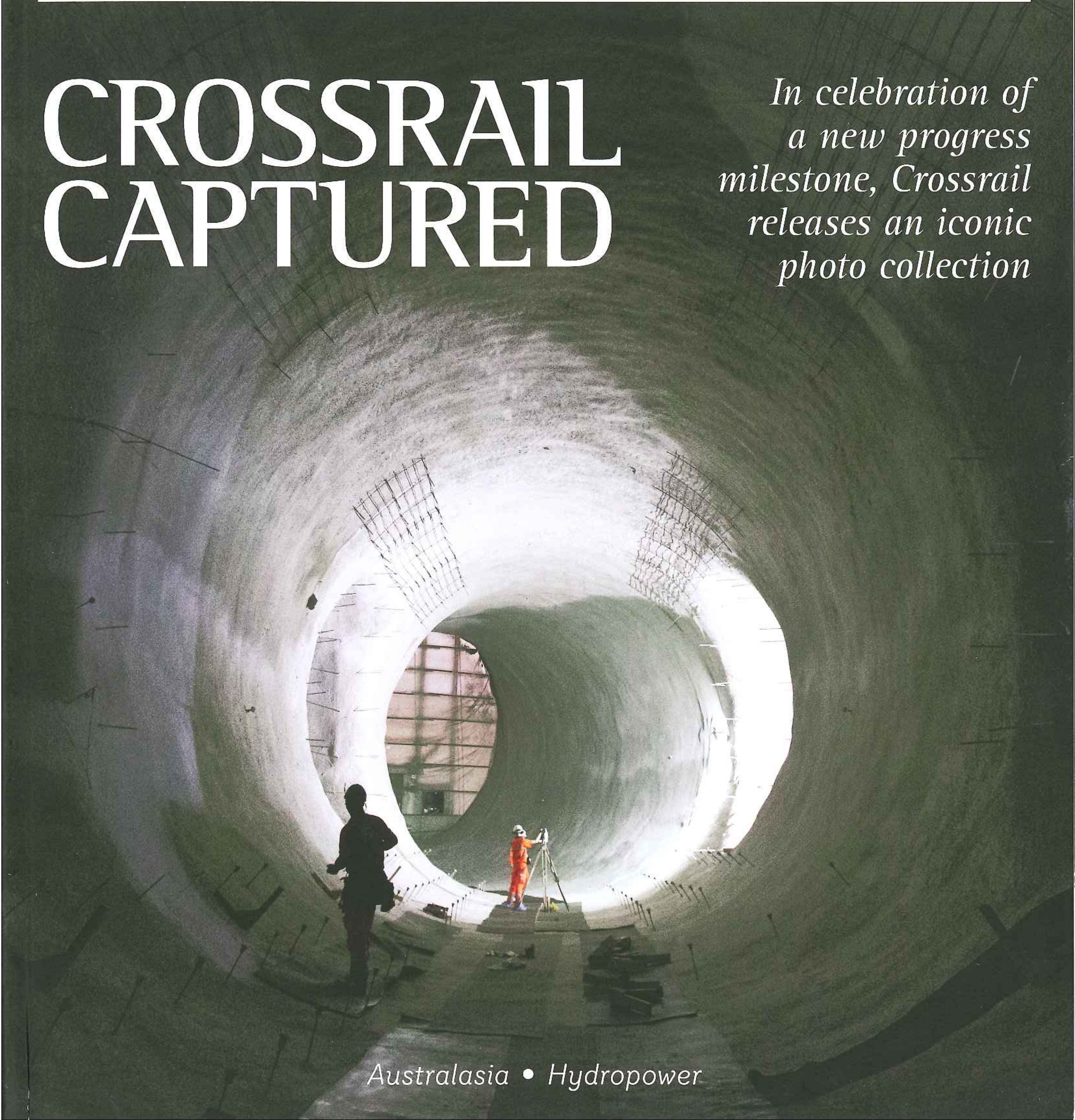
INTERNATIONAL EDITION
December 2014

Tunnels AND TUNNELLING

CROSSRAIL CAPTURED

In celebration of a new progress milestone, Crossrail releases an iconic photo collection



Australasia • Hydropower

OLD WINE FOR NEW WINE

POPE FRANCIS delivered a pep talk to the European Parliament last month. In it, he gently styled the continent as feeling haggard and elderly. No longer able to meet its challenges with vigour or vitality.

He identified what he sees as a "common disease", a "loneliness" created by lack of connection between people and (implicitly) the policy-making institutions. And then lamented the dominance of technical and economic questions in bureaucratic political debate "to the detriment of genuine concern for human beings".

Meanwhile European Union leadership seems to be losing faith in programmes of austerity, as the continent's levels of investment dry up and the economy grinds to a halt. The latest solution, and perhaps a boon to the construction industry, is a three-year venture called InvestEU, which aims to kick-start private sector infrastructure investment of over EUR 300bn (USD 373bn) with a modest "seed fund" of EUR 20bn from the public coffers. This seed money will be used to insure investment, and keep everything flowing if the project gets off to a rough start.

With the UK demanding no increase in the EU budget, Germany carefully eyeing EU debt, and France calling for a four-fold increase in the seed fund, the Pope's warnings on the nature of modern decision-making seem to emerge. The practical result of this division is a reallocation of, rather than requisition of funds. But this in itself presents an opportunity.

The European Investment Bank clings to its AAA credit rating, and is risk-averse because of this. A vice president in the European Commission likened InvestEU to a new EIB being created within the EIB, a more dynamic entity capable of taking bigger risks, and supposedly capable of attracting the as-yet unseen private capital. President of the European Commission Jean-Claude Juncker has enjoyed solid support in Strasbourg for this, his first big initiative. He announced that Christmas had come early for Europe, and that his projected investment would raise European investment to pre-crisis levels. Lofty hopes for a comparatively small amount of money, and a region seen as a dark cloud over the global economy. Hopefully the expected 15-fold return on this money in the form of private sector investment isn't a fabrication. But there's another factor to take into account. Detractors have had a lot of fun calling InvestEU "old wine in new bottles", arguing that it is just existing funding being allocated to a different sector. Some media has called attention to the earlier provision of extra money to banks in the mistaken hope that they would lend more and spur the economy. But investment in infrastructure has a key benefit that other stimulus plans simply lack: the physical infrastructure left behind after the money has been spent. Which is much harder to lose in the paperwork.

And if the EUR 1.3tn (USD 1.62tn) long-list of projects to be considered that has been leaked online is genuine, the demanded work is just waiting to get done. It will be satisfying if the money does become available, and we are able to take the Pope at his word, and literally build connections

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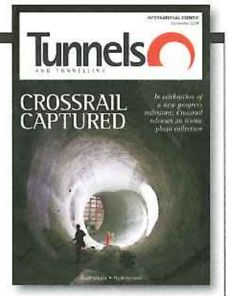
What do you think? Send your views to the editor and join the debate

Cover
The front cover displays one of the photos released by Crossrail to celebrate 60 per cent completion.



Next issue
In the next issue of Tunnels and Tunnelling International, our regional focus is on North America, with articles from the United States and Canada. Topics also covered include risk and insurance, with a guest article from AON, and logistics.

This month...

10 YEARS AGO

Despite early delays, Leighton Contractors (Northern), the Hong Kong-based subsidiary off Australia's largest construction firm is moving ahead on its USD 235M contract to build the Eagle's Nest road tunnel with joint venture partner Kumagai Gumi of Japan. A Highways Department spokesman said the project is slightly behind schedule after the contractors had to overcome poor ground conditions in one of the drives. A spokesman said that the ground was heavily faulted, and excavated using pipe piles and steel sets, but fortunately no water was present. The twin 2.1km, 18.5m-diameter tunnels have been excavated with drill and blast, and the finished tunnel will form part of the Route Eight Highway between Tsing Yi Island and Sha Tin.
Tunnels and Tunnelling, December 2004, p.6

30 YEARS AGO

The Government of Hong Kong has decided that a second fixed vehicular harbour crossing should be built providing a road tunnel of a minimum of four lanes (two in each direction) linking Quarry Bay on Hong Kong Island and Cha Kwo Ling on the mainland. Consortia have been invited to submit proposals for financing, constructing and operating this Eastern Harbour Crossing. While there is a good deal of freedom to suggest variations, Edward Youde, the governor of Hong Kong suggested the best solution would be a submerged tube tunnel.
Tunnels and Tunnelling, December 1984, p.7

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

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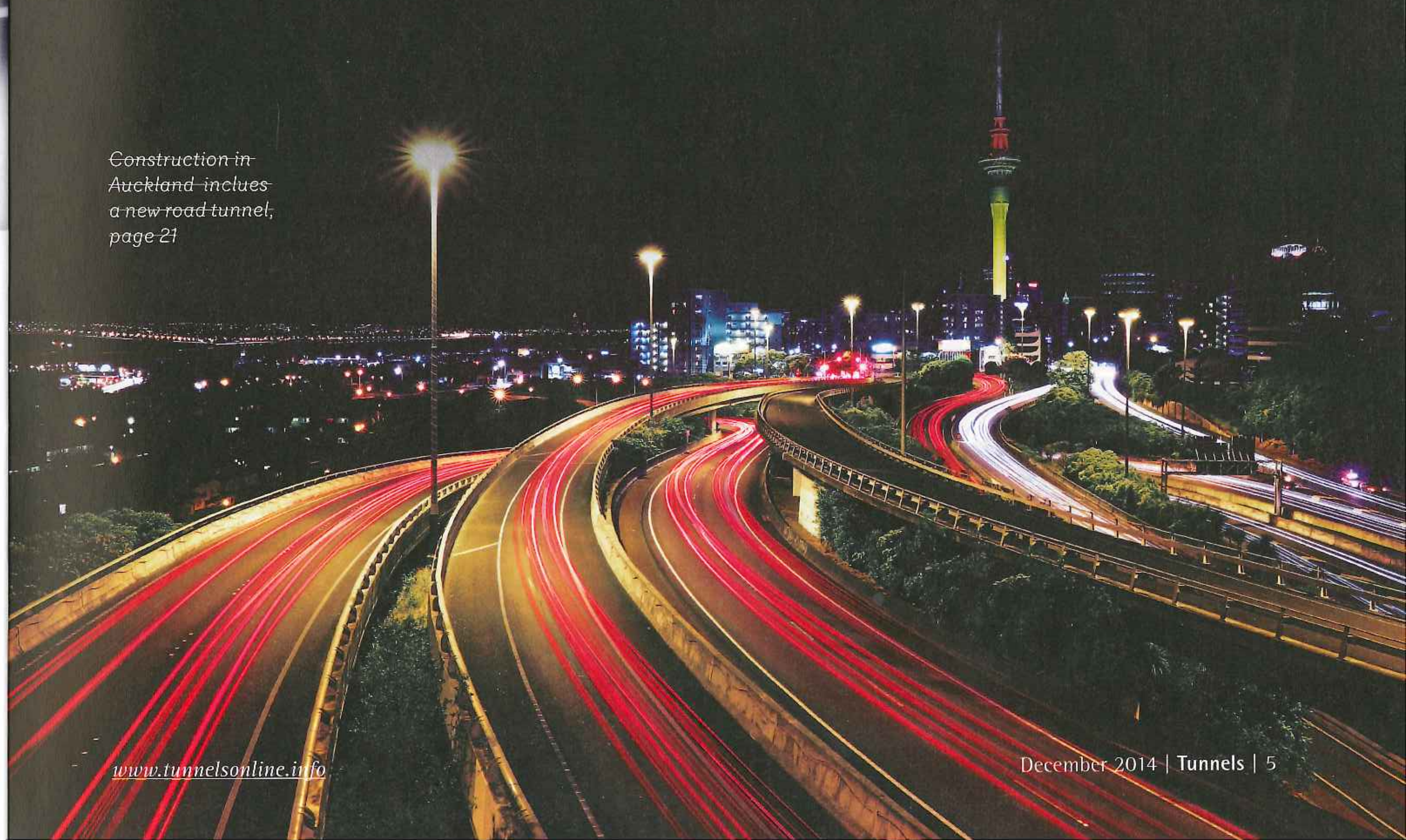
DAVE YOUNG
Dave specialises in tunnels and trenchless technology, covering all phases of delivery. He is also deputy tunnel practice leader at Hatch Mott MacDonald.

GORDON REVEY
For the past 20 years, Gordon has been an independent blasting consultant - Revey Associates - providing design, training and risk management.

