacklist, Sir Robert McAlpine was not prosecuted by the Information Commissioner's Office and was not even served with an enforcement notice."

A Sir Robert McAlpine spokesman said, "Sir Robert McAlpine has never operated a 'blacklist'. We are, and have always been, wholly committed to maintaining good relationships with our workforce and to responsible trade unionism. We recognise and respect the rights of workers to observe a day of action. We have apologised for our involvement with The Consulting Association and the impact that its records may have had on any individual worker.

"We have joined with other companies to form The Construction Workers Compensation Scheme which is intended to make it as simple as possible for any worker with a legitimate claim to access compensation"

Alex Conacher

OBSTACLES TO THE UNDERGROUND

Chair of the Underground Construction Association, part of the US' Society for Mining, Metallurgy, and Exploration, **William Edgerton** of *Jacobs Associates* discusses barriers to the advancement of the underground industry in North America.

THOSE OF us in the underground industry recognise the many benefits of building infrastructure underground. These benefits include less disruption during construction and significantly reduced environmental impact. Moving major portions of transportation infrastructure underground can preserve the urban historical heritage and restore public space for better use, including parks and recreation. Higher and better uses of scarce real estate can translate to increased tax revenue. Reliable communication facilities can be constructed without unattractive aboveground equipment. And for water infrastructure, large volumes of water can be conveyed, and sewage moved, to treatment facilities, thereby opening up development to increase the tax base and cleansing existing watercourses that have been fouled by decades of human activity.

So what keeps us from putting more facilities underground and taking advantage of these benefits? One barrier is that we still don't seem to be able to accurately predict the final cost and construction duration for our major projects. Although tunnel projects can be the lowest cost alternative in many instances, especially when considering social costs of disruption to neighborhoods and other real but soft costs, the final cost and completion time for underground work has historically been very unpredictable when compared to aboveground construction. There have been numerous well-publicised cost overruns on underground projects, for which many reasons and/or excuses have been provided. These include the insufficiency of pre-tender subsurface investigations; design solutions that are not constructable; unfair and one-sided contract terms and conditions; procurement methods that carry high contractual risk, permitting inefficiencies, mismanagement by either or both of the contracting parties; and a lack of mutual respect that can arise from not understanding the other parties' motivations.

Another barrier is the advancement of alternative technologies. In the wastewater industry, the standard "convey and pump" solution to combined sewer overflows is being replaced in some areas by a green infrastructure solution. Such facilities allow storm water runoff to infiltrate the ground instead of being captured by storm drain systems and diverted to underground conveyance systems. Although not usually as effective a solution in terms of CSO reduction, such green solutions can be orders-of-magnitude less expensive. Although the long-term reliability of these solutions has yet to be evaluated, the lower capital cost is an extremely attractive feature.

Alternative technologies are also emerging in the field of power generation. Some of these technologies can threaten the development of major hydropower developments, many of which rely on penstock and tailrace tunnels and in some cases underground powerhouses. However, other technologies, such as offshore wind and geothermal, actually present opportunities for underground construction.

Another obstacle to our industry is the fact that most underground projects take a long time to develop. The time needed for planning, alternative analysis, subsurface investigation, design, procurement, construction, and commissioning can easily run from 10 to 20 years. The funding for publicly owned projects of such long duration can be uncertain, especially when they are subject to political pressures, as is typically the case for high visibility publicly funded projects. Political stability is a necessary component to completing a controversial public underground project.

As an industry, we can do better. In fact we must do better if our industry is to grow and develop to serve the needs of society. It is vital that we improve our project performance, particularly in the prediction of the time and money necessary to complete the work. We, that is all of the project participants (owners, contractors, engineers, and suppliers), can do this by learning from our past successes and failures. Some of this lessons-learned analysis can be done through the sharing of positive and negative case studies, in the forms of articles, conferences, and other educational media. This exchange of information is currently much less effective than it could be. This is in part because few project participants are willing to share what went wrong, despite the well-known fact that we learn much more from our failures than we ever do from our successes. Risk management is another area needing improvement. In addressing cost and schedule risk, the industry should develop a more robust risk analysis than is currently available, with the objective of quantifying the uncertainties. Simply maintaining the current qualitative approach to risk management will not resolve our inability to get the cost and schedule predictions right.

Equally important, we need to develop further advances in underground technology. Material suppliers and equipment manufacturers have been at the forefront of technological advances in the underground industry. While not discouraging this innovation, we must engage other stakeholders and inspire them to generate more innovative ideas. Much of this innovation can be done by academia, through graduate research programs, provided sufficient feedback is available as to what research is needed. Most of today's underground projects are instrumented with volumes of data, from both mining equipment and geotechnical instrumentation. But on-site project staff typically have neither the time nor the motivation to analyse these large volumes of data for future use. Overcoming contractual barriers to data ownership so that this information can be made available to academia for research would be a giant step in furthering technological advancement. Such advances in technology will make tunneling more efficient, and thus less expensive.

Because a large portion of the underground business is for public owners, industry representatives, including owners, contractors, engineers, and suppliers can and should become active in the political process. This can be done by providing factual information to political decision makers, particularly on how underground solutions can help solve public problems—in transportation, water and wastewater, and other societal uses. Our underground societies and associations, as well as the International Tunneling and Underground Space Association (ITA) can all play a role in this. Another avenue is the active collaboration with industry groups in the areas of urban planning and design. Many of the benefits of underground construction match up well with the goals of urban planners—e.g., less sprawl and more green space. Becoming involved is critical to the long-term health of our industry.

If the industry successfully addresses even some of these barriers, the demand will outstrip the supply of engineers and contractors to service it. To be ready for this, we must reboot our basic educational programs across the board, including secondary school systems, undergraduate, and graduate institutions. And practitioners—including owners, contractors, engineers, and suppliers—must not forget that a significant part of a tunneller's education has been and will always be on-the-job training. I would welcome an industry dialogue with a view to developing a worldwide strategy for how each of these education systems can best contribute to the efficacy of our industry. The underground industry faces a number of barriers, but if all of the stakeholders in our industry participate in advancing the state of the practice, the underground construction industry can become one of the most efficient sectors of the world economy

William Edgerton
Bill is a principal with Jacobs Associates, directing strategic planning for 10 years

Above, all: Tunnelling at the Forrest Kerr project in British Columbia. This 195 MW run-of-river hydroelectric project will help the Province achieve its goal of energy self sufficiency by 2016. Photos courtesy of AltaGas.

The John Hart Spillway Dam

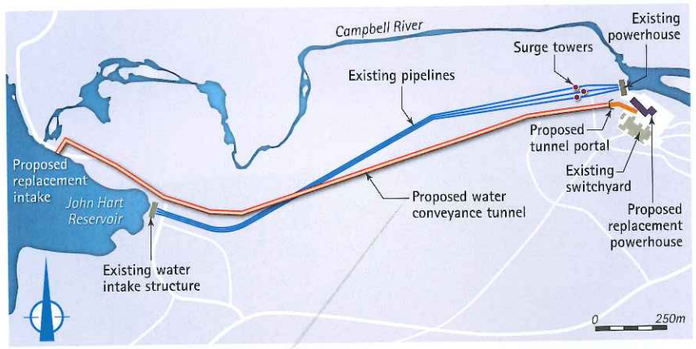
SAVE THE SALMON

BC Hydro has announced the preferred bidder for its John Hart Generating Station project. **Nicole Robinson** looks at a crucial part of this project: 2km of tunnels to preserve the region's water supply as well as the facility's environmentally-sensitive surroundings

Nicole Robinson
Managing editor of *Tunnels North America*
Nicole is based in Minneapolis, Minnesota

IT TOOK one storm in February 2013 to knock out two of the three pipelines to the John Hart Generating Station on Vancouver Island in British Columbia, Canada. Crews from BC Hydro—the region's electric utility—leapt into action.

At any time flows in the Campbell River drop, it's a potentially dangerous situation for the salmon downstream. The river supports spawning grounds for all five species of Pacific Salmon, and both summer and winter runs of Steelhead



Left: The original pipelines

Above, right: Figure 1, The proposed alignment

Below: The existing John Hart facilities

In less than an hour that early February morning, water from the dam had been released to restore water levels.

Before the decade is out, this scenario will be more avoidable once the estimated CAD 940M (USD 910M) John Hart Generating Station replacement project is completed. Construction on the project, expected to start later this year, includes replacing the current pipelines with a 2.1km-long tunnel.

CAMPBELL RIVER

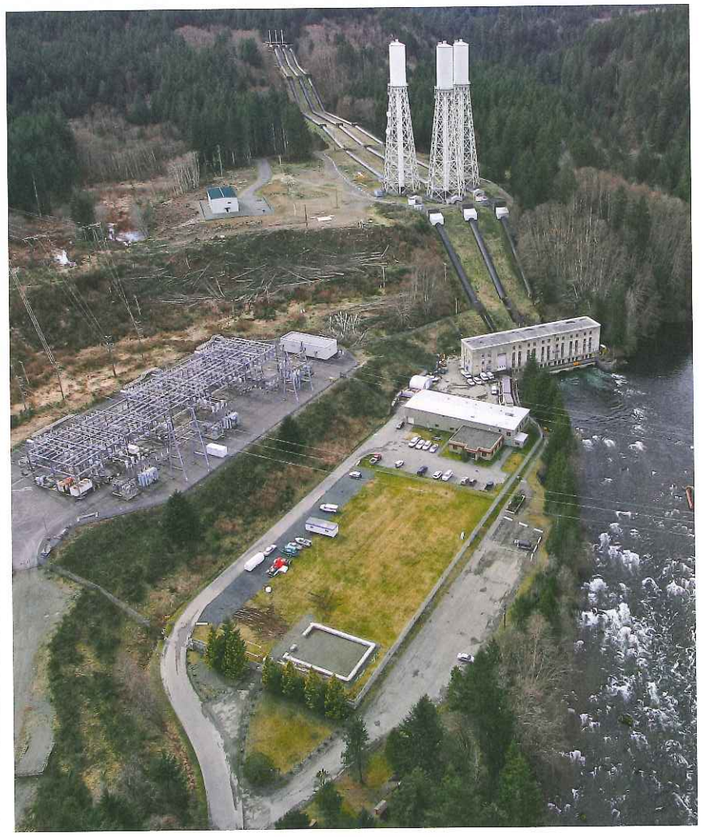
Located within the City of Campbell River on Vancouver Island, the John Hart Generating Station has been operating since 1947 and is one of the oldest generating facilities in BC Hydro's hydroelectric system—and one of the most important assets on Vancouver Island.

The Campbell River System comprises three power-generating stations. Upper Campbell Lake discharges through the 65MW Strathcona Generating Station into Lower Campbell Lake. Lower Campbell Lake is the headpond for the 47MW Ladore Generating Station. And Ladore discharges into John Hart Lake, which is the reservoir for the 126MW John Hart Generating Station. Upper Campbell Lake is the storage reservoir for all four installations.

Currently the three 1.8km-long woodstave and steel pipelines built some 60 years ago carry water from the John Hart reservoir and Dam to the generating station. There are three main drivers for the project. One being the risk of a station shutdown and river flow reduction, which would have subsequent impacts to fish habitat, as seen just this spring. Secondly, the generating station and pipelines may not withstand a low to moderate earthquake. Finally, the six generating units are in poor condition and their capacity is declining.

"We were originally going to replace the three above-ground penstocks," explains Stephen Watson, John Hart Communications Lead for BC Hydro. "However, our site investigations and previous drill holes showed that while potentially possible to seismically prepare them by spiralling the ring-girders into the ground, they are ultimately sitting on soil and sand.

He explains, "the structures could still liquefy during an earthquake and it was decided to be too great of risk for the investment. We then moved to the tunnel option through bedrock."



The 2.1km-long replacement tunnel will need to carry water at a rate of 124m³/s. Other construction in the project include constructing a replacement water intake at the John Hart Spillway Dam, a replacement generating station next to the existing facility and a new water bypass.

Following an RFQ issued by BC Hydro in March 2012 the three consortia were shortlisted (see box) for the design, construction and partial financing of the John Hart Generating Station replacement project. BC Hydro announced in November 2013 the SNC-Lavalin had been selected as the preferred contractor to design and construct the John Hart Generating Station Replacement Project. The two will now begin final discussions toward a contract signing that will likely take place early this year.

The exact placement of the new generating station and the tunnel design will be determined after the contractor is formally in place.

JOHN HART

The tunnel will be 60-100m below ground and up to 8m in diameter. Some lengths of the tunnel will be unlined while others are steel-lined, particularly where the alignment goes under the Earthfill of the John Hart Dam.

"In case there are any fissures in the rock we would not want any upward water seepage," Watson says.

The tunnel will be mostly in relatively massive and un-fractured igneous bedrock with hydraulic conductivity estimated to vary from less than $1x10^{-10}$m/s to about $1x10^{-8}$m/s. He explains, "Leakage rates over the full length of the tunnel are estimated at 6 litres per hour. There is the potential for some minor and major fracture zones but these are not expected to be extreme."

These zones will be sealed and leakage is considered to represent a negligible effect to groundwater. Elk Falls Canyon is very close to the John Hart site, and runs parallel to the BC Hydro property, which is surrounded by Elk Falls Provincial Park (a Class A park). The canyon has elevation drops of approximately 90m from top to bottom. The groundwater would move toward the canyon, Watson explains.

For the new intake, it will shift about 300m from the existing intake dam to the spillway dam, where the contractor will bore through the concrete dam and then go straight down into the bedrock.

"There is no exposed rock by the existing water intake so it is being moved over to get direct access to the rock. Most of the John Hart Dam is earthfill," he reiterates.

With the proposals process still underway as *Tunnels* went to press, the method of excavation, or how and where spoil will be removed from the site is to be determined.