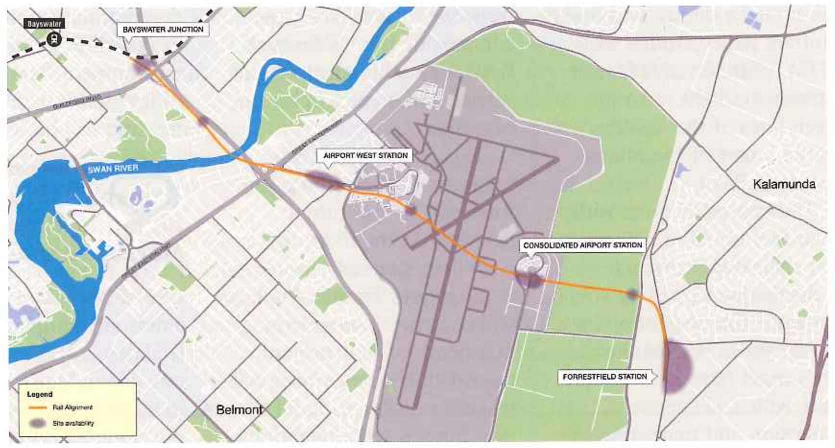


Construction in Auckland inclues a new road tunnel, *page 21*

FORRESTFIELD-AIRPORT LINK PROCUREMENT BEGINS

AUSTRALIA — An industry briefing was held on 14 November as the start of procurement activities for the Forrestfield-Airport Link. The project, to be located in Perth, Australia will create a rail link branching out to the airport and the Forrestfield suburb in the city's southeast. Twin 6.2m-diameter 8km-long twin tunnels are to be bored through soft ground conditions, with a requirement to pass under the Swan River and Perth Airport, which will be operating throughout the project. Nine cross passages (three with egress shafts) will be required, as well as three new stations, of which two will be underground. Excavation method should be TBM, but type has not yet been determined.

Preliminary geotechnical studies have revealed Common Perth Units and Ascot Formation (calcerous sand to calcarenite cobbles). All geological units are Potentially Acid Sulphate Soils. Some 1Mm³ of spoil will be produced, and re-use will be looked at.



Potential worksite locations along the Forrestfield-Airport Link alignment

The delivery model is a lump sum design and construct contract. Expressions of interest will be called for early in 2015, requests for proposals in the middle of 2015, contract award will be in mid 2016, tunnelling commences in 2017, completes in 2019, and trains should be running by 2020. The contract will include responsibility for commissioning, some elements of maintenance, but will exclude rolling stock. Separately the client, Public Transport Authority of Western Australia, will be tendering some utilities relocation work ahead of the main contract.

Third NWRL TBM

AUSTRALIA — The third North West Rail Link (NWRL) TBM has arrived in Sydney and has been named Isabelle by tunnellers working on the project. The first of the four machines were due to be in the ground before the end of 2014, but now there are three on-site in the North West, ahead of schedule.

Gladys Berejiklian, transport minister, said: "Isabelle is the first of the two tunnel boring machines which will start work from Cherrybrook, digging the longest railway tunnels ever built in Australia.

"The first tunnel boring machine Elizabeth is already more than 330m along her underground journey from Bella Vista to Cherrybrook, while the second machine Florence is now being assembled at Bella Vista to start digging before the end of this year.

"The third tunnel boring machine Isabelle, which weighs more than 900t, is being assembled and tested about 14m below the surface at the new Cherrybrook Station before she also starts digging in the next few months."

Berejiklian added that work was powering ahead on the North West Rail Link – a project that will transform public transport in Sydney. "The North West Rail Link includes eight new railway stations and 4,000 commuter car parking spaces. The project is due to open in the first half of 2019 and is the first stage of Sydney Rapid Transit, the city's new fully automated rail network."

Sound Transit second TBM launch

USA — The TBM mining light rail tunnels from the Northgate neighborhood in Seattle to the University of Washington launched on November 20.

"Northgate Link is expected to be one of the busiest new light rail lines in the nation," said Sound Transit Board Chair and King County Executive Dow Constantine. "The action we're taking today will help us meet the increasing demand on one of the most popular corridors in the central Puget Sound region."

The Northgate extension is expected to add more than 60,000 riders a day to the light rail system by 2030 and be a key component of a region-wide light rail system that will carry an estimated 280,000 riders a day by 2030.

Sound Transit contractors are using two TBMs to mine the twin Northgate Link tunnels. The first TBM launched in July and has mined about 3,200ft so far. The machines will mine approximately 3.6 miles from the tunnel portal just south of the Northgate Transit Center to UW where the tunnels will connect with the University Link line into downtown Seattle. That section between downtown and the UW is scheduled to open in early 2016.

The USD 2.1bn Northgate extension includes underground stations in the U District and Roosevelt neighborhoods and an elevated station at Northgate. The line will add major new capacity to the region's transportation system, offering fast, frequent and congestion-free service 20 hours a day.

The tunnels are being constructed by Jay Dee Contractors of Livonia, Mich., Frank Coluccio Construction Company of Seattle, and Michaels Corporation of Brownsville, Wis., that successfully completed two one-mile tunnels for the University Link light rail project.

Bouygues signs contract for Baku metro

AZERBAIJAN — Bouygues Travaux Publics, a subsidiary of Bouygues Construction, has signed a design and build contract worth around EUR 147M (USD 184.3M) for the separation of the red and green lines of the '28 May Station', part of the metro system in Baku.

The contract signed with Baku Metropolitan is the first civil works contract in Azerbaijan signed by Bouygues Construction. The project forms part of the city's mass transit extension plan, which will see an expansion and upgrading of the metro with completion expected in 2030.

Philippe Bonnave, Deputy Chief Executive of Bouygues Construction, said: "We are proud that our client, Baku Metropolitan, has shown such confidence in us and we trust that this augurs well for further collaboration between us in the future. This project will provide the residents of Baku with a better quality of service and greater frequency of trains."

The project consists in separating the two lines that form part of the current network. At the moment, both lines share platforms.

Bouygues Travaux Publics will construct two caverns at a depth of 25m around the existing tubes, which will make it possible to build the new tunnels with operations being interrupted for only five weeks throughout the 36-month period the project will last. The works are scheduled to begin in February 2015, and will involve 250 people at peak periods. The teams will face a technical challenge, because the tunnels are situated in a dense urban environment and in very difficult geological environment. The techniques of jet grouting and ground freezing will be used.

Transport chiefs planning major work on Mersey tunnel

GREAT BRITAIN — Transport chiefs are planning GBP 9M (USD 14.3M) of works on one of the Mersey tunnels in a bid to make sure it is not plunged into darkness if there is a major crash or fire, local press reported recently. The planned project, currently awaiting approval, will see all 1,800 lights inside the Kingsway tunnel to Wallasey replaced.

The improvements are needed because of where the current electricity supply lines run through the 1.5 mile-long (2.4km) tunnel. Since they are threaded along behind the cladding at 'deck level', if a major impact took place or there was a serious fire, the whole system would short out. Currently, there is no battery-powered emergency back-up lighting that would come on in the event of an emergency.

The current electrical cabling is made of aluminium, which was cheaper to install than copper cabling. It is now nearing the end of its useful life after 40 years, and must be replaced.

GREEK YOUNG MEMBERS EMERGE WITH ATHENS CAREER DAY

GREECE — The first activity of the Young Members Group of the Greek Tunnelling Society (YMG-GTS) enjoyed an enthusiastic industry reception. The 'Career Day for Tunnel and Geotechnical Professionals' was held on 28 September during the 2nd Eastern European Tunnelling Conference in Athens, Greece, and its attendance of 80 professionals exceeded expectations.

The main objective was to bring together tunnelling engineers with companies from Greece and the rest of Europe. The two-part event began with presentations, first from the companies setting out their work and development plans, then a talk by the ITA Young Members Group leadership on the growing role of young engineers in the ITA. The second part of the event was a networking session between the companies and attendees.

The GTS has informed *Tunnels and Tunnelling* that following the event; at least ten professionals are known to have been invited to a second interview stage with a view to employment.

A GTS spokesman assessed the success of the day: "Both the companies and participants requested a one hour extension at the end of the day. We also had more companies and participants than expected, and the feedback was entirely positive. But we are most pleased with the number of follow-up interviews."

Career Day organising committee with special guests at the conference dinner

Companies involved included: Hill International; Dr. Sauer and Partners; Systra; Geos Ingenieurs Conseils; Geodata; Vinci Construction; Omikronkappa Consulting; Lombardi; and Pini Swiss Engineers.

The spokesman added, "We believe that this event proved that despite the financial crisis of recent years, Greece has a very high level of students and professionals in tunnelling and geotechnical engineering. [Due to the success], our intention is to organise another event in the future. However it is too early to say exactly when."

BIRMINGHAM COUNCIL CONSIDERS 'SUPER TUNNEL' UNDER CITY CENTRE

GREAT BRITAIN — A giant super-tunnel the length of Birmingham city centre is being considered to combat traffic congestion, local press announced recently. The underground motorway is one of a host of prospects put forward by Birmingham City Council.

The re-routing of the road is a major part of the Birmingham Mobility Action Plan white paper, unveiled on November 13, setting out the city council's 20-year vision for improving transport.

The super-tunnel option - creating a new underground motorway similar to one in the US city of Boston - is one of many options being looked into. Other options include joining up the existing St Chad's and Queensway tunnels or filling them in and ushering traffic around rather than through the city centre.

David Harris, transport policy manager at the city council, said the changes were part of an over-arching plan to offer more transport options and encourage people out of their cars.

Harris said: "It is about people, not vehicles, and better ways of moving people through the city. We want a walkable city. The A38, particularly where it comes out of St Chad's tunnel, seems to create a massive barrier.

"Basically, we are saying there are options for the tunnels. Do you close them or join them up or close them and build new ones?"

The A38 currently sees 85,000 traffic movements daily, around half of which involve journeys by people purely wishing to get from one side of the city to the other.

Five consortia express interest in Australian WestConnex Stage Two

AUSTRALIA — The Australian and New South Wales Governments have announced the WestConnex Stage Two project has entered a new phase with five consortia expressing interest in delivering Sydney's M5 East corridor.

These new motorway tunnels will run from the existing M5 East corridor at Beverly Hills via tunnel to St Peters. Assistant minister for infrastructure Jamie Briggs and NSW minister for roads Duncan Gay announced the international companies and consortia bidding to build the WestConnex Stage Two tunnels are: Lend Lease Acciona Joint Venture; Leighton Dragados Samsung Joint Venture; Salini Impregilo; Strabag; and TunneLink (consisting of Ferrovial Agroman, Ghella and McConnell Dowell Constructors).

The preferred design and preferred contractor for the Stage Two tunnel work will be selected by mid-2015, ahead of the exhibition of the environmental impact statement.

The Stage Two tunnel contract is the second multi-billion dollar WestConnex contract to go to market.

NEORSD awards Dugway tunnel to Salini Impregilo

USA — Italian company Salini Impregilo signed a contract to build the Dugway Storage Tunnel in Cleveland, Ohio, worth USD 153M the company announced November 10.

The Dugway Storage Tunnel is 4.5km long, with a diameter of 8m. The contract also envisages the construction of six shafts of varying diameters and depths, connections between the tunnel and the shafts and a series of concrete structures for the collection and transporting of wastewater and rainwater.

The project is part of a broader plan for the collection, storage and treatment of these waters, with the objective of reducing the level of environmental pollution in Lake Erie.

Test train runs through Delft tunnel

NETHERLANDS — The Infrastructure manager ProRail has run its first test train through a new four-track railway tunnel beneath the city of Delft in the Netherlands. The train ran through the 2.3km tunnel beneath the city at the beginning of this month.

The tunnel and a new station with 340m long platforms 8m underground will replace the existing railway viaduct. Putting the line underground will reduce noise and release around 30 ha of land for property developments including offices and 1,000 homes that are being used to part-fund the project.

The Dutch Ministry of Infrastructure & the Environment has contributed EUR 330M (USD 413.2M) to the EUR 1bn (USD 1.25bn) cost of the project, with the rest of the funding coming from various tiers of government. When the tunnel opens in Spring 2015 it will open with two tracks through the tunnel, but there is provision for a further pair to be installed later which would provide an increase in capacity with wider benefits across the national network.

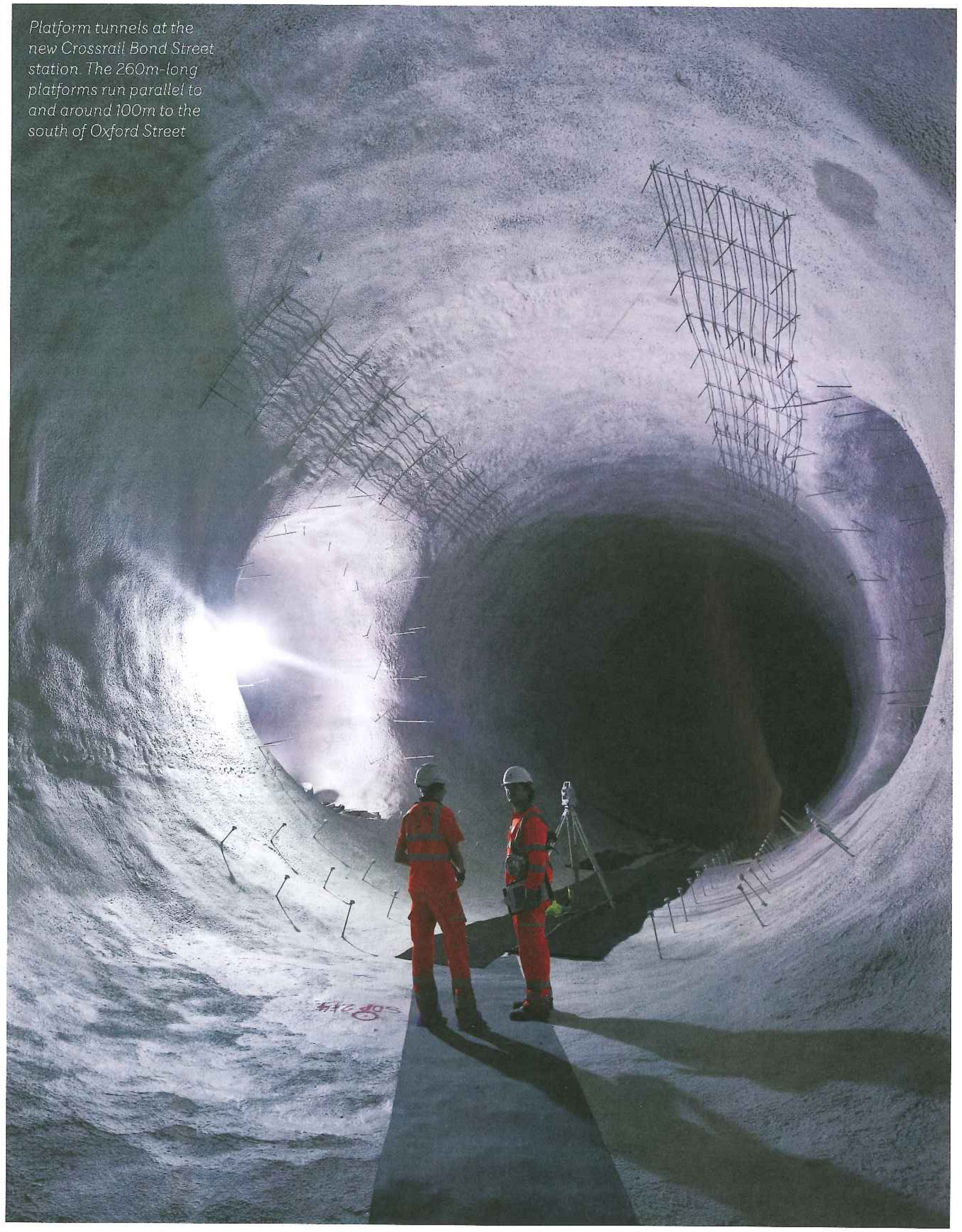
Ad Brothers, project manager for ProRail, said: "The old two-track railway viaduct, so characteristic in Delft, will soon be exchanged for a quiet tunnel with room for four tracks. There will be a better traffic flow, which offers advantages in the Netherlands."

The CrommeLijn consortium of CFE, Mobilis and Dura Vermeer began construction in 2008.

News briefs

USA

The TBM cutterhead that will excavate portions of the Crenshaw/LAX light rail in Los Angeles arrived in late November. The Crenshaw/LAX Line is an 8.5-mile (13.7km) light rail line that will run between Exposition Boulevard and the Green Line. Walsh/Shea Corridor Constructors is the contractor for the project. Metro says it expects the TBM will be assembled and ready to start excavations by mid-2015. Ground conditions are expected to be both coarse and fine-grained soils consisting of clays, silts, sands, gravels and cobbles typical of the LA basin. The Walsh-Shea JV will use one Herrenknecht TBM for the drives, launching the machine at the future Crenshaw/Exposition station on the southbound excavation first, followed by the northbound.



Platform tunnels at the new Crossrail Bond Street station. The 260m-long platforms run parallel to and around 100m to the south of Oxford Street

Crossrail celebrates progress with photos

GREAT BRITAIN — Crossrail has released a selection of photos to celebrate reaching the "60 per cent complete" point of construction. Over the coming months, while tunnel construction is still ongoing, Crossrail's focus will shift to the substantial job of fitting out the stations and tunnels. A spokesman said, " More than 23 miles (nearly 90%) of train tunnels are now complete, with tunnelling due to finish in spring next year. Six of Crossrail's eight tunnelling machines have now completed their drives. The construction of ten new stations is more than half complete."

Contractor pleads guilty in Toronto death

CANADA — The 2011 death of a worker and injury to another at a Toronto Transit Commission (TTC) subway construction site in North York has resulted in a guilty plea and a CAD 400,000 (USD 350,000) fine, the Ministry of Labor of Ontario announced on November 28.

On October 11, 2011, workers were on the job site at 4700 Keele Street near York University, where twin bored tunnels are under construction to add an 8.6km subway line from the existing Downsview Station to the Vaughan Corporate Centre in York Region. The project is being constructed by a limited partnership, 1842887 Ontario Ltd./ OHL-FCC GP Canada Inc. On the day of the event, one worker, an employee of Advanced Construction Techniques Ltd. (ACT) and subcontracted as a general contractor, was operating a drill rig equipped with an auger to create a shaft. Another worker, under the direction of ACT crew, was operating an excavator digging dispersal holes near the pile being drilled so wet waste material from the drill casing could be discharged into them. A third worker employed by Anchor Shoring and Caissons Ltd., which was also a subcontractor, was operating a backhoe loader to remove excavated earth from the drilling that Anchor Shoring was performing in the same area.

On that afternoon, the worker operating the drill rig raised the auger from the hole and swung the mast. The worker saw the boom of the machine going to the right and felt the machine move; witnesses saw the rig moving back and forth with the auger in the air and saw one of the tracks go into a rut. The drill rig suddenly toppled and the mast and casing crushed the excavator as well as the backhoe. The worker operating the excavator was seriously injured and the worker operating the backhoe was killed.

Subsequent investigation determined that inadequate site preparation and a soil base unable to withstand the weight and pressure created by the drill rig, combined with a procedure of digging dispersal holes filled with wet material, significantly reduced the ground-bearing capacity of the prepared working surface where the drill rig tracks were located. In addition, the drill rig was operating on a slope greater than allowed within safe parameters. These were the major factors in the tipping of the drill rig.

OHL-FCC GP pleaded guilty to failing as a constructor to ensure that safety measures required by the Occupational Health and Safety Act were followed, and was fined CAD 400,000. In addition, Ministry of Labour inspectors attended a tunneling construction project for the TTC subway expansion at 2735 Steeles Avenue West to conduct a routine inspection on March 15-16, 2012. The inspection was mainly for the purpose of determining whether rescue equipment necessary in the tunneling process was current, acceptable for the task and in good working order. During the course of the inspection it was determined that the tunnel rescue equipment - specifically self-contained breathing apparatus necessary for a tunnel rescue procedure - were not being inspected at least once a month, contrary to the law. As a result, OHL-FCC GP Canada Inc. pleaded guilty to failing to ensure the monthly inspection took place, and was fined CAD 20,000. The sentences were imposed by Justice Melvyn Green in Old City Hall Court in Toronto. In addition to the fine, the court imposed a 25-per-cent victim fine surcharge as required by the Provincial Offences Act.

CH2M HILL NAMED PROGRAMME MANAGEMENT ADVISOR FOR SAN MATEO'S CLEAN WATER PROGRAM

USA — The City of San Mateo awarded CH2M HILL a program management advisor contract to oversee its Clean Water Program, the company announced November 11.

The Clean Water Program includes approximately USD 900M in total program costs escalated over a 20 year period to upgrade the City's sanitary sewer collection and wastewater treatment system.

CH2M HILL will provide program services, including Program Planning and Administration, Program Controls, Technical Planning, Engineering Support, Portal Management, and Construction Support, to implement the combined Clean Water Program (CWP) Master Plan. Currently, the City of San Mateo is finalizing a key component of the Master Plan - their capital improvement program (CIP), with partners, stakeholders and regulatory agencies.

Like many cities across the U.S., the City of San Mateo's original sewer pipes date back to the early 1900s and the wastewater treatment plant was largely constructed from 1935 to 1980. The facility's aging assets have reached the end of their useful service life and are in need of rehabilitation or replacement. The City is also under two regulatory programs driving them to stop Sanitary Sewer Overflows (SSOs) and storm water events from blending, as well as upgrading both its collection and treatment systems. The City's CWP Master Plan will not only address aging infrastructure and regulatory needs, but will help the City achieve its sustainability goals by optimizing wastewater treatment, biogas utilisation, and conveyance infrastructure.

"We are honored that the City of San Mateo selected CH2M HILL as its advisor on the Clean Water Program," said Jay Witherspoon, CH2M HILL Vice President, Program Manager, and Global Service Team Leader, Water Resources & Ecosystems Management. "Implementing the combined CIP will require a tremendous effort in planning, coordination, standardization, and program controls.

Our experience and technical knowledge in programs, planning, designing, constructing, starting-up, and commissioning wastewater collection systems and treatment plants will be beneficial to the success of this project."

BREAKTHROUGH ON OTTAWA LRT

CANADA — The roadheader mining in the central shaft from the east segment to the west segment punched through on November 7, according to the City of Ottawa.
At the time of the breakthrough, 48 per cent of Lyon Station cavern excavation has completed.

Three roadheaders are mining Ottawa's 2.5km-long downtown tunnel. It is part of phase 1 of the city's light rail transit (LRT) system called the Confederation Line.

This initial segment is 12.5km long with 13 stations, three underground. Most of the alignment is between 16m to 24m below ground.

The Confederation Line is being built through a public-private-partnership with the Rideau Transit Group (RTG), which will maintain the line through 2038. RTG comprises ACS Infrastructure Canada Inc., Dragados Canada Inc., EllisDon, SNC-Lavalin, Dr. Sauer & Partners Corporation, Hatch Mott MacDonald and Thurber Engineering Ltd., among others.

Tunnelling started in late fall 2013. Construction is scheduled to complete on the Confederation Line in 2017.

Tully to be awarded USD 282.5M repairs contract

USA — MTA Bridges and Tunnels announced on November 17 it plans to award a four-year, USD 282.5M contract to Tully Construction Company for repairs and restoration projects related to damages at the Hugh L. Carey Tunnel in New York caused by Superstorm Sandy.

"We learned just how vital the HLC Tunnel is to the region in 2012 after Superstorm Sandy flooded the tunnel with approximately 60M gallons of brackish water compromising the life safety systems in the tunnel," said MTA Bridges and Tunnels president James Ferrara. "This project will increase the level of resiliency against future weather events. This is the largest construction contract in our agency's history."

In addition to Sandy restoration, the contract with the Queens-based Tully Construction firm will also include previously planned capital improvements at the tunnel, formerly known as the Brooklyn-Battery Tunnel. The coordinated approach of matching Sandy-related restoration with other necessary work is a more effective way of addressing multiple project needs.

The scope of the project includes:

- Replacing the tunnel's entire traffic control and communications system
- Replacement of the entire tunnel lighting system, including use of new LED light fixtures and emergency way-finding safety lights - Replacing the drainage pump and fire line systems
- Concrete repairs
- Environmental clean-up to address residual salt, oil and other contaminants swept into the tunnel with Sandy flood waters
- Replacing tunnel wall tiles, ceiling finishes, catwalks and duct banks
- Rehabilitation of tunnel curbs and gutters
- Repaving of tunnel roadways, and
- Rehabilitation of the Brooklyn toll plaza to improve traffic flow.

A total of 24 construction firms or joint venture teams received the request for proposal under a resolution adopted by the MTA Board in September 2013 allowing Bridges and Tunnels to pre-qualify prospective bidders based on qualifications including experience and expertise in doing tunnel repairs and financial capabilities based on the complexity of the project. Of those, 14 were deemed eligible and Tully Construction was the low-bidder at.

MTA Bridge and Tunnel staff said most of the work will be done during off-peak and nighttime hours. Single tube closures will be necessary but one tube will remain open at all times, with one lane operating in each direction. The project is partially funded through a FEMA grant for Sandy-related repairs. MTA entered into an agreement with FEMA in April, which will provide USD 403M for repairs to the Hugh L. Carey and Queens-Midtown Tunnels and measures to prevent damage to the tunnels from future flood events. The remaining portion of this project, which consists of previously planned capital work, will be funded from MTA B&T's Capital Budget.

Brierley Associates to investigate tunnel for Minneapolis LRT

USA — The Minneapolis Park and Recreation board approved a USD 245,000 contract with Brierley Associates on November 19 to consult on potential tunnel options for the Southwest Light Rail (SWLRT) project through the city's Kenilworth Corridor.

The region's Metropolitan Council prefers to bridge the light rail over the Kenilworth Channel, which connects two of the city's popular lakes, in combination with existing freight lines and recreational trails.

The Parks board said it has been advised that the proposed alignment "has failed to properly consider a tunnel under the Kenilworth Channel to determine if it is a prudent and feasible alternative and further that the proposed SWLRT alignment has not included all possible planning to minimize the harm to the park, recreation areas, and historic sites."

Brierley Associates will determine the feasibility of a tunnel alternative to bridging light rail over the Kenilworth Channel within the Kenilworth Corridor and perform an initial comparison of the effects of a tunnel alternative on the park, recreation areas, and historic sites to the SWLRT proposed alignment. As part of the contract Brierley Associates will identify additional work, investigations, or study that would be required to more fully frame the feasibility of the tunnel alternative and to more fully understand various impacts. On Monday the Metropolitan Council released bridge concepts for the Kenilworth channel calling them, "a nod to nature."

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

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PUTIN FAVOURS CRIMEA TUNNEL

A tunnel link is favoured over a bridge to join the Crimean Peninsula to the Russian mainland, according to government sources

THE RUSSIAN government plans to abolish a project to build a bridge to Crimea via the Kerch Strait and replace it by a tunnel, according to Oleg Savelyev, Russia's minister for Crimean affairs.