BC Hydro has calculated that about 290,000m³ (an Olympic-sized swimming pool is 2,500m³, so 116 pools) of loose rock materials, primarily from the tunnel, will need to removed from the narrow site.

"One of the unique aspects of the tunnel work will be considerations for ground movement," Watson says. "The existing John Hart facility is very susceptible to ground movement with the dam intake gates that pass water from the reservoir and into the woodstave penstocks.

"To protect the facility these pressure and movement alarms that can shut down one or more penstocks. Therefore we would not want ground movement from the boring machine or controller blasting. That will be a significant construction technique challenge."

Looking back to February's storm event for the existing facility to lose two units from equipment failure—or worst-case scenario up to all six units through such occurrences as a lightning strike—and if BC Hydro can't get the units back online quickly, it must release water from the dam down Elk Falls Canyon.

"It takes about 45 minutes once the water is released from the dam to travel about 2km to the generating station area to restore the river flow. These kinds of unplanned flow reductions, on average once per year, can impact downstream fish habitat. That's why ground movement during construction because of penstock sensitivities will be so important."

The project, which is scheduled to be complete in five years, by the end of 2018, will create about 400 jobs a year over the five year process, and will see the removal of the original pipelines, allowing surrounding wildlife and vegetation to take over

Shortlist

Elk Falls
- Ontario Pension Board / Brookfield Financial
- Flatiron Construction Canada Limited*
- Fiera Axium Infrastructure
- Connor, Clark & Lunn GVest Traditional Infrastructure LP / Gracorp Capital Advisors
- Bouygues-Graham
- Knight Piesold Consulting
- Alstom Power & Transport Canada

SNC-Lavalin Inc
- SNC-Lavalin Inc
- IMPSA

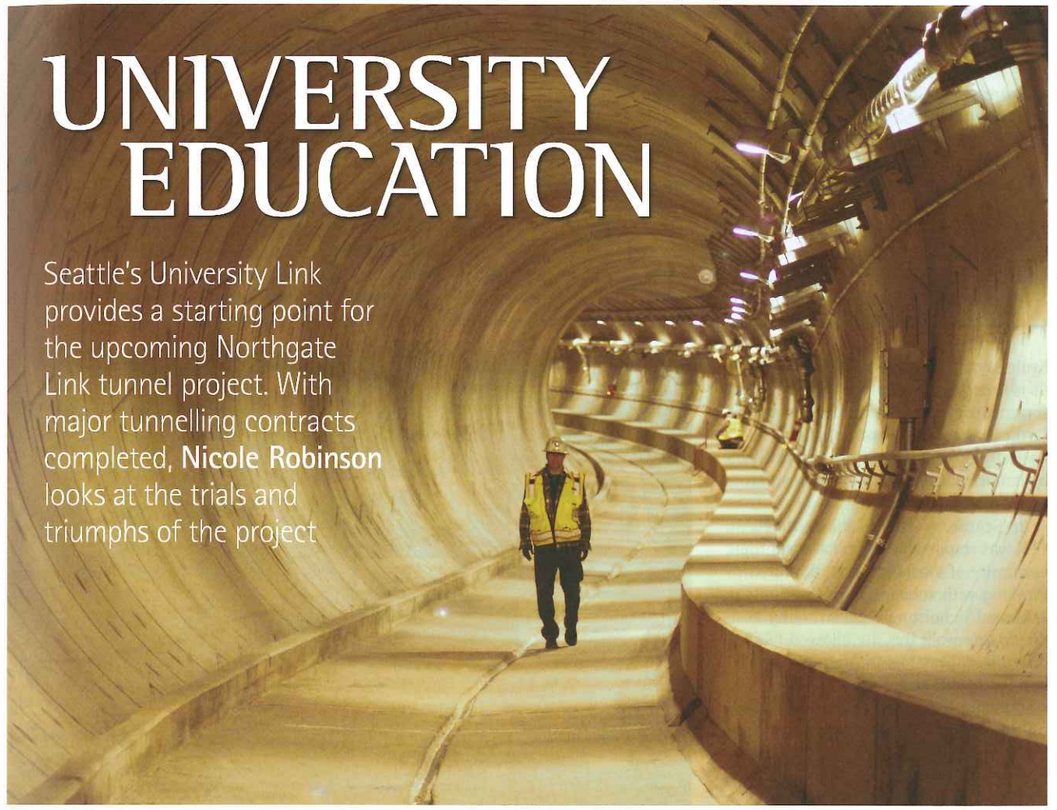
Salmon River Hydro Partners
- Bilfinger Berger
- Acciona
- Barnard Construction
- Klohn Crippen Berger
- Voith Hydro
- F&M Installations
- HMI Construction
- Siemens

**replaced Bouygues Travaux Publics in December 2012*

124
The required rate of water transfer for the replacement tunnel in m³/s

"The structures could still liquefy during an earthquake"

UNIVERSITY EDUCATION



Seattle's University Link provides a starting point for the upcoming Northgate Link tunnel project. With major tunnelling contracts completed, **Nicole Robinson** looks at the trials and triumphs of the project

NAMED CAPITOL Hill, this Seattle neighborhood is quite literal. The mix of residential and commercial property is located on a steep hill.

Glacially overridden, Seattle's topography varies enormously, and one of the new stations for the north-south University Link (U-Link) light rail extension is located atop Capitol Hill. And not just any station—it is also the reception point of two TBMs and the launch site of another, twice. Whether heading up or down the hill on their mining journey, all three TBMs saw steep grades of some 4.5 per cent.

Sound Transit bid the 6.4m-excavated diameter tunnels in two different contracts: U-220, awarded to a joint venture of Traylor Bros/Frontier-Kemper (TFK), and U-230 awarded to a joint venture of Jay Dee/Coluccio/Michels (JCM).

GOING UP

TBM mining for the U-220 drives went extremely well, says Paul Gasson, program manager for the Seattle Tunnel and Rail Team (START JV), the construction management consultant for U-Link. For him one thing that really stands out is not just the unexpected speed at which the mining completed, but rather the lack of wear on the cutterheads. "Stunning," he calls it. In all his experience he'd never really seen anything like it.

To best understand why the tunnel drives on U-220 went so well, it's important to look first at Los Angeles' Metro Gold Line Extension completed in 2007. Traylor Bros, in a JV with Frontier-Kemper, used two Herrenknecht EPBMs to mine the 7,500ft (2.3km) long tunnels in alluvial soils, both above and below the groundwater table.

Above: Completed and lined tunnels

TFK chose to refurbish the trailing gear from the Gold Line TBMs for the U-220 contract. "They were identical machines with the trailing gear mirrored," explains Michael Krulc, of Traylor Bros. "We bought new shields and cutterheads for U-220 due to much higher pressures."

Traylor added a third screw conveyor to the Metro Gold line TBMs because the project was anticipating high levels of gas and methane, and the third screw conveyor moved the discharge point farther back, providing more ventilation. TFK reused the numbers two and three screws on U-220.

"We didn't have to use the number three screw but we chose to do it,"

TBM timeline

- U220 – both drives ~11,400ft (3.5km)
- Southbound: May 31, 2011, through March 21, 2012
- Northbound: July 1, 2011, through April 2, 2012
- U230 – both drives ~3,800ft (1.2km)
- Northbound: July 8, 2011, through November 21, 2011
- Southbound: January 27, 2012, through May 2, 2012

Capitol Hill handover

- Areas G1/G2 were handed over to U220 contractor for breakthrough of the U220 TBMs at the end of their drives from UWS and subsequent retrieval of the machines. March 2012 and July 2012 respectively
- Area A was handed over to the U240 CHS finishes contractor in Nov 2012
- Area B was handed over to the U240 CHS finishes contractor in Dec 2012
- Area C was handed over to the U240 CHS finishes contractor in March 2013 (substantial completion of U230)

Krulc says. "One of the things it does for us is it gets the dump point from the screw conveyor to the tunnel conveyor farther back in the gantries, and it basically takes it away from where all the hydraulic motors are and it cleans that area up a bit."

In Seattle, on the U-Link contract, TFK was responsible for excavating the University of Washington station box. Working with subcontractor Condon Johnson/Nicholson JV constructing a diaphragm wall, this site allowed two different contractors to progressively handover and work from the same station site. The same method was used on the Capitoll Hill station site with the U-230 contract (see Figure 1 and side bar above).

Each of the two tunnel drives was approximately 11,400ft (3.5km). Within the first 100ft (30.5m) of launching the TBMs, TFK successfully mined beneath the Montlake Cut, an early 20th century shipping canal now used for recreation. For more information on that portion of the project, see *Tunnels North America*, February/March 2013, p.20.

After the Montlake Cut the U-220 alignment enters a basin with long reaches of clay and buried river valleys. Then after the first mile of tunnel the machines entered another area with 200ft (61m) to 300ft (91.5m) of overburden, with an up hill grade of some four per cent.

This area of up to 300ft overburden, is also where the alignment had the potential for the highest ground water pressures. "Everything showed us we could be nearing up to 150ft to 200ft of ground water pressure," explains Gasson. "The good thing was, on the U-220 drives there were such long reaches of good hard solid clay that we didn't have to actually go in [under hyperbaric entry]. It was there if we needed it."

Another concern was hitting boulders that the machines wouldn't be able to handle, which would require TFK to go in under hyperbaric condition. It turned out to be a nonissue.

Gasson explains, "Because the ground is so consolidated and it does hold the boulders well within the matrix that they do get ingested."

Finally, these high overburden areas also had more buried valleys coming out of the clay and going into the water-bearing sands. Referring to Seattle's Beacon Hill tunnelling project, Gasson say, "They had similar geology to this where you are going through long reaches of permeable hard clays, and then you hit these water-bearing sand-filled valleys. If the machine's not set up right, if you haven't got the face pressure there you can over-excavate."

Above: Figure 1, the progressive handover of Capitol Hill station between contractors, which happened similarly at University of Washington station as well

This was the impetus for specifying twin screw conveyors, and TFK used the third as well. "Certainly between the single and the two you get much more control even if you get a changing face condition. You've still got a plug of good solid material in your screw conveyor so you can still control your face pressure," he says.

As the alignment approaches the station box at Capitol Hill, in addition to becoming shallower the ground becomes more complex with more interlayering. On the U-220 southbound drive the TBM stopped for a tool change after mining 5,326ft (1,600m), and on the northbound drive the TBM had a tool change after mining 4,863ft (1,500m).

"The ground's not very abrasive here. They had very simple conditioning in these long reaches of clays. The roller cutters were the scalloped type so they were equipped to crack boulders and cut the boulders when they did get them—and we did see them because we saw the fragments coming through," Gasson recalls. "I think there just weren't that many reaches of abrasive soil."

Another reason for making such great advance rates, says Traylor's Krulc, is using machines similar to those on the Metro Gold Line project, which reduced the learning curve. "We're pretty particular about machine specification, and the machine that we used on the Gold Line performed very well. The mining crews, the chief mechanic and supervision that we used on U-220 knew the machines really well. It just made sense to refurbish them and put people back on the same machine."

Nicole Robinson
Managing editor of *Tunnels North America*
Nicole is based in Minneapolis, Minnesota

TFK worked 24-hour days (three eight-hour shifts). On the northbound drive the best day saw 155ft (47.2m) or 31 rings, and the overall average production was 68ft/day. For the southbound drive the best day saw 150ft or 30 rings with an overall average of 64ft (19.5m)/day.

All tunnel lining segments for both tunnel contracts were cast at the Traylor/Technopref precast yard, which was established in Tacoma, Washington. Typical rings were 5ft (1.5m) long with a five plus key configuration for an 18ft 10in (5.5m) interior diameter. U220 used two different types of segments of 7,000 psi and 8,000 psi (48-55MPa) concrete to accommodate for the change in depth along the alignment. U-230 used the standard taper and a special tape for its 550ft (168m) radius curve (see box).

DOUBLE UP

According to early baseline schedules TFK didn't think there was enough time to finish the TBM drives before starting cross passages six through 20. The solution was to mine the cross passages concurrently with the TBM drives, starting once the TBMs were more than halfway through their drives.

With 15 passages to build, using traditional steel propping frames that brace the tunnel lining where the opening is formed had the potential to eat up valuable time. TFK chose to use temporary shotcrete instead, which meant cross passages could be prepared without waiting for pairs of steel frames still in use at other locations. "They actually did a temporary shotcrete lining inside of the precast tunnel lining to act as a propping frame," says Gasson. "They just basically went through the whole tunnel and formed these at every cross passage location."

In combination with the shotcrete propping TFK put collapsible steel decks across the tunnel. The locomotives carrying segments to the TBM could pass underneath the steel deck, and the mining crews worked above the track on the cross passages off to the side.

"We figured we had to do the cross passage mining the at same time we're doing the TBM mining and we thought there is really only two ways to do that: You either build elevated steel decks and work of off those or you could make a passing track," says Krulc.

300
Feet (91m) of overburden on portions of the U-220 drive

"But we were a little bit worried about that because the U-220 alignment is a pretty steep grade."

There was a debonding agent on the lining to make a clean break for the shotcrete when it was later broken off and removed. The tunnel lining, propping and temporary decking design come from Halcrow and Alpine BeMo was the SEM consultant.

UNLUCKY 17

As part of the contract specifications, TBMs stopped at cross passage locations to get an early view of the ground conditions to confirm its suitability for cross passage mining.

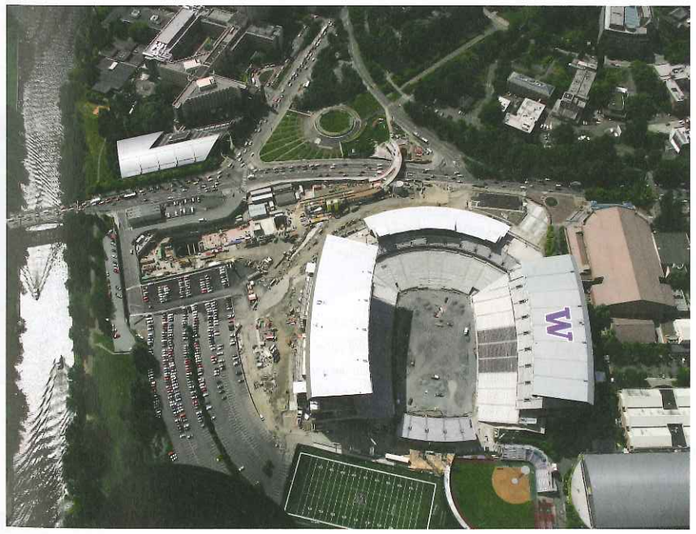
Cross passage 17 is in a low-laying area at the northern end of the U-220 alignment. After the TBM passed through the team inspected the ground at the cross passage location and discovered it wasn't as good as expected. "There was flexibility to move the cross passage a little further to the south," says Gasson. "The ground looked much better, so that was determined as the best location for mining."

The TBM moved on and then some six months later the cross passage work actually started. The early cross passages were all located in good clay and the work went well. It was late in March 2012—the southbound TBM had just broken through at Capitol Hill and the northbound TBM was close to its own breakthrough—when crews were mining the heading for cross passage 17.

"Groundwater started to seep up from below and very soon we realized the water pressure was from the aquifer beneath the tunnel," Gasson explains. "Mining had to be suspended and initially we used a system of in-tunnel drains to try and relieve the pressure, so you could finish the SEM mining for the cross passage.

During May and June of 2012 TFK installed the in-tunnel vacuum dewatering. "The in-tunnel drains just couldn't take off that amount of water," says Gasson. "After various attempts in-tunnel we needed to drill wells from the surface."

It was midsummer 2012 that they installed wells from the surface. First there was a 300 gallon (1,130 litre) per minute pump in well number one that was only achieving very slow drawdown. In early September 2012 TFK installed a purpose-built 60hp pump capable of



Below: Aerial view of the work site environment

500 gallons per minute, and five days later the tunnel achieved draw down. Mining and initial shotcrete lining for the cross passage competed on September 19, 2012.

"It was a real problem, there is no doubt about it," says Krulc. "You couldn't really tell what was going on. There was all this sand below us—you couldn't see it or know where it was and it was just difficult to get to the source of the problem, to get a probe hole to it or get grout to it. We had so much water even when we did try to grout it."

Gasson says, "the cross passage itself was in clay, but this water bearing pressurised sand layer was literally just immediately beneath the cross passage."

Relocating number 17 made the job easier, he says, "but we didn't get completely away from the problem."

Cross passages had been spaced either side of this sand valley in the original design. The aquifer extended further south than had been anticipated from the borings. "There is no contention over it," he says. "Everyone thought that the valley was just to the north, and it proved to be slightly to the south. We moved it a certain distance to the south to get away from what we thought was the extent of the valley, this proved we didn't move it quite far enough but you can only move these passages so far."

In January 2013, during demolition of the temporary shotcrete something disturbed an in-tunnel well that had not yet been grouted and the cross passage sprang another leak.

The surface wells had already been decommissioned and the only option was for TFK to do in-tunnel grouting through February and March.

Tunnel lining

Typical
18ft 10in (5.7m) ID
10ft (3m) wide segments
5ft long (60in nominal)
Straight bolts to longitudinal joint
Plastic alignment dowels to circumferential joints
5 + key configuration (five segments at 67.5 degrees, key at 22.5 degrees)
Elastomeric gasket in formed groove
Ring tapers – contractor design

U220
Standard taper of 2.5in (+/- 1.25in of the nominal 60in ring)
Type A (shallow) 7,000 psi concrete
Type B (deep) 8,000 psi concrete

U230
Standard taper (as for U220)
"Specials" taper of 4.5in for use in 550ft radius curve

While cross passage 17 was one of the first to be mined, it was the last to complete. Despite the challenge of drawing down the water, work on all other cross passages continued, the tunnel invert concrete had been poured, the tunnel walkway was in and cabling and conduits had been installed on other sections of the tunnel.

"The reality is the TBM drives went so fast, they almost had enough time to leave it all to later," says Gasson, "but not quite had drives gone slower. It could have been a struggle."

The U-220 contract reached substantial completion on June 7, 2013, two weeks early.

FACE DOWN

JCM and subcontractors DBM/KLB/Grady excavated the Capitol Hill station box, which would also act as the TBM launch site and the reception for the two Herrenknecht TBMs used to mine the U-220 drives.

For the U230 contract, JCM chose a Hitachi Zosen machine to excavate both drives of approximately 3,800ft (1.2km) each, starting with the northbound tunnel in July 2011. Launching at Capitol Hill station, the drives are almost completely downhill, nearly reaching a 4.7 per cent grade.

The ground at Capitol Hill is more mixed face and saw overburden in the range of 100ft (30.5m) to 150ft (45.7m). "It's a shallower area and you've got these multiple phases of glaciation that have laid down deposits and then washed out deposits," recalls Gasson. He says, eventually the reaches of ground got more consistent and longer. Ground conditioning was key in the early part of both drives.

"Based on the risks associated with this project, we had the TBM set up in such a way that we had several fail-safes in regards to tunnelling in flowing ground," explains Glen Frank of Jay Dee and project manager for the JCM JV.

"We wanted to be doubly (or trebly) sure that we were not going to be in a situation where we were losing ground uncontrollably at the face. This resulted in a tunnel spoil transport system in the TBM that was not terribly efficient in cohesive ground such as clay and till.

Below: U-220 finished tunnel

Bottom: Geology along alignment

"When there was a significant amount of granular material in the face the system ran very well, but if it was all clay we had to work pretty hard to get the muck through the screw. We conditioned based on the possibility that we could encounter flowing ground on any push, because we were continuously below sensitive infrastructure."

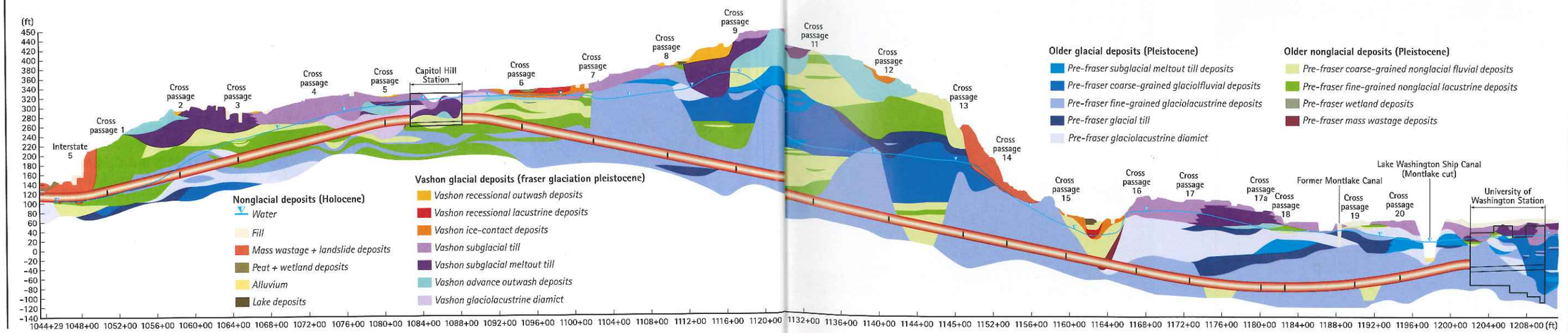
After crossing under I-5, the U-230 TBM broke through at the Pine Street stub tunnel in downtown Seattle where it was retrieved and brought back to Capitol Hill to be relaunched for the southbound drive. JCM completely redressed the cutterhead between drives, and no other tool changes were necessary during the drives, including when the machine stopped inside the CDF-filled shafts before the undercrossing of I-5, see *Tunnels North America*, August/September 2013, p.31.

The TBM made its breakthrough into an adit at the stub tunnel in May 2012.

"As always the second drive was more efficient. The full production mining rates (with conveyor) were not significantly different but the initial drive rate increased from 15ft [4.5m] to 20ft/day and the switchover from initial drive (with skips) to production mining was quicker," Glasson says.

JCM worked a 20-hour day of two, 10-hour shifts. For the northbound tunnel the best day was 25ft (7.6m) or 19 rings, and the overall average was 26ft (7.9m)/day. On the second drive the best day was 105ft (32m) or 21 rings and the overall average was 37.5ft (11.43m)/day.

Gall Zeidler provided SEM consultation to JCM. The U-230 contract closed in March 2013



READY TO GO

Roadheaders arrive on site in Ottawa to start excavation on a 2.5km tunnel for the city's core, **Nicole Robinson** looks at what the city envisions and what the ground may hold for the future

Nicole Robinson
Managing editor of *Tunnels North America*
Nicole is based in Minneapolis, Minnesota

TODAY A Bus Rapid Transit system services downtown Ottawa. Approximately 180 buses, per hour, per direction, work their way through 14 lighted intersections. Meanwhile, vehicles, pedestrians and an ever-growing number of cyclists swarm through the same downtown corridor.

Throw in a special event, car accident, bad weather or an ambulance—or any combination of these—and buses are plagued by delays; transit downtown is unreliable and the disruption ripples through the system.

Not in 2018, though, when the City will operate a light rail transit (LRT) system in this core where ridership volumes are the highest. More than 50 per cent of buses currently running will be deployed in suburban communities.

"In addition, the use of LRT within the core will allow Ottawa to accommodate ridership increases over the coming decades much less expensively than by continuing to

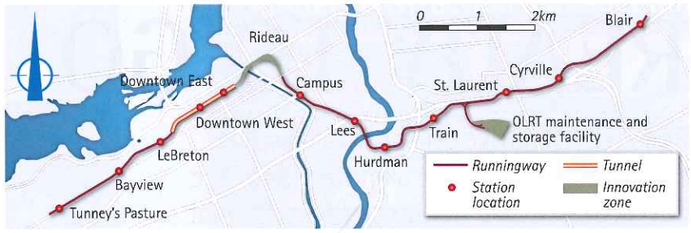
Conceptual image of LRT project

acquire buses and push them through already congested downtown streets," says John Jensen, director for rail implementation with the City of Ottawa.

He describes the future of downtown Ottawa, "For the 10km of existing grade separated Bus Rapid Transitway, there will be no bus operations, those will be entirely replaced by light rail vehicles. Downtown, where the system currently operates at-grade in a bus only lane, bus traffic will be significantly reduced. Cross town buses will be replaced by LRT operations in the 2.5km underneath downtown, only local bus service will continue on surface streets."

LRT will run from Tunney's Pasture in the west to Blair Road in the east. For those not local to Ottawa, Tunney's Pasture is home to the city's federal government buildings and Blair Road is a major north-south artery.

Running 12.5km, the 13-station line includes a 2.5km tunnel through the city's downtown to address a transit bottleneck (Figure 1). The tunnel's west portal will be located east of LeBreton Station, and there will be three underground stations (Downtown West, Downtown East, and Rideau) before the east portal located north of Campus Station. Each underground station will have platforms 150m long on each side of the tracks.



Above: Figure 1, the light rail alignment through Ottawa

Below: Artist's rendering of the Downtown East station

PLANNING

Ottawa's Light Rail Transit (OLRT) project began in January 2007 with the mayor's Task Force on Transportation, which recommended an east-west rail tunnel bored through downtown.

Planning and development continued with a preliminary geotechnical program by Delcan Corporation as part of the environmental assessment. In September 2010 the city hired Capital Transit Partners (CTP, a joint venture of Morrison Hershfield Limited, Jacobs Associates, STV Canada Consulting Inc, and URS Canada Incorporated) for the preliminary engineering program.

The city issued an RFQ in July 2011 and later in October

> "The original alignment was based on... the limited available geotechnical data"

RTG makeup

Rideau Transit Group (RTG) led by ACS Infrastructure Canada:

- EllisDon Corporation,
- EllisDon,
- Dragados Canada,
- SNC-Lavalin Capital,
- SNC-Lavalin Constructors (Pacific)
- Veolia Transportation Services.
- Additional team members include: Adamson Associates, BBB Architects Ottawa, Dr. Sauer & Partners Corporation, Fast + Epp, Hatch Mott McDonald, IBI Group, L2 Advisors, MMM Group, Scotia Capital, Sereca Fire Consulting, SNC-Lavalin, SNC-Lavalin O&M, SNC-Lavalin Operations & Maintenance and Thurber Engineering.

2.1
The bilions of Canadian dollars the enitre light rail project with cost

announced a shortlist of three consortia. Rideau Transit Group (RTG) won the CAD 2.1bn (USD 2.13bn) contract for the 12.5km east-west Confederation Line in late 2012. RTG is led by a builder ACS Infrastructure and includes Quebec engineering firm SNC-Lavalin and assorted subsidiaries playing roles as financiers, engineers, operators and maintenance overseers.

OLRT has been procured as a Design-Build-Finance-Maintain (DBFM) project. The city is requiring RTG to provide private financing of up to CAD 400M of the construction costs to stand behind overall contract performance. DBFM proposals are asked to provide a fixed-price to complete construction and maintain the system for a minimum of 15 years.

Above: Artistic concept of a station entrance

Below: Road-header excavation

DEPTH DECISIONS

In 2010, the city hired Golder Associates to do a detailed geotechnical and hydrogeological investigation as part of the preliminary engineering program.