This will be mainly due to cost issues, as building the bridge will allegedly be up to four times more expensive than the tunnel. In addition, construction of the bridge and its further use could have been complicated by adverse weather conditions in the area.

Georgi Muradov, presidential envoy in the Crimean region said, "Building the bridge would be very dangerous, and it would be closed for at least a month per year due to stormy winds and freezing rains during winter. We are taking into account the experience of foreign companies specialised in the construction of such crossings."

According to estimates by the Russian government, the volume of investments in the tunnel is expected to reach RUB 80bn (USD 1.58bn), while in the case of the bridge it would be up to RUB 228bn (USD 4.48bn). Exchange rates subject to rapid change as Tunnels went to press.

It is expected that the project may involve participation of Vision Transportation Group (VTG), a global consulting company, which was involved in various infrastructure projects, including construction of the underwater tunnel under the Bosporus in Istanbul.

According to an official spokesman of Dmitry Kozak , Russia's deputy prime minister, who is responsible for the implementation of the project, VTG has already sent an application for the implementation of the project to the Russian government.

The tunnel could be built in the Kerch Strait, where a ferry route currently exists. This alignment is much narrower than those of Tuzla's, and provides a possibility of the use of those construction technologies that will not interrupt the operations of the ferry line. According to an official spokesman of the Crimean government, this will be a modular, flexible tunnel. Geology is expected to be sandy ground.

Above: *Putin's administration has enjoyed increased influence in the Crimean Peninsula*

FREDERIC LEGRAND - COMEO / SHUTTERSTOCK.COM

There is a possibility that the project may be implemented by Stroytransgaz, one of Russia's largest engineering holdings, owned by Gennady Timchenko, one of Russia's richest businessman, a figure close to Putin.

Gennady Timchenko added, "Building the tunnel is an acute need, as it will allow Russia to significant increase cargo supplies to Crimea. At present ferries transport just four trains per day. With the commissioning of the tunnel this number will tenfold to 40."

At the same time, there is a possibility that, due to the high risks associated with the implementation of the project, Timchenko's Stroytransgaz may be appointed just a sub-contractor of the project, while the major risks will be borne by the Russian State Agency for Special Construction (Spetsstroy), which will act as a general contractor. The project may also involve participation of Chinese investors, which have already built a tunnel in the Macau autonomous territory on the bottom of the South China Sea, as well as some investors from Canada. At the same time in the case of participation of Chinese investors in the project, part of the funding could be provided by leading Chinese banks.

According to Evgeniya Bavykina, Crimea's vice prime minister, the new tunnel is expected to of two rail lines, a six-lane highway and a pipe for electricity and gas supply. The project also involves construction of related port infrastructure and road junctions.

A feasibility study of the project should be completed by 15 December 2014. According to state plans, the new tunnel should be commissioned by 31 December 2017 in accordance with a recent order by President Vladimir Putin

Eugene Gerden
Russia Correspondent

ANTIPODEAN ANXIETY

Hailed as one of the world's top safe-haven, value-retaining economies in recent years, New Zealand has been basking in the warm glow of a successful battle against a crash, but for how long? **Rhian Owen** reports

GLOBAL REPORTS suggest that the country's economic bubble could be dwindling. For example, the prices of dairy exports – on which the country's economy relies heavily – have dropped by 40 per cent since the beginning of this year, mostly due to falling demand in China, the country's main trading partner. Mining, retail, manufacturing and tertiary education job cuts have been made.

Rhian Owen
As a technical journalist Rhian began working for *Tunnels and Tunnelling* in 2011

However, the construction sector is one of largest employers in the New Zealand economy, employing seven per cent of the workforce and still growing, a new Government report shows, and is vital to help grow the economy, it states.

Construction Sector Report, the fourth in a series of seven that make up the New Zealand Sectors Reports Series 2013, reveals that the construction sector generates annual revenues of more than NZD 30bn (USD 23.3bn) to the New Zealand economy. It employs 170,000 people, which is more than the agriculture, forestry and fishing sectors.

Steven Joyce, economic development minister, says: "Construction has a vital part to play in our communities and its activity can be felt throughout the economy. From infrastructure and telecommunications to city and community development, it has a direct impact on the quality of life of all New Zealanders.

"Importantly, demand from the construction sector drives a wide range of other activities in the economy. It is part of the fabric of society and that is why this sector is so important."

The timing of the projects coming to the table is important. According to the Construction Sector Report the number of firms is 10,000 higher than 2002. However, Brett Gliddon, highways manager for Auckland and Northland. explains that a key consideration for the NZTA when the Waterview Connection project was tendered was "the availability of tunnelling resources in the Australasian market".

"The Waterview Connection project **commenced in 2011** as a number of large tunnelling projects in Australia were nearing completion."

Gliddon adds: "The Waterview Connection project commenced in 2011 as a number of large tunnelling projects in Australia were nearing completion, making the timing favourable."

There is a treasure trove of underground opportunities in New Zealand with many tunnelling projects underway or in the pipeline.

Last year the NZ Transport Agency (NZTA) revealed plans for a second Mt Victoria Tunnel, as part of a NZD 800M (USD 621.M) traffic improvement project from Ngauranga to the airport.

Construction of the Mt Victoria Tunnel is expected to take place from 2018 - 2022, although construction has yet to be formally confirmed. The tunnel will be roughly 14m wide, 650m long, and located about 25m to the north of the existing tunnel. NZTA states that next year the agency will seek RMA approvals for the highway improvements via the national consenting process.

Just north of Auckland an underground tunnel is currently being constructed from the Watercare Pump Station off Millwater Parkway at Orewa to subdivisions north of Grand Drive. McConnell Dowell Constructors is drilling the 3.15km tunnel for the Millwater project using TBM Nancy. The company also bored wastewater micro tunnels for the NZD 83.5M (USD 64.9M) Christchurch Ocean Outfall, the largest civil engineering project undertaken by the Christchurch City Council before the Canterbury earthquakes.

Auckland is now home to New Zealand's longest road tunnel, and the most expensive tunnel project in the country.

Below: The tunnel is the most expensive in the country's history

Auckland has a population that is expected to continue to grow faster than the national average and there are numerous infrastructure projects planned for the city - including the Auckland CBD rail link and the Second Harbour Crossing - are planned for the city.

Gliddon says: "The size and geographic location of Auckland, a city with a population of 1.5 million people and growing by three per cent annually, is situated on a narrow isthmus between two harbours. Space available for necessary infrastructure to support the city is at a premium.

"Auckland's transport authority, Auckland Transport, is planning an underground extension to the commuter rail network known as the City Rail Loop (CRL). While the metropolitan water authority, Watercare, is applying for consent for a 14km wastewater tunnel."

The City Rail Link (CRL) is an underground rail line linking Britomart and the city centre with the existing western line near Mt Eden. The New Zealand government has said that the project is a top priority for Auckland as current public transport will be unable to cater for the growth expected in the city, hindering economic development.

The current phase is to confirm and protect a route to enable future construction. The CRL will use twin 3.4km long tunnels up to 42m below city centre streets. It is estimated to take five and a half years to build at a cost of NZD 2.4bn (USD 1.9bn) when inflated to 2021, which will overtake the Waterview Connection as the country's most expensive tunnel.

The proposed Additional Waitemata Harbour Crossing (AWHC) project is part of NZTA's long term planning to meet Auckland's future transport needs, the agency states. The AWHC project is currently in the investigation stages.

The recommended option, selected from several hundred considered alignments, comprises four tunnels - two for trains and two for the motorway - east of Auckland Harbour Bridge. The Central Motorway Junction on the isthmus would link to the Northern Motorway, while the suburban rail network could in future be extended northward from the Auckland Central Business District to the North Shore.

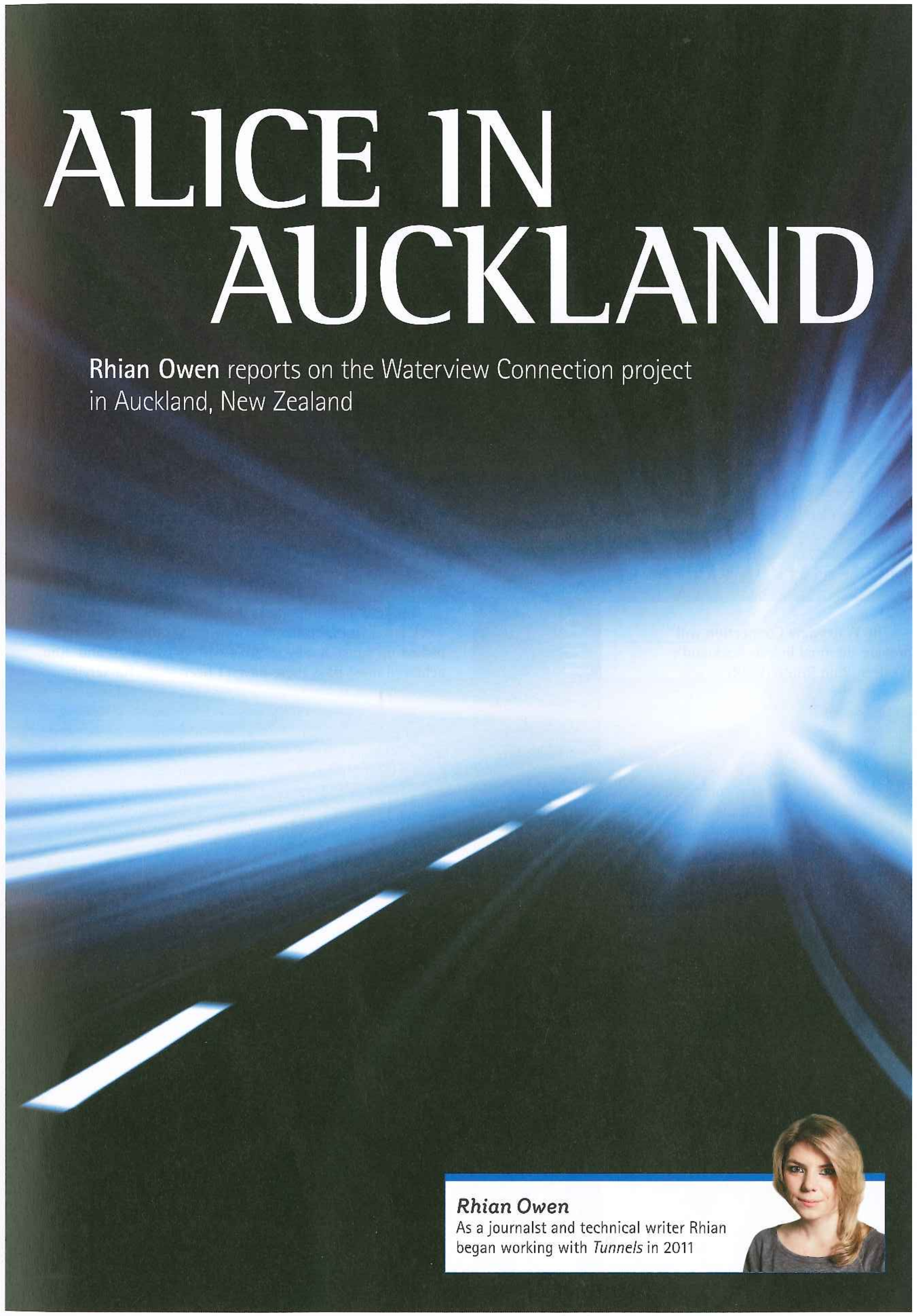
While the Waterview Connection project, which will provide the final link in Auckland's Western Ring Route, has recently reached its halfway point. The first of the twin road tunnels on the NZTA Waterview Connection project has been completed and the TBM, named Alice, is currently being turned around to bore the northbound tunnel. The project is the country's biggest and most complex roading project to date and is due to be completed by 2017.

"At some 2,450m long the Waterview Connection tunnels will be the longest road tunnels in New Zealand surpassing the 1940m Lyttelton road tunnel near Christchurch, which opened in 1954. Regarding cost, the NZD 1.4bn (USD 1bn) Waterview Connection is the largest and most expensive roading project undertaken in New Zealand," says Gliddon.

When tunnelling in New Zealand, it is vital to consider the country's topography and geology. Gliddon adds: "The Waterview tunnels are being undertaken in an urban environment in NZ's largest city, through predominantly sedimentary sandstone with average strengths between 1MPa and 5 MPa. By contrast, the Manapouri Tailrace tunnel (a 10kn-long, 10m wide tunnel using a 1,000t TBM) was constructed in an extremely remote location in the southwest of the South Island through with rock exceeding 100MPa"

ALICE IN AUCKLAND

Rhian Owen reports on the Waterview Connection project in Auckland, New Zealand



Rhian Owen
As a journalst and technical writer Rhian began working with *Tunnels* in 2011

RECENTLY, LYTTELTON Road tunnel, which runs beneath the Port Hills to the south of the New Zealand city of Christchurch, was in the news marking its 50th birthday as the country's longest road tunnel at 1,994m. Just as Lyttelton marked the anniversary, the Waterview Connection tunnels inched passed it in length, reaching 2km and taking the title for itself.

It is not surprising that Auckland is now home to New Zealand's longest road tunnel - and the most expensive tunnel project in the country, costing NZD 1.4bn (USD 1bn). Auckland is the largest Polynesian city and has a population that is expected to continue to grow faster than the national average.