Boreholes were advanced using truck-mounted or track-mounted conventional drill rigs (operated by George Downing Estate Drilling Ltd. of Grenville-sur-la-rouge, Quebec, and Marathon Drilling Company Ltd. of Ottawa), or using a sonic drill rig operated by Boart Longyear of Marysville, Ontario. Stanton Drilling Inc. of Pakenham, Ontario, using cable tool or percussion drilling techniques to drive the boreholes for installation of pumping test wells, according to Golder's December 2011 report.

After the final depth was reached, the boreholes requiring geophysical logging were left open (with a flush mount cover in place) for up to approximately one month until logging within the boreholes was carried out. On completion of the drilling operations, the soil and rock samples from the boreholes were transported to various laboratories for testing and to an off-site storage facility.

Initially, the tunnel would have four underground stations and run for 3.2km. A report released in December 2010 by Golder, after the first phase of its geotechnical investigations, recommended the City shorten the tunnel by 600m to 900m.

Rock samples from 34 boreholes drilled between May and August 2010 show the ground to be as expected except for in one area of the alignment where bedrock is 2m to 10m deeper than anticipated, the recommended design modification would have Campus Station on the surface.

Jensen explains they reduced the tunnel length to 2.5km "when further design work indicated that grade separation could be maintained without requiring a tunnel for the portion of the alignment from Mann Avenue to just south of Laurier Avenue."

The December 2011 report finds that for most of the downtown area, "the bedrock formations are anticipated to be flat lying to gently dipping, although zones of local folding are evident. In general, the limestone is medium bedded, but occasionally thinly to thickly bedded horizons exist with thin shale partings and interbeds."

Generally, the overburden in the area of the tunnel ranges in thickness from about 2m to 8m, except in two zones. The overburden is locally thicker at Rideau Street, "where an infilled valley in the surface of the bedrock is indicated to extend to depths in excess of 30m below ground surface." The overburden is also locally thicker at the east end of the tunnel alignment, where the surface of the bedrock is at depths ranging from about 7m to 15m.

The overburden generally consists of

fill, related to underground services and or previous uses in the area, underlain by glacial till, containing sand and or gravel layers at some locations. Localised deposits of silt and silty clay/clayey silt were encountered along Rideau Street at the valley in the surface of the bedrock. A more extensive deposit of silty clay to clayey silt exists at the east end of the tunnel alignment.

Originally the alignment's depth would be approximately 40m. During preliminary engineering, CTP identified a shallower tunnel by moving the alignment north by one block for the western portion of the tunnel.

"The original alignment was chosen based on the understanding of the limited available geotechnical data at that time," Jensen says. He adds, "The adjusted alignment runs underneath Queen Street instead of tunnelling deep underneath building foundations with extensive underground parking structures. The result is a far shallower tunnel that is substantially less expensive to build and service."

The Ottawa City Council approved this change in design, among others in July 2011. "Prior to these design changes our project estimate was CAD 2.1bn in 2009 dollars; it is now CAD 2.1bn but in construction dollars—equivalent to CAD 1.74bn in 2009 dollars, a CAD 360M saving," says Jensen.

START UP

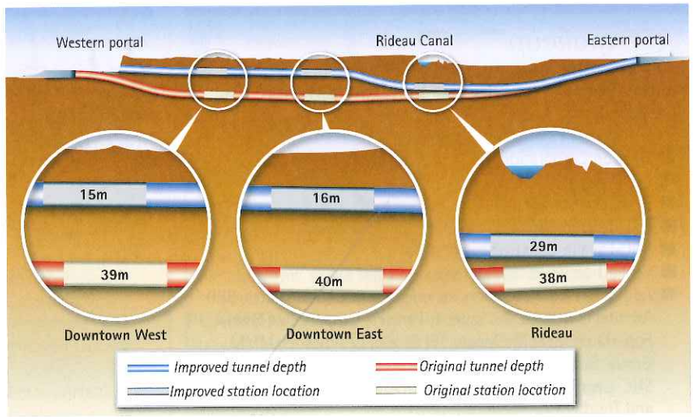
RTG has chosen to use three Sandvik MT720 roadheaders for the excavation of the tunnel. Assembly for the machines started in mid-September 2013 with the first starting mining on November 8, at the West Portal moving east toward Lyon Station. Central shaft tunnelling will follow later, moving east toward Parliament Station.

The East Portal excavation will move west toward Rideau Station, linking underground to the central shaft and West Portal tunnelling.

Each roadheader has a cutting profile of 9.1m in width and 6.6m in height, and each cutterhead contains 78 picks made from tungsten carbide. RTG is using shotcrete to reinforce tunnel support.

Prior to launching the first machine, RTG built an umbrella support structure using horizontal pilling with steel pipes and grout. As this issue of *Tunnels* goes to press RTG is installing concrete reinforcement of the Central Shaft and excavating the overburden. At the East Portal, overburden excavation has been completed, while crews were getting started on the tunnel support umbrella.

In February 2013, as RTG and the client formalised their contract, Gerry Grigoropoulos from the Rideau Transit Group announced that "approximately 80 per cent of all work will be completed locally. In addition, we will be developing educational opportunities and apprenticeships with local colleges and universities to improve local skill development. We are not only building a transit system we are building community partnerships that will last the next 35 years"



2.5
The number of kilometers the tunnel will run under downtown Ottawa

Above: Preliminary engineering reduced the tunnel's depth

Below: Conceptual image for the LRT project

FROZEN EARTH

Two more-advanced applications of reinforced frozen Earth are currently being proposed on tunneling projects in the US. **Joseph A. Sopko**, director of ground freezing, and **Robert R. Chamberland**, project engineer, both of *Moretrench*, discuss a new application of ground freezing

Joseph Sopko
Joe is director of ground freezing at Moretrench and has 30 years experie--nce in geotechnical construction

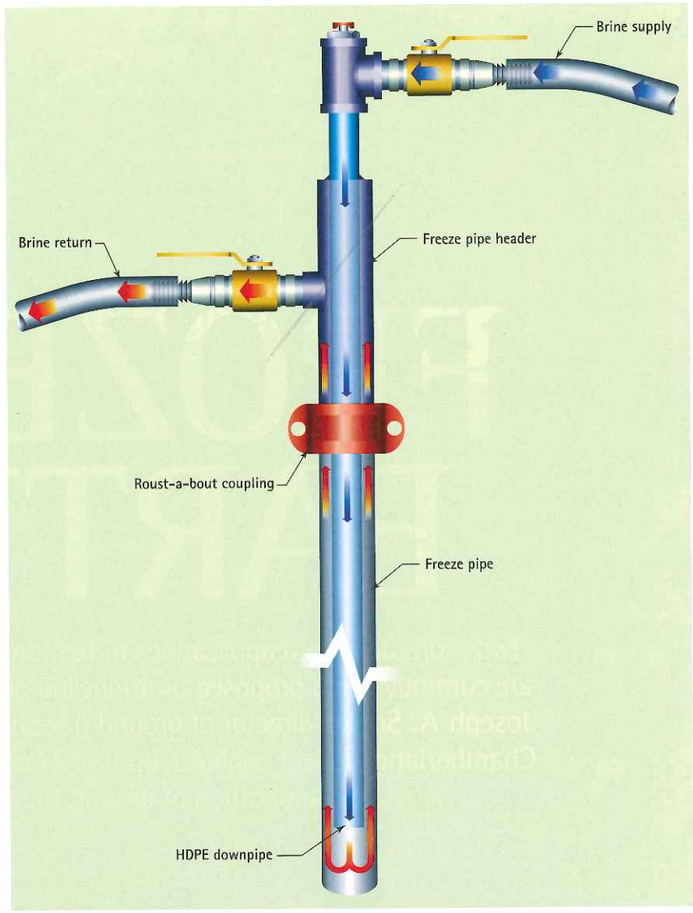
Robert R. Chamberland
Robert R. Chamberland is a project engineer at Moretrench. He has assisted Sopko on freeze jobs since 1997

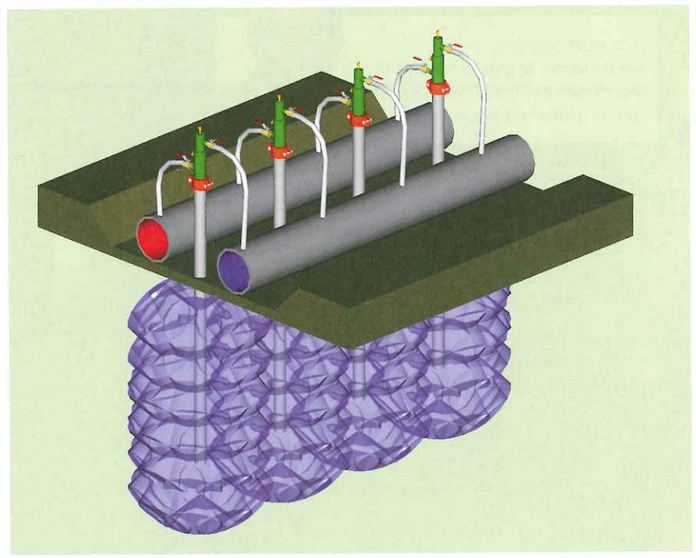
ARTIFICIAL GROUND freezing to provide temporary earth support and ground water control for the construction of deep shafts has been used in the mining and civil construction industry since the late 1800s. The process of converting the pore water within a soil to ice creates a strong, impermeable material with properties similar to low strength concrete

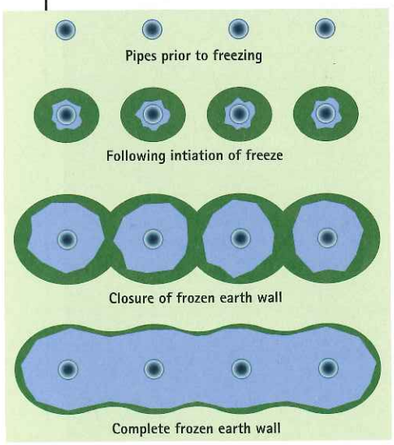
The applications of ground freezing can generally be divided into three different types or variations of these types: shafts, tunnels and large-scale groundwater barriers. Regardless of the application, the process is relatively standardised. A series of closed end freeze pipes, ranging in diameter from 76 to 114mm are drilled and installed around the perimeter of the proposed excavation. The pipes are drilled with a variety of site-suitable drilling methods, mud rotary, casing advancers and resonant sonic are the most common. Regardless of the method, it is necessary to keep the borehole open during the installation process of the freeze pipes.

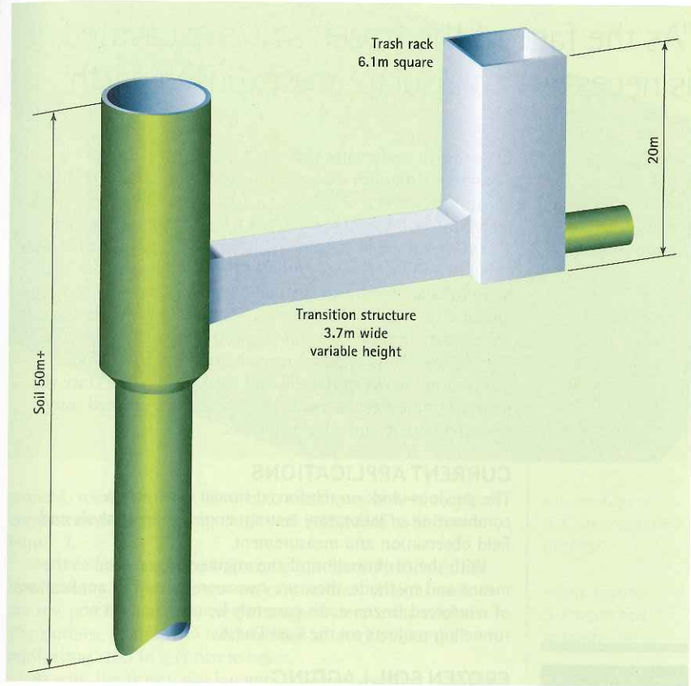
The freeze pipes are typically steel, although current research is evaluating the feasibility of other materials. Within the steel freeze pipe, smaller diameter down pipe or feed pipe is installed as shown in Figure 1. The circulating coolant, or bine, is pumped down this inner pipe using a specially made pipe head also illustrated in Figure 1. Once each individual freeze pipe is installed it is both pressure tested and surveyed for verticality using gyroscopic survey equipment. It is imperative that reasonable alignment between adjacent pipes be maintained. Excessive spacing between pipes can extend the freezing time significantly, and in cases of very large spacing prevent freezing altogether.

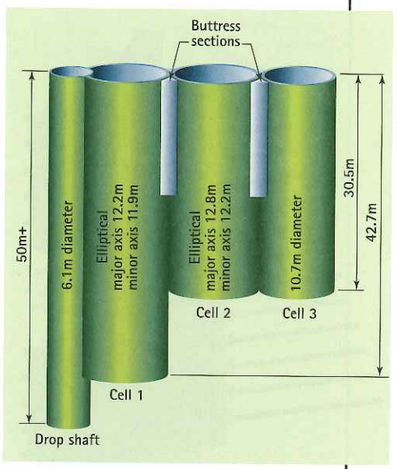
The circulating brine is actually a secondary coolant which is contained in a closed loop and refrigerated in a heat exchanger that using refrigerant gases such as anhydrous ammonia as a primary refrigerant. The refrigeration plants are electrically powered and can be installed on mobile trailers or built in permanent installations for larger or long-term applications. The brine











circulates through the pipe, back to the refrigeration plant in a completely closed loop. No chemicals or gases are injected into the ground or released at ground surface. In cases where very rapid or flash freezing is required on small isolated areas, liquid nitrogen can be pumped into the freeze pipe and the nitrogen gas released directly into the atmosphere, this specialized application warrants consideration in a separate article.

The brine is cooled to temperatures of -25°C or colder and pumped at flow rates to ensure that sufficient heat transfer is occurring. It is important to note that this process is extracting heat from the ground, not injecting cold, in a similar manner as a well extracts groundwater. The heat that is extracted from the ground is expelled to the atmosphere via an evaporative condenser within the refrigeration plant.

As heat is extracted from the ground, cylinders of frozen earth form around each pipe and continue to increase in size. These cylinders eventually overlap each other forming the groundwater barrier.

As the frozen mass increases in size with time, its temperature continues to decrease and a structural frozen earth barrier is formed. Frozen earth strength increases substantially when the temperature is lowered. Like concrete however, frozen soil is only strong when in a compressive stress state and exhibits very little, if any tensile strength. Because of the lack of any significant tensile strength, designers of ground freezing systems create structures that are essentially circular keeping the stresses in a totally compressive state.

Unfortunately, project constraints do not always allow for purely cylindrical frozen earth structures. Even elongating the structure to an ellipse doesn't always fit the project constraints. In recent years, ground freezing has been used extensively on projects in congested urban areas where straight sections of frozen walls are required. Areas between adjacent structures close to underground subways and utility tunnels do not permit the simplicity of designing purely compression, circular frozen earth cofferdams. In such cases, the frozen wall has straight sections and tension stresses develop. Reinforced steel can be used to accommodate the low tensile strength of frozen earth tension zones within the frozen mass.

Above: Figure 3a (left) CT-8 underground structures; and 3b (right) CT-8 tunnel frozen structures

Opposite, top: Figure 1, Typical freeze pipe header

Opposite: Figures 2a (left) Freeze wall formation; and 2b (right) Freeze wall

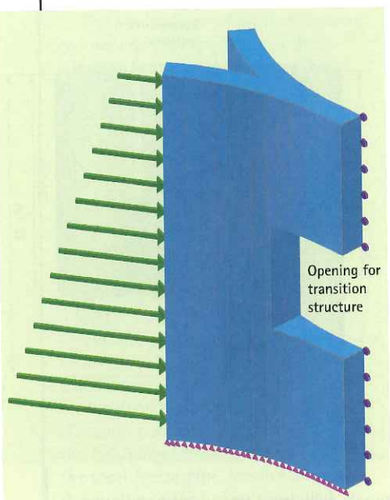
"Like concrete, frozen soil is only strong when in a compressive stress state"

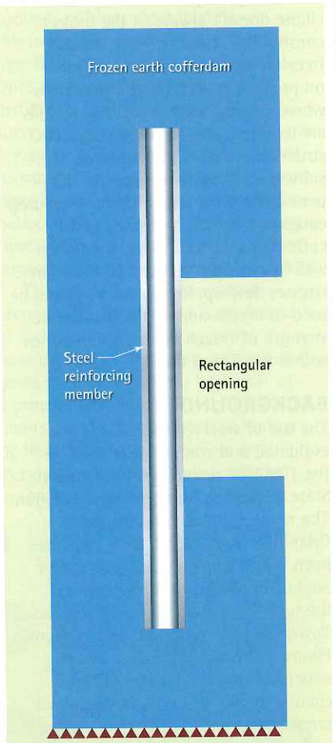
BACKGROUND

The use of steel reinforcements was evaluated and studied extensively in the 1980s by researchers at Michigan State University, East Lansing, Michigan. The research, headed by Professor Orlando B. Andersland, Ph.D., was has been well document (Andersland and Sopko, 1990). A field application of the technology was used on the Cross Town 8 Tunnel in Milwaukee, Wisconsin. Figure 3 illustrates the CT-8 frozen structures that are a series of four circular or elliptical cofferdams joined tangentially.

To construct the drop shaft and ancillary structures it was necessary to mine rectangular openings between adjacent ellipses. These openings created tensile stresses which could not be supported with frozen earth only, hence the need for steel reinforcing members on each side of the opening as shown in Figure 4.

Reinforced frozen earth was used





Left: Figure 4a (left), Buttress section; and 4b (below), Steel reinforcement

"As the face of the frozen soil is excavated, it is necessary to insulate the exposed earth"

again on the North Shore 10 project in Milwaukee in 1988. NS-10 was similar in shape to CT-8. The technology was not used in the United States until 2006, once again in Milwaukee on the Harbor Siphons project.

In the cases of each of the three projects, the concept of tangential frozen earth cofferdams permitted the construction of elongated structures that without reinforcement would have to be constructed in a very large circular shaft. In all three cases, project site constraints prohibited a large single excavation.

The design of the reinforced frozen earth structures is more complex and described by Sopko (1990). In addition to the conventional frozen earth compression tests, tension tests and 'pullout' tests can be conducted. The tension tests are typically not needed since the tension strength is typically neglected. The 'pullout' tests are used to evaluate the strength of the frozen bond between the soil and steel reinforcing. Once the material properties are evaluated analysis can proceed using several different numerical solutions.

CURRENT APPLICATIONS

The previous work on reinforced frozen earth was a combination of laboratory testing, engineering analysis and field observation and measurement.

With the confirmation of the engineering, as well as the means and methods, there are two more advanced applications of reinforced frozen earth currently being proposed on tunneling projects on the East Coast.

FROZEN SOIL LAGGING

Frozen soil lagging is an approach where conventional soldier piles are drilled and installed, in the same method as used on wooden lagging systems. The only difference is that a pipe sleeve is welded onto the steel beam to allow the drilling of a freeze pipe through the sleeve deep into an impermeable subsurface stratum as shown in Figure 5.

The wood lagging is replaced by a series of two to four freeze pipes arranged in small compression arches as shown in Figure 6. Each of these small arches reacts against the soldier pile that is braced across the excavation. Using this approach the frozen soil is kept entirely in compression. The advantage of this system is that the frozen soil, unlike wooden lagging provides an impermeable barrier, eliminating the need for any dewatering.

As the face of the frozen soil is excavated, it is necessary to insulate the exposed frozen earth. Typically, a layer of five to ten centimeters of polyurethane insulation is sprayed on a mesh fabric installed on the face of the frozen soil. Unlike the conventional soldier pile and wood lagging system, frozen soil is subject to long-term creep deformation. Attention must be paid to the concentrated stress zone where each individual arch reacts against the soldier piles.

Frozen soil laboratory tests must be conducted to evaluate the creep susceptibility of the particular soil. Research has shown however, that creep deformation can be reduced significantly when the temperatures are lowered. The average design temperature for frozen earth structures is typically -10oC. The purpose of the sleeve and freeze pipe at each pile is to keep the pile temperature as cold as possible.

The circulating calcium chloride brine is -25°C or colder. Creep deformations are substantially reduced at this temperature.

REINFORCED FROZEN WALL

Another proposed application of reinforced frozen earth is a straight, reinforced wall. Similar to the theory behind reinforce concrete, a straight frozen earth wall is installed as shown in Figure 7.

As previously explained, frozen earth has very little or no tensile strength. For this reason, cantilevered, straight walls are not practical, as they cannot support deep excavations. The purpose of the steel reinforcing is to act just like the reinforcing steel in a concrete beam.

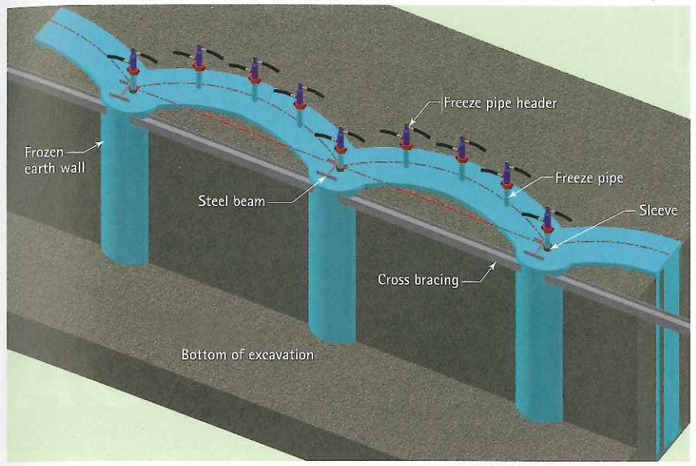
As with the frozen soil lagging, a sleeve is welded to a steel beam prior to installing the beam into the ground. The beam is off set from the line of freeze pipes forming the impermeable barrier as illustrated.

The frozen earth wall acts essentially as a cantilever structure, with tensile stresses developing on the side of the frozen wall opposite the excavation. The steel beam relying on the ad-freeze bond against the soil acts at a reinforcing element and provides the necessary tensile strength of the frozen wall.

As with the frozen lagging concept, installing the freeze pipe within the beam results in a very cold contact surface, significantly increasing the ad-freeze bond.

SUMMARY

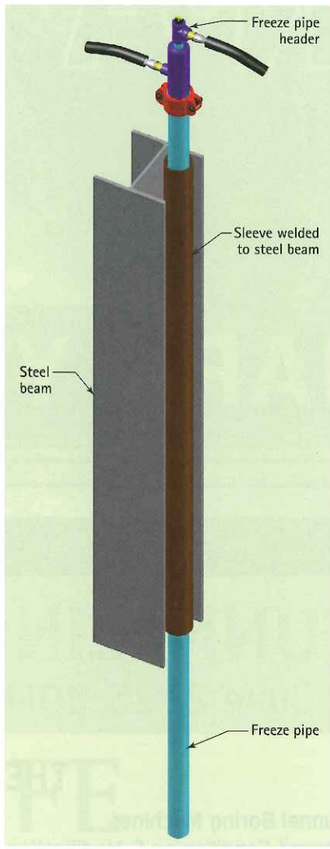
The application of the Michigan State University research to the project in Milwaukee, including the recent Harbor Siphons Tunnel permitted the construction of frozen earth structures at locations that otherwise could not be completed due to project site constraints.

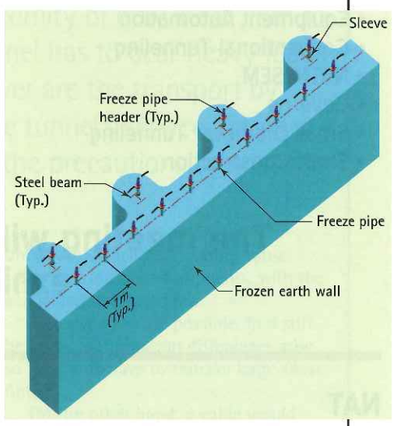


Above: Figure 6, Compression arches

Right: Figure 5, Frozen soil lagging

Right, below: Figure 7, Reinforced frozen wall





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The measured field performance confirmed the design techniques required for reinforced frozen earth. The success of these projects has enabled Moretrench to move forward with this technology on upcoming projects in Washington, D.C, and other locations on the East Coast

The crossing

SERVICE FOR LIFE

The Second Coen Tunnel has been constructed in a close proximity of only 10 to 15m to the east of the existing Coen Tunnel. This immersed tube tunnel has to bear heavy loads during the service life. The governing design scenarios however are the transport by sea and the impact of a sunken ship. This article goes into the tunnel's service life, and covers the structural behaviour of the immersed tunnel and the precautions against fire

IN ADDITION to the transport situation, the service life also imposed requirements on the design of the Second Coen Tunnel. In this phase, the tunnel lies on an elastic support. The tunnel is loaded by soil and water and is also exposed to physical working environment risks during operation such as a dropped anchor or a sunken ship.

BEAM ACTION

As explained in the previous article (see *Tunnels International*, November 2013, pp.22-26), due to the weak foundation applied with the sand-flow method, the tunnel will not be evenly supported over its whole length.

Besides this, the profile of the canal bed, banks and dykes will cause irregular permanent loadings, while under a heavily-sailed route like the North Sea Canal, account also has to be taken of the local loading of a sunken ship.

If the tunnel is considered as a beam on the canal bed, the uneven loadings and bedding cause transverse forces and moments, with the associated deformations.

Two extremes are possible. In a stiff beam, no deformation differences arise, so the joints have to transfer large shear forces.

On the other hand, a cable would be essentially stress-free, at the cost of

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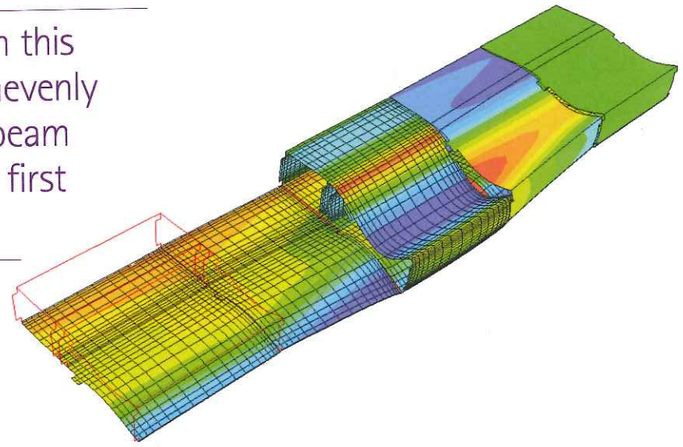
"The force distribution in this elastically supported, unevenly loaded and subdivided beam is more complex than it first appears"



Above: Model calculating the effects of a sunken ship

major deformations. Reality, as always, lies in between.

When the existing Coen Tunnel had been built, it was opted to build an intermediate solution of the stiffer type: tunnel elements with a length of 90m without dilatation joints; so the majority of the deformations have to be taken up in the immersion joints between the elements.

In the Second Coen Tunnel, a flexible compromise was chosen: long tunnel elements, each one being divided into seven sections.

In this solution, both the immersion and segment joints serve as expansion joints.

The force distribution in this elastically supported, unevenly loaded and subdivided beam is more complex than it first appears.