In 2002 the New Zealand government began an investment programme for Auckland's transport infrastructure. The country's biggest and most complex roading project - the Waterview Connection – is due to be completed by 2017, which includes one of the country's most challenging tunnels to-date, 2.4km of 14.1m diameter twin bores. The project is expected to reduce congestion by some 14 per cent by 2021.

The Waterview Connection will provide the final link in Auckland's Western Ring Route (WRR). It will connect the Southwestern Motorway (SH20) at Mt Roskill to the Northwestern Motorway (SH16), providing a 48km motorway. Five years ago, the government announced it as one of the seven 'Roads of National Significance', because it will improve transport links and contribute to the country's economic wellbeing.

NZ Transport Agency's (NZTA) announced that it had chosen its preferred tenderer for the project construction in August 2011. The project attracted a high level of interest both nationally and internationally and was awarded to a specialist team, known as the Well-Connected Alliance, to manage the design, construction and operation. The consortium includes Fletcher Construction, McConnell Dowell Constructors, Obayashi Corporation, PB New Zealand, Beca Infrastructure and Tonkin & Taylor. The consortium includes five sub-alliance partners and contractors: SICE, Wilson Tunnelling, Downer EDI Works, Boffa Miskell and Warren and Mahoney.

Most recently, the Waterview Connection project reached its halfway point. The first of the twin road tunnels on the NZTA Waterview Connection project has been completed.

1bn
The cost in USD of New Zealand's longest road tunnel

BEGINNING THE DRIVE

Brett Gliddon, highways manager for Auckland and Northland, NZTA, explains that the launch of Alice was "extraordinary" given the complexity of the project. "Each task – which are major projects in themselves – were delivered on or within days of the exact dates they were required. They included the completion of the southern approach trench; design, fabrication, factory testing and delivery of the TBM; assembly and commissioning of the TBM on site, design, construction and commissioning of a pre-cast yard for the manufacture of tunnel lining and inverted culvert segments; and preparation of a 27ha. cleanfill site for disposal of 800,000cu.m of spoil being excavated from the tunnels."

The TBM berthed at the Ports of Auckland's Waitemata terminal in July 2013. The machine arrived in 100 separate 'bits' including 20 containers of small parts, where it took some 10 days to transport the TBM to the project's southern portal at Owairaka where it was reassembled.

At 18 months into into its five-year construction programme, the Waterview Connection project was ready to start tunnelling. Alice started boring on the 31 October 2013 as planned.

"The programming and sequencing of work on this project is an enormous task. The project comprises projects within projects, all of which need to be co-ordinated and resourced," says Gliddon. "An extraordinary success was being ready to bore on the very day that had been planned more than two years earlier. Hitting the target required the completion of major tasks on the critical path, each with significant risks associated with it."

The TBM's drive towards the northern portal began one week later. "Initial tunnelling was slower than expected but picked up substantially in 2014 with between 20 and 30m achieved most days there haven't been stops for service extensions or cutterhead maintenance," says Gliddon.

The tunnel was a long way underground – reaching a depth a depth of 45m – to avoid the remaining volcanic rock layer. Gliddon notes: "For the most part the tunnel route passes through sandstone and siltstone that varies in strength from 1MPa to 5MPa. The machine was selected because it provided the best capability to handle the varying soil and rock conditions that would be encountered and this has been borne out by experience during the first tunnel drive."

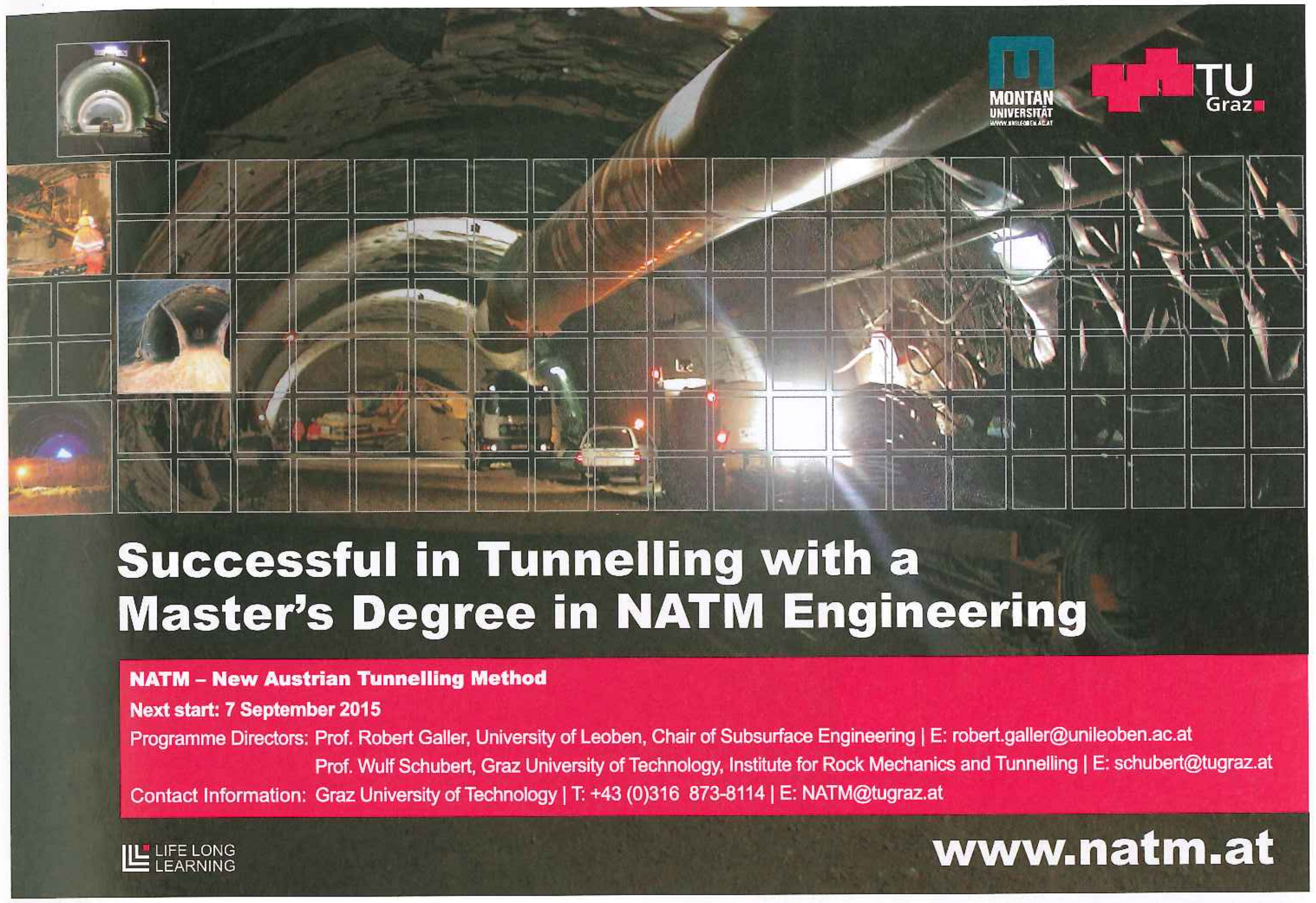
Gliddon adds that the geology was as anticipated, with no surprises encountered. "The geology and groundwater conditions have been as expected. There was a small risk that the tunnel route would intersect layers of cemented sandstone of up to 120MPa. However, this has not eventuated."

ALICE AND THE GANTRIES

Tunnelling was completed with a earth pressure balance (EPB) machine from Herrenknecht. With a cutting diameter of 14.46m, Alice is the 10th largest diameter TBM in the world.

The TBM alone weighs 2,400t and weighs 3,100t including the three backup gantries. The length of the TBM is 12.4m while the overall length including backup gantries is 87m. The gantries house all the equipment needed to run it, place the precast concrete rings that line the tunnels and to remove the material extracted.

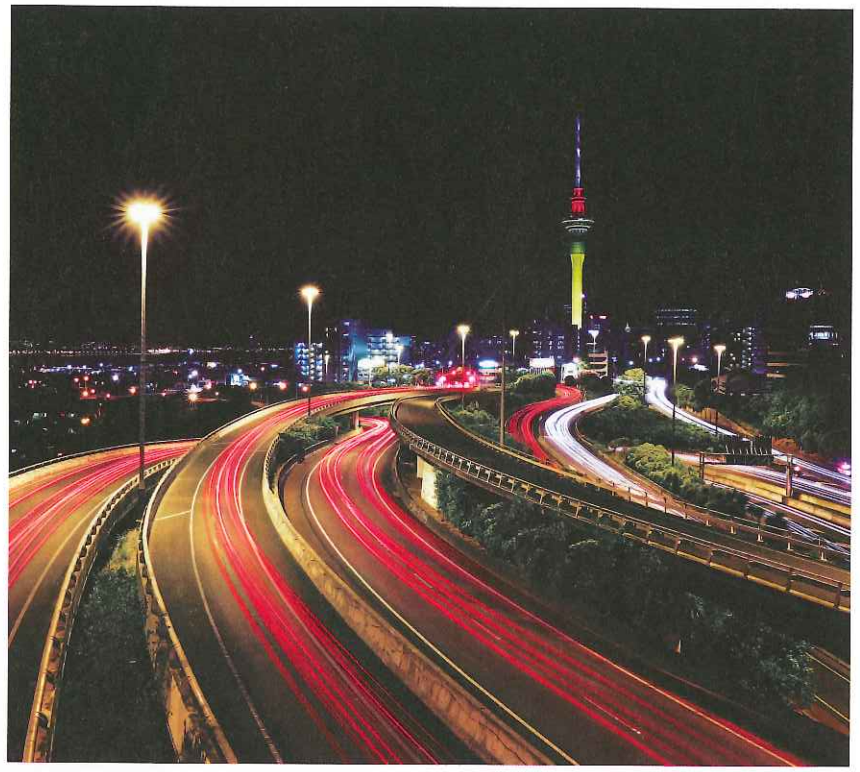
The Waterview Connection project is the first time in TBM history that the installation of the services culvert and the actual tunnelling have been separated. After beginning work 500m behind the machine, the culvert gantry caught up with the TBM. Catching up with the TBM was a priority so that the culverts could provide a secondary emergency escape route as close to Alice as possible, which improves safety in the tunnel.



"A purpose-built culvert gantry is installing the culvert units for the invert culvert that will run under the motorway through the tunnels and carry the services required to operate the tunnel," says Gliddon. "This significant piece of machinery was also designed and supplied by Herrenkencht. It is 95m long and weighs 400t. The objective is to allow the TBM to run at maximum production, unhindered."

Indeed, NZTA stated that on most tunnelling projects the culvert gantry forms part of the TBM itself and the culverts are placed as the machine moves forward. The problem with this is that progress of each activity is affected by the other, which means delays with culvert placement can potentially slow down the tunnelling operation and vice versa.

Gliddon adds: "The gantry was installed in the tunnel in March 2014, with the tunnelling operation stopped. The operation of the culvert gantry has been an outstanding success. By August this year it had come as close as it can work to the TBM while still allowing for survey."



Above: *Alice broke through on 29 Sepember*

THE BIG BREAKTHROUGH

Alice broke into daylight on the 29 September this year at the end of her 10-month 2.4km underground journey from Owairaka to Waterview, marking the project's half way point.

"The TBM has performed as expected," says Gliddon. "The machine stopped on three occasions for other than routine maintenance, service extensions and cutterhead interventions. The first stop was so that the culvert gantry could be installed in the tunnel. The next two were for replacement and refurbishment of the steel brushes that seal the machine's tailskin. The latter stops had been anticipated and planned for."

The TBM will now be turned around to bore the northbound tunnel. Gliddon states that the size of the machine and the limited space in which Alice has to manoever makes the turn unusual.

"The turnaround will be undertaken inside the northern approach tunnel, in an area constricted by the permanent trench structure. In fact the area for turning is just 25m by 39m.

"The TBM and backup were optimised for easier turnaround within the northern portal trench," says Gliddon. "For this reason the number of gantries is limited to just three, with the first gantry behind the TBM carrying most of the vital TBM installations."

The cutting head and its three trailing gantries will now be disconnected and each piece taken one at a time from the completed tunnel and turned. Gliddon adds: "The TBM shield and gantries will be retrieved one at a time from the completed tunnel, pushed sideways on a steel cradle, turned 180 degree and then pushed up against the entry portal of the northbound tunnel."

There is not enough space in the tunnel for all three gantries to be positioned behind the TBM shield for the relaunch. Therefore the shield, Gantry 1 and a temporary second gantry, named Gantry 2.1, will be introduced while Alice is relaunched and bores the first 300m of the second tunnel. "Gantry 2.1 will then be removed from the tunnel and Gantry 2 and 3 will be brought out of the completed tunnel, turned and positioned behind the TBM.

"Only with all three gantries in position will the main drive south resume," says Gliddon. Following this, the culvert gantry is then turned to begin installing the services culvert in the second tunnel.

Tunnelling works to construct the northbound tunnel is expected to recommence in early 2015, and preparations are currently underway to start boring the second of the twin road tunnels

Aerial photograph of existing facilities at the John Hart Generating Station

HYDRO
Supplement

British Columbia's minister of energy **Bill Bennett** opened the *Vancouver TAC* conference in October. With attendees from around the world, he had the perfect opportunity to boast. Some 80 per cent of the energy powering the province comes from hydropower. Bennett cites estimates that as many as one million people could move to BC over the next 20 years, requiring up to a 40 per cent increase in electricity demand. The region is looking to refurbish and replace many of its old facilities. In this section we present several of the papers from *TAC Vancouver* in light of the importance of hydropower work to Canada

ROMAINE DIVERSION

To build a dam for the La Romaine project in Quebec, a joint venture of EBC-Neilson needed to build a river. **Donald Proulx**, vice president of heavy civil works and mines, business development proposals, for *EBC Inc*, based in Quebec reports

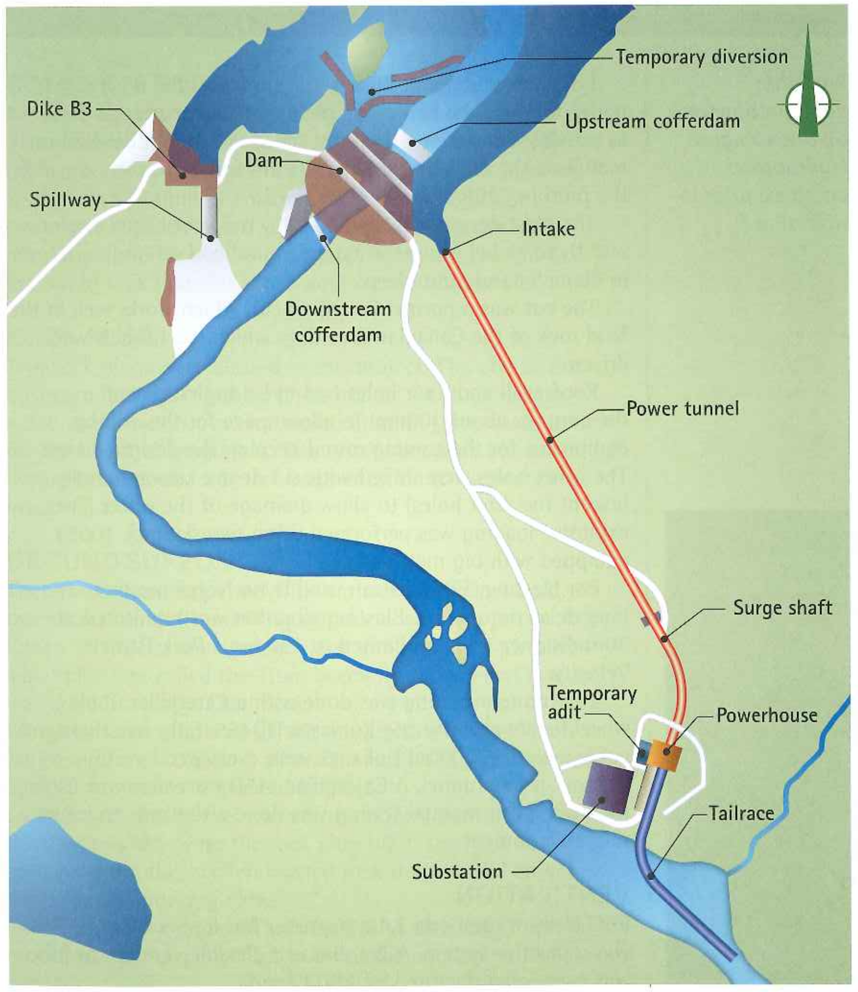
Donald Proulx
Donald is vice president of heavy civil works and mines at Quebec-based EBC

THE ROMAINE 3 temporary diversion contract is part of the construction of a 1,550MW hydroelectric complex. Located 980km northeast of Montreal, the project includes a dam 95m high, a reservoir of 38 square kilometers and a 1,690m-long intake tunnel.

Hydro-Quebec granted contract works for the hydroelectric development of Romaine 3 to the EBC-Neilson consortium. Works consisted mainly of above ground and underground excavation, concrete work of the temporary diversion and associated works: road design, construction and maintenance of temporary roads, scaling and consolidation of rock cliffs, excavation of overburden and rock to open the upstream portal, intake channel excavation, tailrace and spillway excavation and underground excavation of the diversion tunnel. Also included were concrete works, shotcrete, drilling and blasting and rock surface cleaning.

The open cut excavation for the intake and outlet channels of the diversion tunnel required the removal of 108,000m³ of overburden material and 212,000m³ of rock excavation.

Below: Layout of La Romaine 3 project in Quebec



TUNNEL ADVANCE

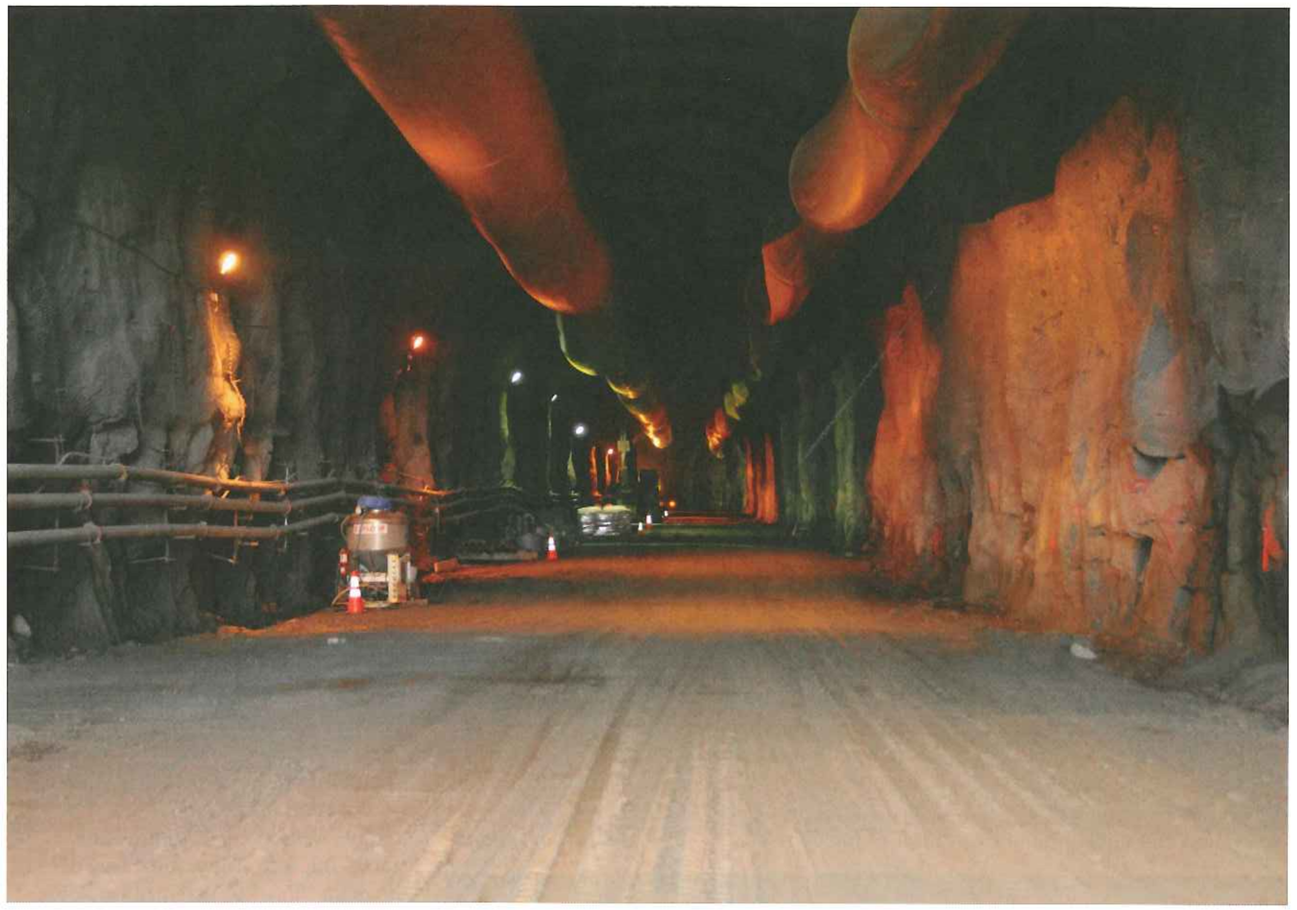
The contract bid by EBC-Neilson was to build the river diversion to allow construction of the dam.

EBC-Neilson chose to drive this tunnel full face. The normal way of driving a tunnel of that size would be in two steps. First, the top of the tunnel would be driven with a jumbo, followed by benching of the bottom section with conventional surface drills.

In construction the tendency is to believe that full face advance is more expensive than benching. At first, it looks that way, but benching is not efficient and it is time consuming, because of the need to install the ventilation and services twice. This makes it difficult to meet the schedule, which is probably the most important aspect of a construction project.

EBC-Neilson chose to use the full face method with two jumbo Tamrock Axera T12-315. The Tamrock was modified to reach 13 meters for the Toulnustouc project done in 2002 and 2003. EBC was the first to own a T-12 in North America and the first owner in the world for a T- 12 capable of reaching 13m.

These jumbos offer other advantages besides their full face capability. The T-12 jumbos are fully computerized. The drilling layout is inserted in the jumbo's computer; the jumbo is stationed at the face, aligned by tunnel laser and, finally, the operator pushes the start button. The computer is then in charge of the drilling. The operator can override the computer and drill manually, but after seeing the final results, anyone would



prefer to leave the computer do the job.

The advantages of the computerised jumbo could be summarised as follows below:

- Less over break;
- All drilling data are kept in the jumbo's computer;
- Penetration rate is maximised;
- Time between holes is reduced;
- The face does not have to be marked up for drilling;
- Blasting results are improved;
- Less manpower for the drilling operation.

All: Other construction work on the Romaine Hydropower complex, prior to Romaine 3

EBC started digging 85m in the tunnel at the upstream portal to allow the beginning of the portal concrete as fast as possible considering the tight schedule. After, EBC-Neilson mobilised the crew on the downstream tunnel to carry on with the finishing 266m.

The blast design was developed by our specialized engineer and Dyno Nobel experts. A typical round had 197 holes, 57mm in diameter and 5.8m deep.

The cut was a normal Canadian cut, which works well in the hard rock of the Canadian Shield, in which the tunnels were driven.

Roof, wall and floor holes had to be angled out of the contour about 300mm to allow space for the drilling equipment for the coming round keeping the designed area. The other holes were drilled with a 3 degree upward angle (except the lifter holes) to allow drainage of the water. The explosive loading was performed using two skytrack 10054 equipped with big man basket.

For blasting, EBC-Neilson used Dyno Nobel products and long delay detonators. Blasting vibration was monitored at 30m distance and was limited to 150mm/s Peak Particle Velocity.

The tunnel mucking was done with a Caterpillar 988H wheel loader and five 55t Komastu HD465. Fifty five thousand cubic meters (55,000m^3) of rock were excavated by EBC-Neilson in this tunnel. A Caterpillar 345D excavator was used for scaling but manual scaling was done afterwards to insure a safe environment.

VENTILATION

EBC-Neilson used one 2.1m diameter fan for ventilation. This was a positive system. A 2m diameter flexible ventilation tube was used, manufactured by ABC Canada.

CONCRETE PORTAL

A concrete portal with two sliding gates was constructed at the upstream end of the diversion. This will allow Hydro-Québec to close the gates to commence filling the reservoir. More than 5,600m3 of concrete were required for the construction of the portal. EBC-Neilson also produced the necessary concrete coarse aggregates using the previously excavated rock material and a sand from a borrow pit.

ROCK PLUG

Two rock plugs were blasted in this project. The one at the upstream had 9,672 cubic meters and at the downstream 4,250 cubic meters. An electronic initiation system was used for the two rock plug blast. This system provides accurate timing benefits and a better fragmentation to facilitate the mucking.

GROUND SUPPORT

The ground was supported with 4m and 6m hollow-core mechanical bolts. The drilling was done with two jumbo Atlas Copco 353. Bolts were put in place using a telescopic boom aerial platform called the Titan boom machine. Final torque was done manually. Then flexible wire mesh was put in place using the same platform, all the way up to the face. When far enough from blasting, all mechanical bolts were checked again for torque and grouted in place.

While the water level was very high (5m) during the spring flood waters following the rock plug blast, the rock was removed from the swollen blasted rock that created an access ramp for the mucking crew.