The force distribution proves for example to be affected by temperature variations in the tunnel, even though these variations in the closed tunnel section are only small compared with, for example, the open approaches.

Besides the vertical bedding, account must also be taken of a longitudinal interaction (friction), and proper account has to be taken of the non-linear stiffness of the rubber seals in the immersion joints (GINA gaskets). In order to calculate and understand the longitudinal behaviour of the tunnel, a special beam action model has been used.

In this model, the segments are modelled independently as elastically supported beams.

Traditionally, a tunnel would have been considered as a chain of hinge-jointed shackles (the chain model). In reality, the segments touch each other either at the upper or the lower edge.

In the beam action model, the longitudinal segment interaction was therefore modelled eccentrically, with a very stiff no-tension-connection (the block model).

Furthermore, in the segment joints only transverse forces can be transferred. Also in the immersion joints, the eccentric contact was taken into account; the force transfer in the longitudinal direction was based on the non-linear compression stiffness of the GINA gasket.

This modelling with eccentricities is particularly necessary to determine the effect of temperature variation correctly. When, for example, a chain of hinged rods would have been used, with a local subsidence due to e.g. a weaker support or a concentrated soil load, then at that point a small negative eccentricity would be present.

An increase in the normal force due to a rising temperature would then have led to an increase in vertical displacements, larger support reactions and thus to lower transverse forces and moments.

In reality, the longitudinal contact in the segment joint at the position of the greater subsidence takes place at the upper edge: a large positive eccentricity.

An increase in the normal force will then lift the tunnel segments, with lower support reactions and a larger shear force as a result.

This realistic modelling led to the discovery that the transverse forces and moments in the tunnel depend strongly on the temperature in the tunnel. Compared with the usual chain model, the block model used here is a better representation of reality.

To prevent differential deformations between the individual segments, both the segment and immersion joints were implemented as a hinge: rotation is more or less freely possible, but (vertical) transverse forces are transferred directly by shear keys in the walls.

Project details

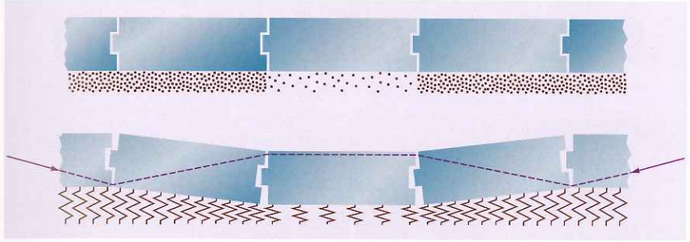
Project: Capaciteitsuitbreiding Coentunnel
Client: Rijkswaterstaat
Private partners: Design, build, maintain and finance in the context of a public-private partnership (DBFM contract) by Coentunnel Company: consortium of ARCADIS, Besix, CFE, Dredging International, Dura Vermeer, TBI Bouw and Vinci Grands Projects
Construction: Coentunnel Construction, a conglomerate of the construction companies Besix, CFE, Dredging International, Dura Vermeer, TBI Bouw, Vinci Construction and Croon Electrotechniek.
Handover: The realisation of the Second Coen Tunnel started in 2008. The tunnel elements were immersed in the spring of 2011. The tunnel was opened for traffic in May 2013. Renovation work on the existing Coen Tunnel until summer 2014.

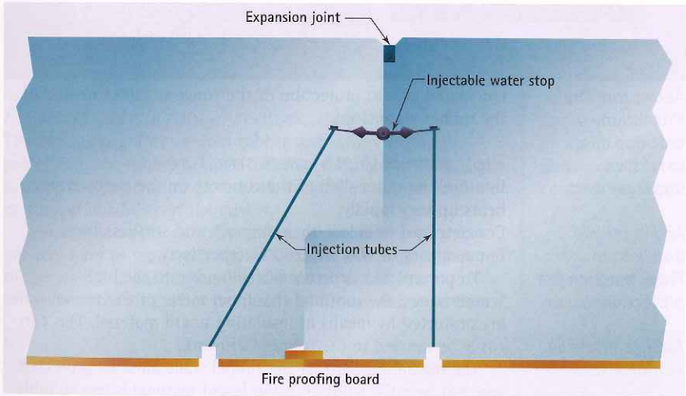
Sand flow method

For the Dutch immersed tunnels roughly speaking three foundation types have been used: gravel beds, pile foundations and sand flow foundations.

In the sand flow method, a sand water mixture (slurry) is jetted below the tunnel, to fill the gap between the tunnel element and the bottom of the immersion trench. It is a meticulous process, in which the mixture saturation and the flow rate are important parameters for the final quality of the foundation. As the tunnel elements have only a small net weight, a relatively weak foundation is sufficient. However: this type of foundation is quite sensible for vibrations because of the possibility of liquefaction and compaction.

150
The loading in kN/m² that the client requires be taken into account when considering sunken ship risks





The horizontal movements are restrained as well, by shear keys in the roof and floor. Particularly in the case of a sunken ship, these shear keys will have to transfer enormous shear forces.

Above, top: Diagram deomstrating beam action

Above, bottom: Fire protection, the traditional solution

SUNKEN SHIPS

With regard of the intensive shipping on the North Sea Canal, the tunnel had to be designed to take the loading of a sunken ship.

The client (Rijkswaterstaat, RWS) prescribes in its Guidelines for the Design of Concrete Structures that a loading of 150kN/m² must be taken into account for sea-going vessels and 50kN/m² for inland waterway vessels (including dynamic behaviour), and also that these loads should be verified by means of a risk analysis.

The loading of a sunken ship affected the design of the concrete structure in various ways:

- The loading must be borne by the roof (roof reinforcement);
- The loading is transferred to adjacent segments by the shear keys (shear key reinforcement) to an certain extent – depending on the stiffness of the support;
- The shear key forces lead to a greater support reaction under the adjacent segments (floor reinforcement);
- The transverse force is taken up in the walls in both the loaded and the adjacent segments (wall reinforcement).

Design for loads like these is a combination of risk analysis and force distribution.

The aforementioned effects are greatest if a ship sinks directly next to an expansion joint. The longer the segments, the smaller the probability that a ship sinks directly next to a joint, but the greater are the forces if it happens.

Probability and risk

As prescribed by RWS, the loading was verified by means of a risk analysis. To determine the governing ship size, we used an inventory of all sea-going vessels that passed the Coen Tunnel in one year.

Based on these ships' characteristics (dimensions, tonnage, type of vessel), we determined for each ship the probability that the ship would sink on to the Coen Tunnel, the loading depending on the position in length and width direction and the probability distribution of this loading.

In this way, a cumulative probability distribution of the loading on the tunnel was determined, and for a probability of failure of 1×10^{-6} per year a representative ship and its associated loading could be determined.

This loading turned out to be only a little lower than the value prescribed by RWS, so it was decided to use the RWS value.

The structural behaviour of the tunnel loaded by a sunken ship was calculated by means of a DIANA calculation, which provided insight into the distribution of the shear key forces over the four walls, the increased support reaction and the associated transverse forces.

SHEAR KEYS

It was stated earlier that the joints have been provided with shear keys to transfer transverse forces and to prevent differential deformations. The shear keys were designed for the structural

behaviour as a result of the uneven loading on the tunnel and the unequal stiffness of the support.

If the forces due to a sunken ship had to be transferred entirely by the teeth, the teeth would have to be extremely strong; twice as strong as was required for the other design scenarios.

To avoid this, it was decided to provide the joints additional deformation capacity for this kind of emergency loading, by allowing the teeth to fail in a controlled way.

The waterstops have been designed to take these large deformations. In this way the tunnel still meets the requirements set out regarding accidental loads, but by means of an economic solution.

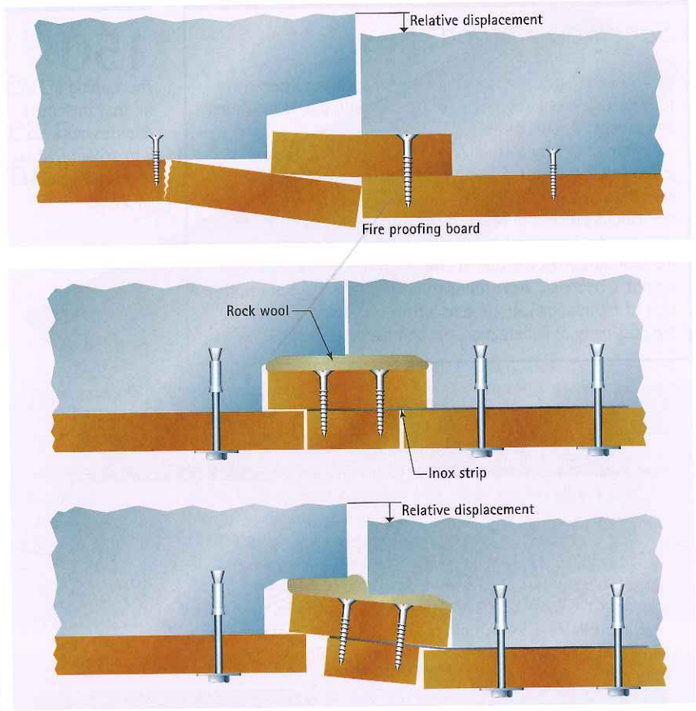
Still the teeth turned out to be the most heavily reinforced parts of the immersion elements.

Fire resistance for the completed tunnel structure

Another extreme situation is fire. The tunnel must resist the extreme temperatures that can arise during a hydrocarbon fire.

The temperature development inside the tunnel is defined in the RWS temperature curve, in which the temperature in the tunnel reaches 1350°C within one hour.

Two aspects of fire resistance are elucidated below: protection of the concrete structure and of the rubber waterstops.



Above, top: Fire Protection - cracking due to relative displacements

Above, middle and bottom: Flexible action fire protection

Top left: Shear key reinforcement

"Due to the great transverse forces in the Second Coen Tunnel, the design opted for teeth in the walls, floor and roof rather than the traditional solution with a circumferential shear key connection"

Protection of the concrete structure

In a fire, the outer shell of the concrete on the exposed side heats up very rapidly.
Concrete and steel lose their strength and stiffness from temperatures of 400 and 250°C respectively.

To prevent the structure of failing due to the high temperatures, the roof and the upper metre of the tunnel walls are protected by means of insulating board material. This can easily be applied to the tunnel formwork.

The remaining parts of the tunnel walls must be protected too, but here the solution using board material is less suitable from the point of view of construction.

Due to the positive experiences with another, previous tunnel project, the team decided to apply a large concrete cover to protect the structural concrete.

For the walls, a limestone concrete mixture was used, with a cover of 100mm on the reinforcement.

After two hours of fire according to the RWS temperature curve the critical concrete temperature of 380°C has reached a depth of approximately 70mm, leaving some 30mm of undeteriorated concrete around the reinforcement.

In the structural calculations undertaken, the concrete cross-section had to be reduced in order to take account of the effect of the degraded concrete on the strength of the cross section. After a fire, the degraded concrete layer must be removed and repaired.

To prevent spalling of the cover, polypropylene fibres were added to the concrete mixture - fire tests have proved that this mixture indeed prevents spalling.

Above: Aerial photgraph of Barendrecht construction dock

Protection of the rubber seal sections

The expansion joints contain rubber waterstops. Without protection, the rubber temperature may rise rapidly when a gap is present. Temperature damage to the gaskets may cause leaks or a lower reliability of the gasket.

In contrast to the concrete surface, the rubber sections are very hard to repair as they are situated in the outer part of the wall. The client therefore demanded a maximum tempreature of 80°C after two hours of fire according to the RWS temperature curve. Traditionally, this type of joints is protected with a double layer of fire protecting board. The disadvantage of this relatively simple method is that the board material can break with differential displacements perpendicularly to the plane of the sheet material.

Below: Sand flow 'pancakes'

Due to the great transverse forces in the Second Coen Tunnel, the design opted for teeth in the walls, roof and floor, rather than the traditional solution with a circumferential shear key connection.

Differential displacements in the plane of the walls are thus avoided, but displacements perpendicular to the plane can happen more or less freely, for example because of uneven loadings or an inhomogeneous support stiffness.

For the Second Coen Tunnel, a flexible joint detail was therefore designed, enabling differential displacements in all directions without actually damaging the cladding itself.

COMPLETION AND ONGOING RENOVATION

In the meantime, the Second Coen Tunnel has been opened for traffic and the renovation the First Coen Tunnel is in progress

CUTTING FOR STONE

Josh Bradley and **Clare Onal** of Mott MacDonald set out the rock classification systems commonly used to inform tunnelling projects in this back to basics article

Clare Onal
Clare is a chartered civil engineer who has worked on numerous international projects, specialising in underground works, engineering geology and rock mechanics.

Josh Bradley
Josh is an engineering geologist with experience gained on-site and in the office on rock tunnelling projects both in the UK and overseas.

TODAY THERE are three main rock classification systems commonly in use which were developed from the mid to end of the 20th Century. All aim to provide engineers and geologists with a quantitative and comparable way of describing the variable rock with which they are working.

The behaviour of rock in response to tunnel construction is determined by both the properties of the intact rock and the properties of the rock mass as a whole. Other factors such as in situ stress and groundwater also have a significant impact.

Properties of intact rock are determined by the materials from which it is composed and the manner in which they are bonded together. The uniaxial compressive strength and the young's modulus of the intact rock are important, especially in weathered or heavily altered rock or in massive rock where the intact rock is the governing feature rather than the discontinuities.

Laboratory testing on samples of intact rock is usually relatively simple and inexpensive, so there is a wealth of information available on the properties of intact rock. However, such testing can be misleading. The chief issue is that samples of highly weathered or disturbed rock may not be available in the required intact volume for testing, so tests tend to focus on good samples of intact, competent rock, which are more easily collected in the field.

Tunnel stability is often dominated by the structural properties of the rock mass – the way in which blocks of intact material behave along with discontinuities such as faults, joints and bedding planes. The properties of a rock mass are difficult to test due to scale effects. Therefore, it is crucial to understand and quantify discontinuity properties such as aperture, undulation, roughness, weathering and infilling.

Unfortunately for the engineer, rock masses are rarely homogenous, continuous or isotropic. A classification system is therefore required to take account of the inherent variability.

Below: Getting up close to the Hindhead Tunnel face. This allowed detailed face logging and RMR assessment when required

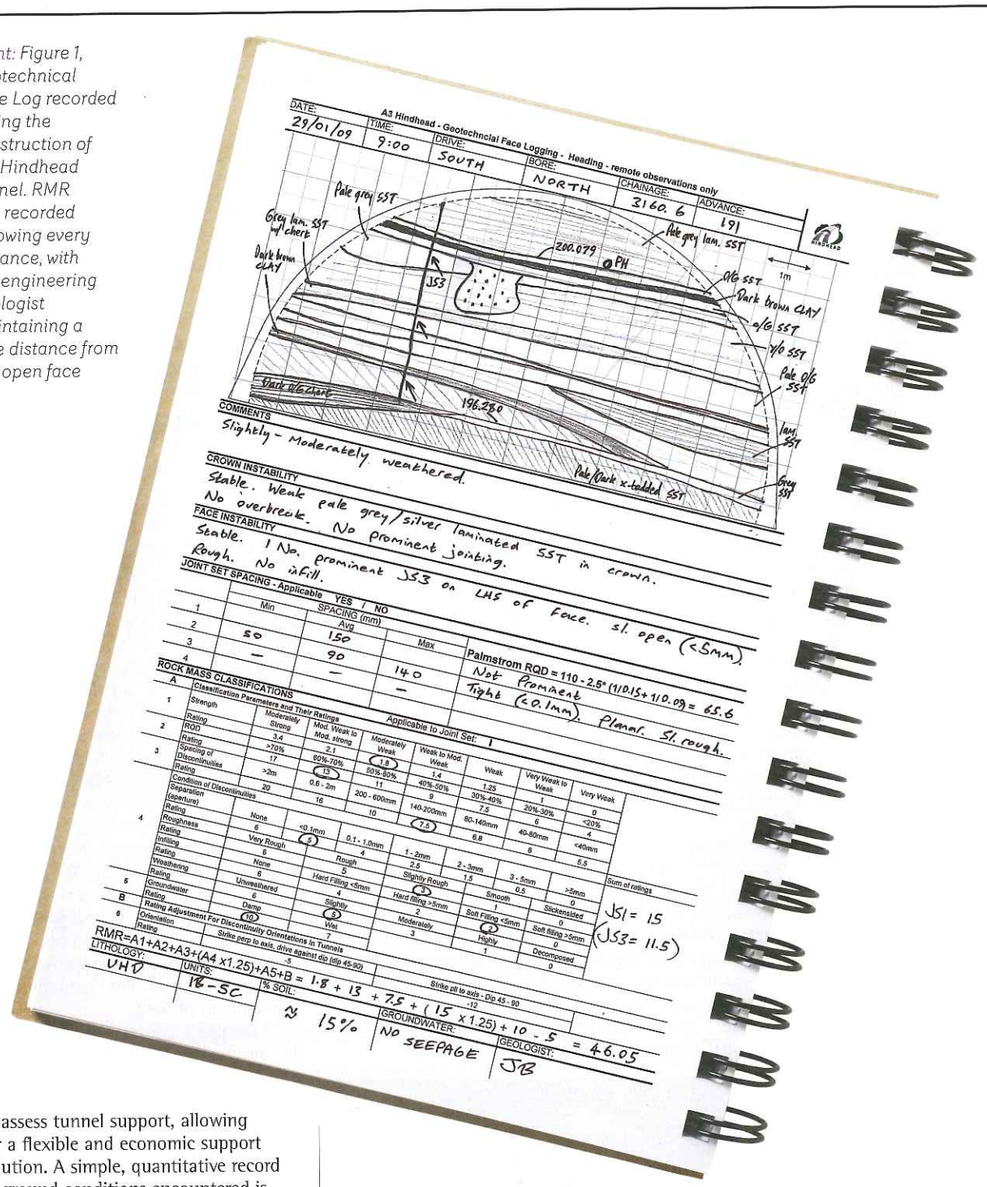
APPLICATION OF ROCK CLASSIFICATIONS THROUGH THE PROJECT CYCLE

In the preliminary or feasibility stages of a project, little information on the characteristics of the rock mass is typically known. However, use of a quantifiable rock classification that is familiar to both engineers and geologists can provide important early insights into tunnelling method, tunnel shape, maximum size and stand-up time. Additionally, it can provide initial estimates of rock support and deformation characteristics. The classification, although based on information gathered from the field, is necessarily empirical and based on a large amount of data.

At the design stages, the rock mass classification can be developed as more information becomes available. Zones of material with similar geomechanical characteristics can be identified and grouped. Parameters such as in situ rock mass strength and modulus of elasticity can be estimated. Empirical estimates of support are then improved and used in conjunction with more complex methods of analysis to better understand tunnel deformation and stability within the different ground classes along the alignment.

Engineers can then develop a flexible design comprising a number of support classes to take into account the full range of ground conditions likely to be encountered.

During construction, real-time classification at the excavation face can allow engineers to continually



Right: Figure 1, Geotechnical Face Log recorded during the construction of the Hindhead Tunnel. RMR was recorded following every advance, with the engineering geologist maintaining a safe distance from the open face

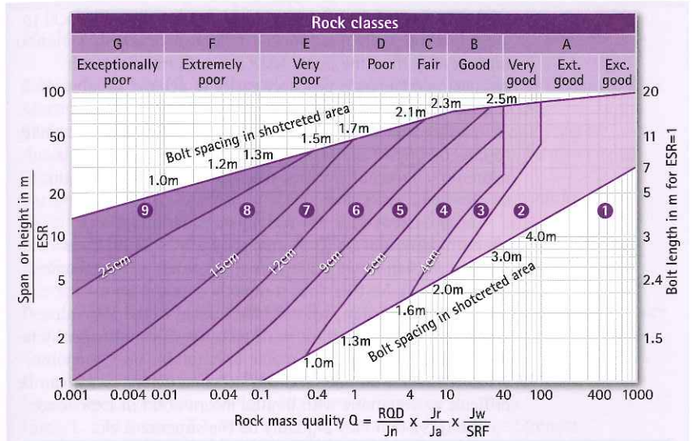
re-assess tunnel support, allowing for a flexible and economic support solution. A simple, quantitative record of ground conditions encountered is also obtained. This is often important in the development or improvement of construction techniques and is widely used in the settling of contractual debates.

THE DEVELOPMENT OF ROCK CLASSIFICATION SYSTEMS

The use of rock classification systems has always been closely linked to advances in tunnel construction. Schemes attempting to formalise empirical relationships in tunnel design were first developed as early as 1879.

The first descriptive characterisation of ground conditions appeared in 1942 and was developed following experiences in steel arch tunnelling through the Alps. In 1946, Karl Terzaghi became the first to publish a simple rock classification system applied to an engineering environment. He understood the importance of the type and intensity of rock discontinuities over and above the rock type. Terzaghi's system was widely used, but its lack of a truly measurable classification, along with developments in modern tunnelling methods, led to the development of the systems more commonly in use today.

Classifications involving stand up time began to develop in the late 1950s, leading to the New Austrian Tunnelling Method (NATM).



Above: Figure 2, Permanent support recommendation based on Q and NMT (Grimstad and Barton, 1993)

Rock mechanics at this time was cutting edge; standardisation of tunnel support was uncommon and tunnelling was subsequently dangerous. The first quantitative schemes to incorporate the engineering geological character of the ground were developed in 1972 and have been developing ever since.

A variety of rock tunnelling projects today still commonly use classification systems such as Bieniawski's Rock Mass Rating, first developed in 1972 and the Q-System developed by Barton et al. in 1974. Although also developed for slopes, rock mass classification systems are primarily designed to be used in underground excavations where the excavation face can be viewed and mapped – for example drill and blast, roadheader or mechanical excavation methods.

The three classification systems most widely used today are Rock Mass Rating (RMR), the Q-System and the Geological Strength Index (GSI).

ROCK MASS RATING

Bieniawski developed his RMR system, also known as Geomechanics Classification, in 1972 and its latest revision was published in 1989.

The system requires an assessment of six parameters; the intact rock material's strength, rock quality designation (RQD), discontinuity spacing, discontinuity condition, groundwater condition and discontinuity orientation relative to the excavation.

Rock strength assessment is ideally based on uniaxial compressive strength testing, but there are certain circumstances which require it to be correlated from point load testing or based on field descriptions.

RQD in itself is a rock classification system, published by Don Deere in 1967, which modifies the core recovery percentage by only measuring sound pieces of core that are ≥100mm in length. Although designed to be taken from rock cores, RQD can also be estimated from outcrops or excavation faces. The other required parameters can be based on a combination of field observations and measurements from mapping and borehole drilling – ideally a combination of both.

> "Unfortunately for engineers, rock masses are rarely homogenous, continuous or isotropic"

The six parameters are each given a rating, which is added together to give the final classification value. The output of RMR classification is a value between 0 (very poor rock) and 100 (very good rock), immediately providing the engineer or geologist with a sense of the relative quality of the rock mass.

The RMR can then be used to provide basic guidelines for tunnel advance length and support quantities based on a 10m span – there is no consideration of the end use of the tunnel. RMR can also be converted into a GSI rating and could provide an estimate rock mass strength and modulus of elasticity (Hoek and Brown, 1997).

RMR can provide an indication of the most suitable tunnel shape and insight into the support capabilities of the shotcrete – for example, whether or not a shotcrete layer can be expected to act as an arch, or just lock together adjacent blocks (Lowson and Bieniawski, 2013).

However, RMR does not consider in situ stress, which can be very important in deep excavations where squeezing ground or rock bursting may be a problem. The number of joint sets is also not explicitly considered and this parameter can be very influential on tunnel stability. Additionally, although RQD is a major parameter, it can be difficult to determine at the tunnel face as it was designed to be measured from drill cores.

On the whole, RMR may be more useful in weaker rock, where methods of support such as spiling, dowels, steel arches or canopy tubes are used. The RMR system was very effective during the construction of the Hindhead Tunnel and a typical classification of the tunnel face is shown in Figure 1, opposite page.

Q-SYSTEM

The Rock Tunnelling Quality Index, or Q-System of rock mass classification, was developed by Barton, Lien and Lunde in 1974 and is also based on assessments of six parameters – although slightly different to those used for RMR. The six parameters are; RQD, joint set number (Jn), joint roughness number (Jr), joint alteration number (Ja),

joint water reduction number (Jw), and stress reduction factor (SRF).

The first four parameters are similar to that of the RMR system. RQD and joint set number give an indication of block size, while joint roughness and joint alteration show the frictional characteristics and shear strength of the joint walls. Essentially, larger, rougher blocks are likely to be more favourable in terms of tunnel stability than smooth, clay infilled joints as the latter will have reduced rock wall contact between blocks. Joint water reduction is a measure of water pressure and groundwater inflow, while SRF is an empirical way of considering the influence of shear zones and rock stress problems in both competent and incompetent rock.The parameters are again given a rating, although RQD is used directly, and they are multiplied to give the classification value.

The Q-System was developed directly with the now widely accepted Norwegian Method of Tunnelling (NMT) support principle, which currently uses steel fibre reinforced shotcrete and fully grouted rock bolts as permanent support.

Empirical assessment of support quantities, taking into account both the span and the end use of the excavation, can be made using the chart shown in Figure 2. By varying the excavation support value, the Q-System considers a range of final uses; from temporary mine openings or water tunnels in hydropower schemes – which are unlikely to see significant access post-construction – to underground nuclear power stations or public railway stations where absolute and continuous stability is required.

Grimstad and Barton (1994) and Barton (2013) state that the large range of Q values possible – from 0.001 (exceptionally poor rock) to 1000 (exceptionally good rock) – reflects rock quality variation more readily than the linear RMR scale. Correlation with physical parameters is probably easier to achieve because of this.

Another important application of the Q-System is its ability to directly predict effective rock mass strength and depth-related phenomenon such as strain bursting, rock slabbing, swelling and squeezing.

The Q-System does not directly consider intact rock strength, although Qc (Q normalised by UCS / 100) does provide an even larger scale over eight orders of magnitude (Barton 2013). Neither does it directly consider joint orientation; it is only indirectly considered in the SRF value and is especially important in tunnels which cannot usually be designed for the most favourable orientation. Also, the joint water reduction number and the stress reduction factor can be difficult to determine with limited information or experience.