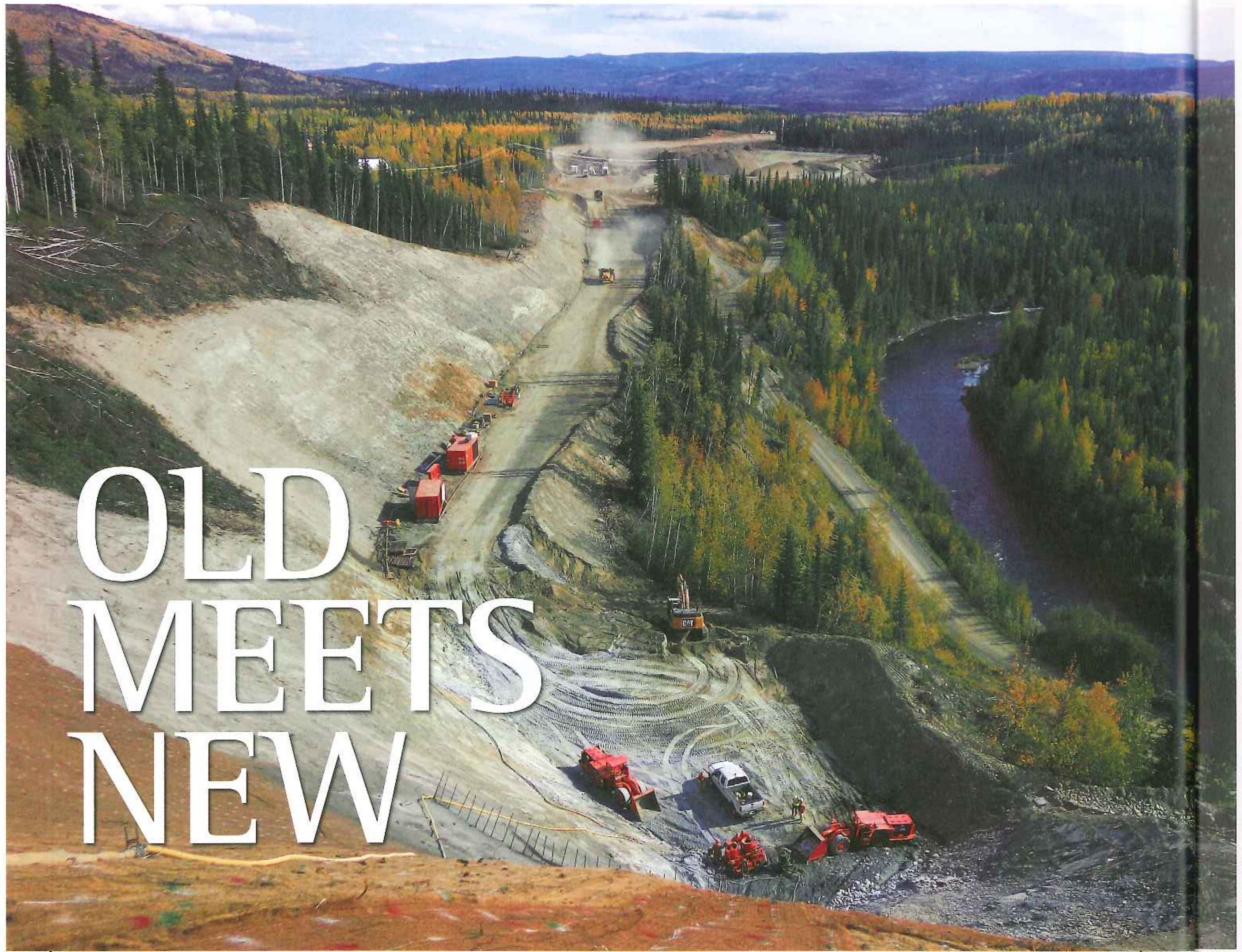
Biological Hydraulic oil was used with the PC800 LC8 for mucking the rock plug blast to avoid the contamination of the water.

CONCLUSION

EBC-Neilson, and its project management team was supported by efficient, dedicated employees. This collaboration and combined efforts were the fundamental elements in making this project a substantial success.

Innovation and creativity were also major factors.

The project was delivered one month ahead of Hydro-Quebec schedule allowing the diversion of the river behind the original schedule by the dam contractor



OLD MEETS NEW

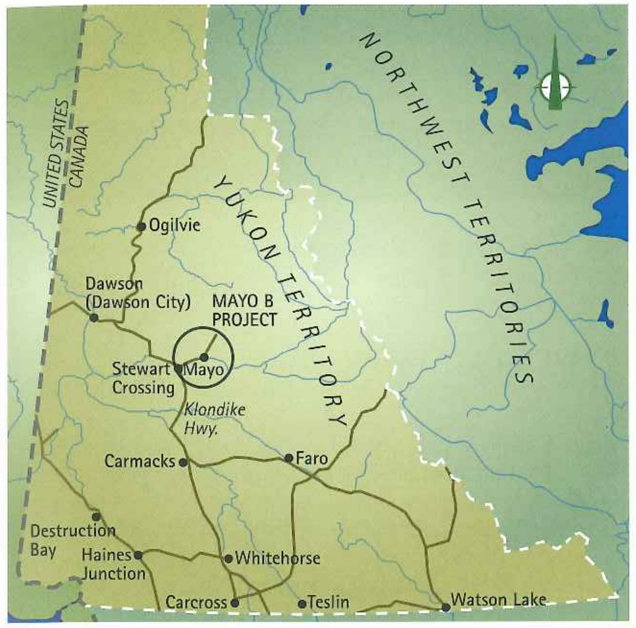
Above: The Mayo B project site located in the Yukon

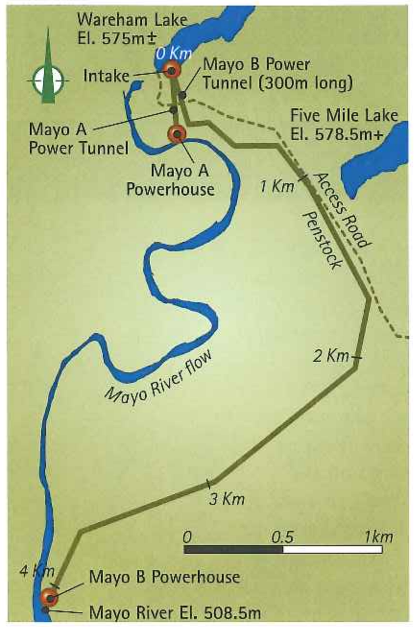
For the Mayo B project in the Yukon, tunnel excavation and structural concrete transition for the tie-in of a new intake power tunnel to an existing intake power tunnel were completed under full reservoir conditions. **Jason Mann, Ryan Dobson & Gordon McPhail** of *KGS Group Consulting Engineers* and independent consultant **Boro Lukajic** report

THE MAYO B project (Figure 1) arose from the need of the Yukon Energy Corporation (YEC) to increase renewable power sources and meet system-wide load demands, while ensuring that diesel consumed to generate electricity was reduced. Load growth in the Yukon is forecasted due to increases in residential/general service, expanded industrial loads, and potential new mine loads. Power for almost three-quarters of the Territory's 116MW generating system originates from hydroelectric sources. The Mayo B project, completed in 2011, increased installed hydroelectric power generation capacity at this site from approximately 5MW to 15MW. The project displaces diesel generation and results in a reduction in annual greenhouse gas emissions of approximately 25,000 tonnes per year.

Jason Mann
Jason is a geologist and hydrogeologist at KGS Group Consulting Engineers

Ryan Dobson
Ryan is is a geotechnical engineer at KGS, with extensive design and fieldwork experience





Far left: Figure 1, Mayo B project location

Immediate left: Figure 2, Plan view of the Mayo B project layout

REGIONAL GEOLOGY

Overburden sediments in the Mayo B project area are dominated by glacial materials in a complex assemblage of moraine tills, with overlying and often intercalated glaciofluvial and glaciolacustrine deposits. Sand and gravel glaciofluvial plains and terraces occur as generally flat-lying outwash areas situated between topographically high bedrock outcrops, and or moraine covered (till) ridges. In some cases, these glacial sediments also form extensive buried bedrock valley fills.

Bedrock in the area is comprised of tightly folded, strongly foliated rocks of the upper Proterozoic to lower Cambrian Hyland Group (Yukon Geological Survey). Predominant rock types are typical of low-grade metamorphic conditions, and include thinly- to thickly-bedded (10mm to 200mm) shales, quartz-meta sandstones, quartz pebble conglomerates, quartz-mica schist, phyllite to sericite/muscovite schists, and weak chloritic schists. The bedding contacts within the rock were often "greasy" to the touch, a result of the mineralogical presence of kaolinite (up to six per cent by weight) within the bedrock. The design friction angle along schistosity or bedding within the phyllite is relatively low, at approximately 17°. Among other constraining site conditions, these rock types and bedrock conditions, particularly where differentially weathered, were contributing factors in defining the final layout of the Mayo B project.

PROJECT CONVEYANCE OPTIONS

Originally, three alternative tunnel alignments were evaluated, with different combinations of open tunnel/canal/penstock conveyance to the Mayo B powerhouse (Figures 2 and 3).

The first alternative required construction of a 2km-long tunnel, discharging into an open canal via a vertical shaft raise. The potential for significant cost increases that could result with the presence of a deep buried soil valley infill between bedrock outcrop areas (Figure 3) was a limiting factor in evaluating this alternative. It was also determined that construction risk existed due to the presence of permafrost, and steep slopes with difficult access conditions. Tunnelling through overburden within the deep buried valley infill would prove risky due to high content of boulders and cobbles. It was deemed to be a non-viable option.

A second alternative specified a full-length tunnel to be driven through bedrock, with a possibility of encountering a major fault zone at the tie-in to the existing Mayo A tunnel. The plan was to break through a possible fault zone, and connect to the Mayo A tunnel near its downstream end, at approximately 30m depth below ground surface. The experience gained from construction of Mayo A tunnel in the 1950s indicated difficult tunnelling through the fault zone, forcing a tunnel diversion and installation of a grout plug to avoid prolonged schedule delays. Therefore, given the previous undesirable tunnelling experience within the Mayo A tunnel, this alternative was rejected.

The third alternative required a tie-in and modification

Gordon McPhail
Is a technical engineer and manager of the hydrotechnical services department at KGS Group

Boro Lukajic
Boro is an independent Consultant, based in Mississauga, Ontario, Canada

Table 1. Summary of blast vibration data (PPV - Peak Particle Velocity)

Rounds	PPV (mm/s)	Charge weight per delay (kg)	Zero crossing frequency (Hz)	Scaled distance (m/kg1/2)
68-80	1.02-15.70	5.5-12.2	51-100	9-33.5

Source: Authors

of the existing Mayo A intake, with construction of a 300m-long bedrock tunnel, and a 3.2m-diameter, steel penstock approximately 3.6km in length (Figures 2 and 3).

By using this arrangement, the modified intake would be common to both the Mayo A and Mayo B hydro plants. The steep rock slope on the reservoir shore at the intake, combined with the depth and design of the intake, made dewatering of the existing intake very challenging, and even more so for construction of a new intake. The reuse and tie-in to the existing Mayo A intake had construction risk, but also significant overall cost savings. This alternative was ultimately approved on the basis of relatively low associated construction risk, suitable access, and competitive construction cost, as compared to the alternatives examined.

CONTRACTUAL ARRANGEMENT

KGS Group consulting engineers (KGS) from Winnipeg, Manitoba, and Peter Kiewit Infrastructure Group (PKI), were the prime consultant and contractor to YEC. KGS and their subconsultants were responsible for overall project design and quality control during construction. PKI was responsible for all construction activities, as well as for the contractual arrangements with their subcontractors.

Several challenges were addressed while planning and constructing the Mayo B project. These included a short construction season due to the cold weather, discontinuous permafrost areas, and other logistical hurdles such as long transportation routes, and timely availability of equipment and materials. Recognising these challenges, and in order to minimise construction risks, YEC and KGS engaged PKI in the project during the planning and design stages. Thus, the experience gained in the early stages of the project enabled the construction teams to meet the challenges associated with a remote site in a sub-arctic climate. The finances for the project were jointly provided by the governments of Canada and Yukon Territory. The total estimated construction cost of the project was in the order of CAD 100M (USD 87M). Mayo B created more than 60 direct jobs for Yukoners during construction, and also provided spin-off benefits to about 120 Yukon businesses.

CONVEYANCE SYSTEM DESIGN

The Mayo B project has a common intake with the existing Mayo A plant. The two systems (Mayo A and Mayo B) bifurcate approximately 10m downstream of the intake gate. From the bifurcation, the Mayo B tunnel advances for about 300m, where it then transitions to the steel penstock (Figures 2 and 3). The design flow for the Mayo Complex (Mayo A and Mayo B Generating Stations) is 25m^3/s. These flows correspond to 6m^3/s minimum flows in Mayo A and 19m^3/s to Mayo B. The tunnel is a 3.5m by 4m horseshoe or inverted "U" by design. A survey of the tunnel cross section shows an average flow area of 16m^2, and an average hydraulic radius of 1m. The Darcy-Weisbach friction factor was estimated to be 0.054 (minimum) to 0.29 (maximum), including friction and form losses.

The buried steel penstock is circular, with an internal diameter of 3.2m, and wall thickness of 12.7mm. The Darcy-Weisbach friction factor is 0.0104 minimum, and 0.0285 maximum. The penstock is designed for a maximum surge increase of 35 per cent above static pressure.

The penstock conveyance also includes a surge facility. This reduced surge pressures on the penstock, but also enhanced unit operation. It consists of an arrangement of two inclined pipes, laid at 90° to the penstock and extending up the penstock route cut slope, on a naturally occurring high elevation ridge. Air from the surge facility is expelled through a heated vent, with a top elevation of approximately El. 598m, or approximately 23m above the typical reservoir level.

TUNNEL PORTALS

Intake rockslope

Immediately behind the existing intake structure, a 25m to 30m high bedrock cliff, including areas of overhanging rock, was present. Inspections and observations of the rock slope conditions began as early as 1979, with inspections and localised works completed during the mid-1990s (by others).