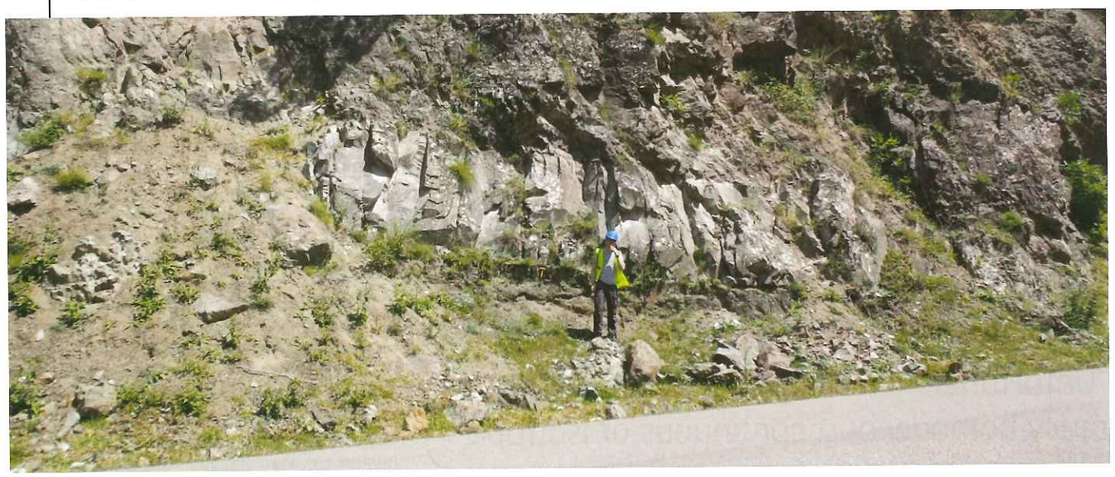
The Q-System may arguably be the superior rock classification system in deep tunnels and in cases of faulted or jointed and clay-bearing rock masses that give marked overbreak during excavation, due to the SRF parameter. The typically rough, irregular surface left by drill and blast excavation in this type of rock is suited to the application of fibre reinforced shotcrete and bolts. Application of the Q-System works best for $0.1<Q<40$ and for tunnels with spans between 2.5m and 30m (Palmstrom and Broch, 2006).

In weaker rock, the Q-System and fibre reinforced shotcrete and are less appropriate. It is also less applicable in TBM tunnelling, although it should not be discounted. Open, hard rock TBMs with bolting and shotcreting facilities behind the drill head mean that use of the Q-System may be relevant.

GEOLOGICAL STRENGTH INDEX

Rather than being a classification system for use during the tender and construction stages for aiding the determination of support requirements, the GSI was developed to link the parameters of the Hoek-Brown failure criterion with conditions that can be observed in the field. This provides an estimation of rock mass properties that can be used in design.

GSI can be estimated directly by combining the surface condition of the discontinuities with the structure of the rock mass. It can also be based on RMR ratings, as shown by Hoek and Brown in 1997, and therefore is closely linked with the RMR classification system.



Below: Undertaking Q-System assessments of jointed surface outcrops to aid in tunnel design on a hydropower project in Shuakhevi, Georgia.

CONCLUSION

The systems discussed are not the only options available. Variations of each system exist, such as slope mass rating, mining rock mass rating and QC. An additional system such, as rock structure rating or rock mass index may be relevant for specific projects. However, the wealth of case studies upon which the better known systems are based lends credibility. These systems are empirical, after all. Nothing beats years of first-hand experience, but for those who have not been around long enough to gain this knowledge, rock classification systems can be an essential tool in leveraging the experience of others.

The advantages of one system over another are not necessarily restricted to specific projects. A large tunnelling project will likely benefit from the use of multiple systems. Combined use of both the RMR and Q-System is often recommended, and there are benefits to this double approach. The number of joint sets and rock stress are absent from RMR, while rock strength is not directly considered by the Q-System. Recording the input parameters of both systems ensures that potentially important properties are not missed. Recording details of the individual input parameters, rather than simply assigning a value, also allows better understanding and verification of the final values – as well as providing the flexibility to take into account additional investigation at a later date. Every year there are more tunnel case studies using both systems, increasing understanding.

A practical example of how a project can benefit from the combined use may involve the Q-System being used to establish an initial estimate of support quantities at feasibility stage, with RMR/GSI being used at a later stage as an input into finite element modelling. Finally, the Q-System can be used again during construction to record ground conditions and determine the required installation of flexible support classes.

For such an approach to be successful, sufficient information must be obtained during the early stages of a project to ensure neither system is restricted should it be required at a later stage. This, together with the variety of data sources available – from field observation of outcrops, to borehole logs and laboratory testing – highlights the importance of the tunnel designer being involved at an early stage in the process.

None of the classification systems are all-encompassing. Intact rock properties such as rock hardness, abrasiveness, durability and mineralogy are not covered, but may still be an important influence in finalising construction details and cost estimates. Similarly, separate seismic analysis is required in certain situations and modifications and further support analyses are required where squeezing ground is present.

Both Q and RMR rely on a fixed boundary system, where, despite the parameter assessments being largely estimated, a value falling close to the classification boundary may lead to perceived excess support being installed. It is possible that the way in which recommended support types are linked with rock mass classifications may be refined to deal with this in the future.

Advances in modelling software such as Phase2 by Rocscience mean that when the rock classifications – particularly RMR and GSI – are available it can be fast and cost-effective to confirm empirical support estimates using finite element stress analysis. However a robust classification system will remain essential, both as a starting point to the analysis and as a major input, as well as then being able to make use of the output in an effective way.

It is important to conclude with Bieniawski's own recommendation, along with similar warnings from Hoek and Terzaghi, that rock classification systems were never intended as an ultimate solution to design problems and should be used in conjunction with – and not as a replacement for – analytical studies, field observations, measurements and engineering judgement

"Rock classification systems were never intended as an ultimate solution"

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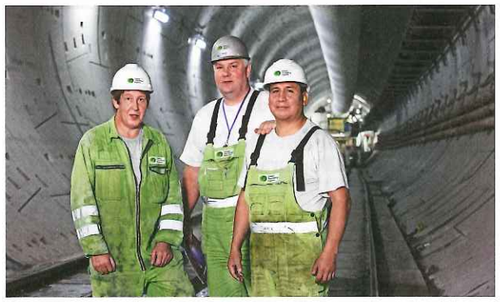

What's on

2014

Middle East Rail
4-5 February 2014
Dubai, UAE
With 82 exhibitors and attendance from nearly every regional rail operator in 2013, Middle East Rail conference and expo had more than 2,500 attendees. It's designed to help operators build and operate brand new rail infrastructure, as well as upgrading legacy networks. The event brings together developers, operators, contractors and suppliers to talk strategy, technology and innovation.
www.terrapinn.com/exhibition/middle-east-rail

CONEXPO
4-8 March 2014
Las Vegas, USA
Held every three years, the exposition showcases the latest construction equipment, products, services and technologies. The show will be held at the Las Vegas convention centre.
www.conexpoconagg.com

Eurasia Rail
6-8 March 2014
Istanbul, Turkey
The Fourth International Rolling Stock, Infrastructure and Logistics Exposition features a tunnel construction section.
www.eurasiarail.eu

ISTSS
12-14 March 2014
Marseille, France
The Sixth International Symposium on Tunnel Safety and Security in Marseille, France will discuss current best practice and emerging demands and trends as well as research.
www.istss.se

World Urban Forum Seven
5-11 April 2014
Medellin, Colombia
The show for the UN-Habitat organisation. The United Nations Human Settlements Programme, UN-HABITAT, is the United Nations agency for human settlements. It is mandated by the UN General Assembly to promote socially and environmentally sustainable towns and cities with the goal of providing adequate shelter for all.
www.unhabitat.org

Samoter
8-11 May 2014
Verona, Italy
This trade show dedicated to earth moving, site and construction machinery is held every three years. In 2011, the exhibition attracted 98,000 visitors and more than 900 exhibitors (of which almost 30 per cent were international).
www.samoter.it

World Tunnel Congress 2014
9-15 May 2014
Iguassu Falls, Brazil
Organised by the Brazilian Tunnelling Committee (CBT) of the ABMS (the Brazilian Association of Soil Mechanics and Geotechnical Engineering), as well as the International Tunnelling Association (ITA), and focusing on "Tunnels for Better Living", WTC 2014 will discuss and illustrate the importance of tunnels.
www.wtc2014.com.br

North American Tunneling Conference
22-25 June 2014
Los Angeles, California
The US Underground Construction Association (UCA)'s biennel tunnelling conferece takes place in Los Angeles, California in 2014.
www.smenet.org

InnoTrans
23-26 September 2014
Berlin, Germany
An international platform for buyers and sellers of passenger and freight transport technology, InnoTrans focuses on railway technology. The Tunnel Construction segment will be accompanied by International Tunnel Forum featuring a series of international discussions
www.innotrans.de

2015

World Tunnel Congress 2015
22-28 May 2015
Dubrovnik, Croatia
The jewel of the tunnelling calendar heads to the Dalmatian Coast for the technical event of 2015 as WTC returns to Europe. Details to be confirmed.
wtc2015.com

British Tunnelling Society

The BTS has a membership of almost 700 individual and 60 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. Events are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month.

Concrete & Materials Engineering and its role in underground construction
16 January 2014
This presentation will explain the fundamentals use of concrete in underground construction and highlight the demanding requirements involved with building tunnel linings. The requirements of the Client, Designer and Contractor will be discussed and examples of concrete engineering and development on projects will be illustrated. Charles Allen, CA Consult, Martin Rimes, MVB JV, and Richard Sutherden, AECOM.

The Use of explosives for New York East Side Access
20 February 2014
The presentation on the use of explosives through the hard granite of the East Side Access (ESA) project in New York will be given by Andy Thompson of consultancy firm Hatch Mott MacDonald.

High Speed Guangzhou-Shenzhen-Hong Kong Railway
20 March 2014
The Contract 824 tunnels will be formed through hard rock using drill and blast techniques over a distance of approximately 2.6km. The tunnel alignment runs beneath the natural terrain of Lam Tsuen Country Park between Ngau Tam Mei in the north and Tai Kong Po in the south. Permanent shafts (over 90m deep) at either end of Contact 824 for the Ngau Tam Mei Ventilation Building and the Tai Kong Po Emergency Access Point (EAP). The majority of the tunnels will be twin bore single track tunnels with an internal span of 7.8m. The scheme also includes a 110m long twin track Crossover Cavern, which will have a maximum internal span of 22m and a maximum internal height of 15m. Two bifurcations with maximum internal spans of 19m for a future spar line are also part of the contract. Speakers are yet to be confirmed by the British Tunnelling Society.

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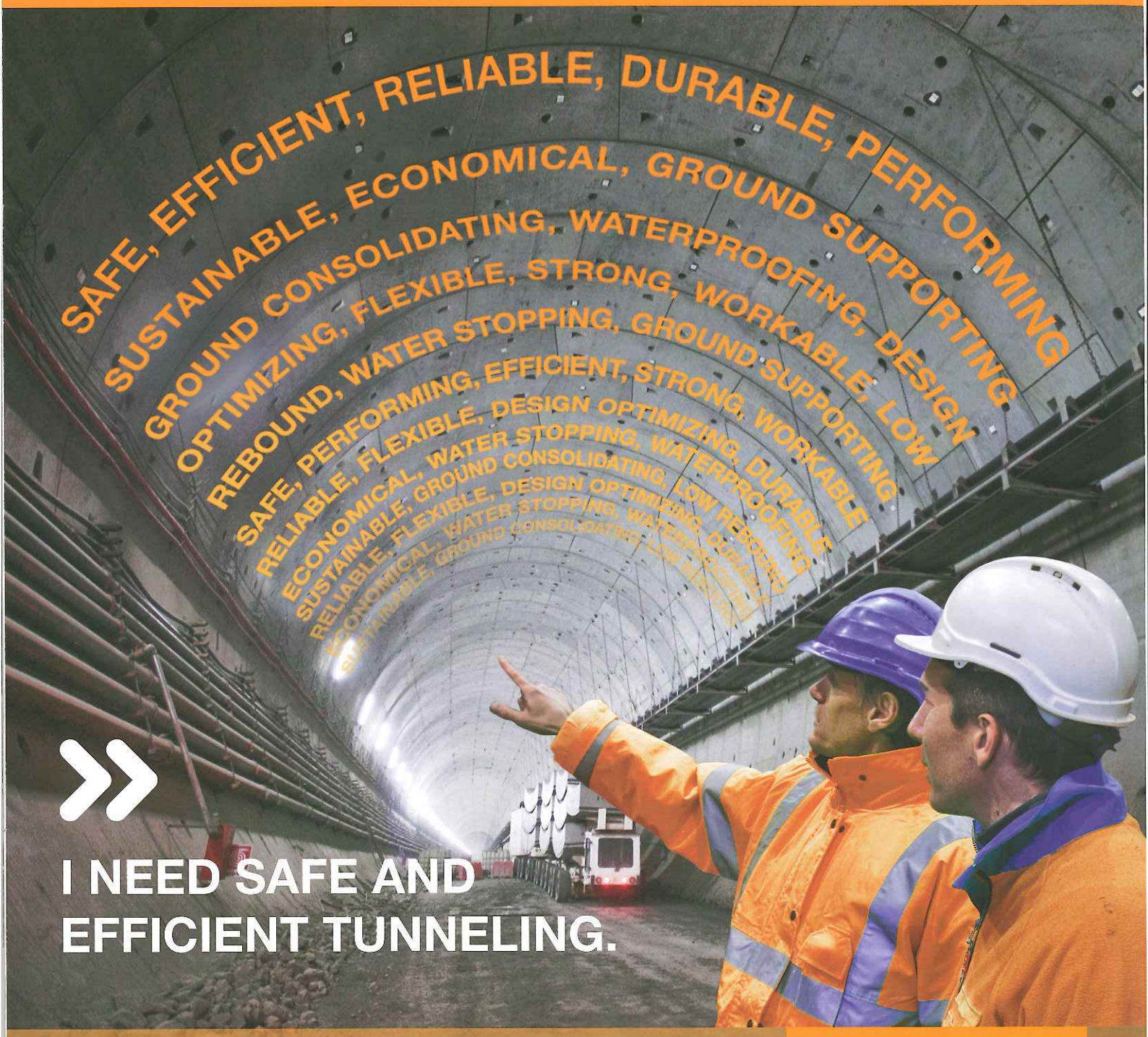

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