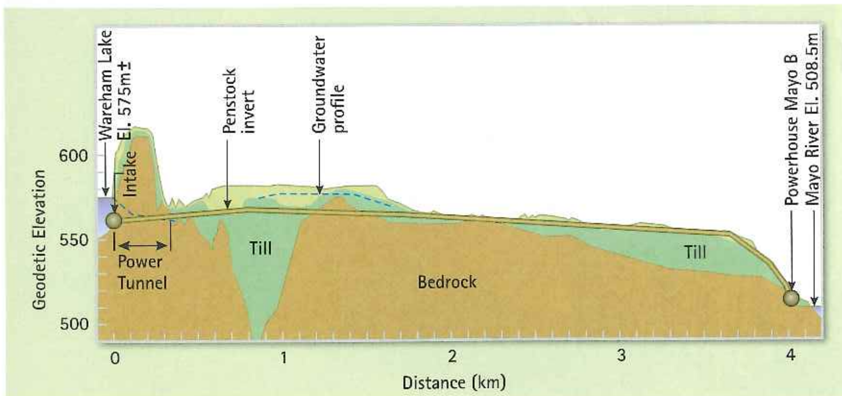
The rockslope inspections during 2007/2008 and 2010 revealed that the slope consisted of well-jointed, fractured, and blocky rock. The bedrock slopes are controlled by bedrock structure, consisting of schistosity (foliation bedding) and at least two major joint sets, with generally subvertical to vertical dips toward the reservoir. Predominant joint set discontinuities include AZ 202° to AZ 262°, dipping 63° to 90° to the northwest; AZ 290° to AZ 325°, dipping 60° to 75° to the northeast; AZ 277° to AZ 346°, dipping 88° to 90° to the northeast; and schistocity striking AZ 22° to AZ 80°, dipping 9° to 30° to the southeast (i.e. into the rock face). Bedding

"Experience gained in the early stages of the project enabled the construction teams to **meet challenges** associated with a remote site in a sub-arctic climate"

Above: Work on the Mayo B project was subject to shortened construction season due to cold weather

thicknesses were typically <25mm and up to 600mm, with joints at sub-meter to 5 to 10m spacing.

Open vertical joints were noted in the rock face on both sides of the intake structure. Frost penetration measured up to 6m depth within the rock face likely played a role in widening and deepening the open joint zones. Additionally, differentially weathered and highly altered chloritic bedrock zones, formed along the predominant schistocity of the rock, were noted at distinct elevations within the rock face at El. 582m +/- and at El. 590m +/- (reservoir El. 575m +/-). Along with the predominant jointing within the bedrock, these "soft" friable bedrock zones created undermined, overhanging conditions at the rock face as well as weak bearing surfaces supporting the columns of detached bedrock above them.

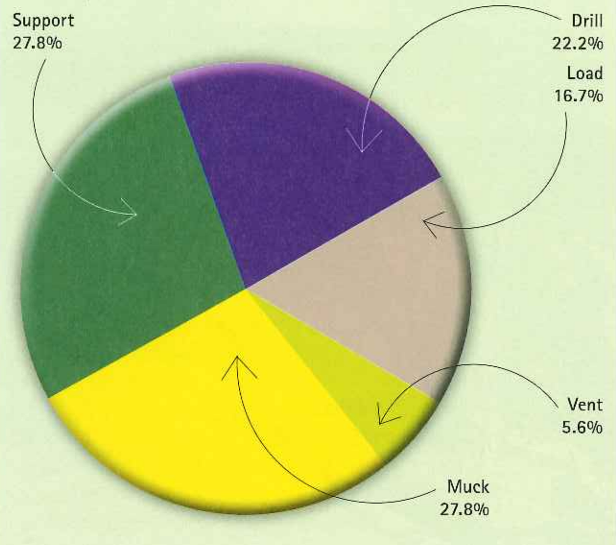


Below: Figure 3, Profile along the Mayo B project

With the bedrock blocks partly disjointed and unstable, inspections identified both potential for toppling and wedge/overhanging rock failures. Stabilising the intake rock slope presented several difficulties and risks to the operations of the intake structure. Failure to successfully remove loose blocks and grade back the soil and rock slopes above the intake could have resulted in catastrophic collapse of rock mass protracting Mayo B construction delays and costly repairs of the intake structure.

Two alternatives were evaluated for stabilisation of the rock face and associated overhangs, including controlled line drilling with light explosive charges, or benching by scaling. The contractor opted for the latter option, using heavy equipment to perform scaling and benching. Blasting proved unnecessary due to the highly fractured and weak nature of the rock. A machine excavated "sinking cut" of approximately 3m to 3.5m was advanced well behind the rockslope face, followed by pulling back of the rock slope face into the sink cut area, using a hydraulic

Typical averaged mining cycle observed at Mayo B



excavator. Rock materials were stripped back into the sink cut along foliation.

Downstream portal

A steep soil slope exists above the bedrock at the downstream portal area.

Evidence of sloughing and sliding of the slope was noted in test excavations conducted during design investigations at the rock slope, associated with the proposed portal area. Unlike at the intake area, the schistocity of the rock at the downstream portal dips out of the rock slope face. A limited number of discontinuity measurements were collected on the rock slope at the downstream portal. Bedrock structure included at least three steeply dipping sub-vertical joints, and a strong schistocity (foliation). Portal stabilisation works required construction of a series of access roads and benches on the slope, then proceeding with stabilisation work from the top down. Design of the portal stabilisation was by Golder Associates, for PKI.

The area surrounding portal opening was stripped down to bedrock, and then reinforced. A series of 6m long, 25mm diameter fully grouted threadbars in a 3m by 2m, offset row pattern were installed on the upper slope, completed with wire mesh and 50mm of shotcrete. The lower slope included 6m long, 25mm diameter fully grouted threadbars on a 2m by 2m pattern, with 2m-long split sets installed split-spaced between each grouted threadbar. Wire mesh and a 50mm layer of shotcrete completed the slope works. Once the invert of the slope was reached, a series of 4m long, 25mm diameter fully grouted threadbar

Above: Figure 4, Typical averaged mining cycle

Below: A stretch of comlpeted tunnel

spilings were installed above the tunnel crown. Steel sets and lagging were also installed to create a canopy, once the tunnel was initiated.

TUNNEL CONSTRUCTION

Structural geology

The predominant schistocity of the bedrock dips out of the tunnel face, with dips up to 30°. As such, the design assumption was that there would be tendencies for rock to fall out, in particular when encountering chlorite schist layers, or where wide zones of weaker quartz-mica schists to phyllites were prominent. The impact of these bedrock zones on the tunnel overbreak conditions was considered during design. Three primary sets of joints were anticipated along the tunnel drive (tunnel drive approximately AZ 333°).

Predominant joints were perpendicular to the tunnel (striking AZ230° to AZ250°, dipping 70° to 90°) and another striking at approximately 45° to the proposed tunnel alignment (AZ285° to AZ320°, dipping 70° to 90°). The third predominant set is parallel to bedding (foliation, striking AZ18° to AZ50°, dipping 10° to 40°. In addition, several persistent, gouge-filled shear zones were identified, including those along foliation (striking AZ06° to AZ40°, dipping 30° to 60°), and others striking AZ315° to AZ335°, dipping 35° to 55°. Other joints and fracture sets of lesser persistence (i.e. <1 m) were identified during tunnel mapping, but are not detailed here. There were no indications for any swelling characteristics of the rock.

Rock strength and stresses

The rock along the tunnel alignment was classified as weak to medium strong rock. Several core samples were tested for uniaxial compression strength (UCS) during the 2008 exploratory programs. One compression test yielded 88MPa strength, while another test failed on a pre-existing joint, yielding 26.5MPa strength. During the 2009 exploration program, additional core samples were subjected to Point Load tests, producing strengths in the range of 2.8MPa to 33MPa.

In-situ stress measurements were not carried out in the project area. Based on the project configuration, tunnelling depths, and bedrock morphology/site conditions, it was anticipated that the in-situ stress condition in the tunnel zone

"Observations during tunnelling did not reveal signs of predominant **stress** relief along the tunnel crown/walls."

was not going to be problematic for construction of the power tunnel. Observations during tunnelling did not reveal signs of predominant stress relief along the tunnel crown/walls, such as spalling.

Tunnel support

In order to provide an index of the relative behaviour of rock mass, the RMR system (Bieniawski 1976 and 1988) was used. The analyses of RMR, based on the exploration boreholes drilled during 2008 and 2009 identified the need for the following classes of rock support:

Type 1 represents ground conditions corresponding to the best rock quality, having uniaxial compressive strength (UCS) in the range of 75MPa, with the RQD = 50 to 75 per cent. The resulting RMR value for a drill and blast method is 65, corresponding to "good" quality rock. Recommended initial support for this rock type consisted of 2m long resin bolts; at 1.3m spacing normal to tunnel axis and 2m spacing along tunnel axis.

Type 2 represents ground conditions corresponding to rock formation having UCS less than 75MPa, RQD = 25 to 50 per cent, and the resulting RMR for drill and blast is 50, corresponding to "fair" quality rock. The main difference between Types 1 and 2 is the spacing of the horizontal joints. Recommended initial support consisted of 2m long resin bolts; installed as per Type 1, with shotcrete as required.

Type 3 represents ground conditions corresponding to "poor" quality schist, having UCS as low as 1MPa, RQD less than 25 per cent, and discontinuities (joints and beds) spaced less than 60 mm. The resulting RMR for drill and blast is 25, corresponding to poor rock. It was determined that the rock of this category would likely have short stand-up time and would produce significant overbreak. Recommended initial installed support consisted of 2m long resin bolts installed on a 1.25m by 1.25m pattern accompanied by 50mm of shotcrete. In all cases, spot bolting was added where required in the field, as directed by the Contractor's engineer. In addition, grouted spilings, plus structural steel sets at 1.2m spacing were installed within the first 15m of the tunnel.

Lagging and timbers were used to bridge and support the rock between the steel sets, to control loose ground, or ground that could be difficult to shotcrete.

Tunnel excavation

Excavation was by conventional drill and blast method with the Contractor using a two-boom, truck mounted jumbo. It was determined that this construction method would have the lowest unit cost and would have the greatest probability of successfully achieving the desired construction progress for the site ground conditions. Furthermore, it was concluded that this method could take advantage of the existing experience and skill sets held by the Contractor's (Procon/ Na-Cho Nyak Dun joint venture) labour force.

Orica Canada supplied all explosives and other blasting accessories for the project. In an attempt to keep overbreak and blast damage at the portal to a minimum, the initial blast rounds were short, and fired with highly accurate eDevTM electronic detonators. As the tunnel advanced into more competent rock, non-electric ExelTM LP detonators were used. Programmable electronic detonators were used again as the excavations reached tie-in structure (closest to the intake and reservoir). All blast holes were 38mm in diameter, primed with Geldyne dynamite. Sticks of Geldyne cartridges were placed behind the primer and tamped (averaging eight cartridges per 3.5m-long drill hole). A 300mm unloaded collar was allocated for each blast hole to ensure that the likelihood of undetonated explosives in the muck pile was minimised. Perimeter holes were primed with Geldyne cartridges, 32 by 400mm size and then loaded with Xactex (19 by 600mm). The "burn cut" for the production rounds consisted of three unloaded 75mm reamer holes. Amex was often used in production holes during general tunnel advancement as well.

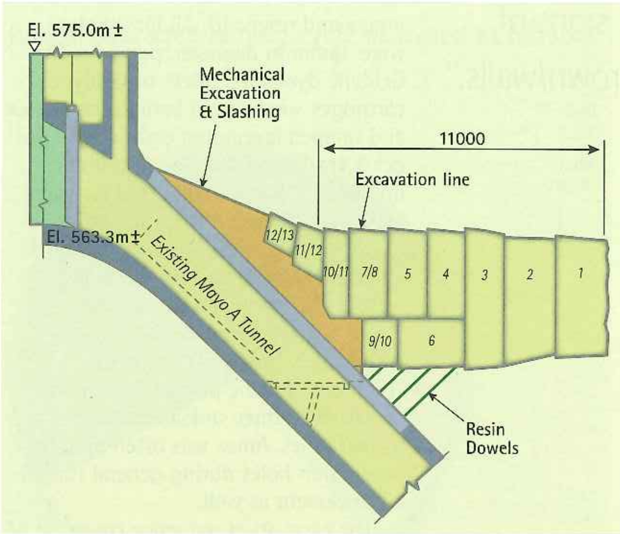
The excavation sequence consisted of drilling, explosive loading, mucking and installation of rock support (advancing in approximately 3m increments). A typical time-cycle of excavation is shown in Figure 4.

Excavation works were conducted 20 hours per day on a two-shift basis from June 2010 to October 2011. Tunnel operations were suspended between Nov 2010 and May 2011, for winter shutdown. A groundwater monitoring program was instituted during shutdown, consisting of the drilling of three horizontal probe holes, advanced at the tunnel face, to 5m, 10m, and 20m depth, and a fourth, 10m-long hole at a 10° decline angle. Initial measurements indicated that flow from the holes, with all holes open, was approximately 140 L/min. Subsequent readings indicated that the flows from the probe holes were gradually decreasing, suggesting that the flows had reached a "steady state" condition. Observations continued through the shutdown period to ensure that a "steady state" seepage condition remained. Construction of the tunnel resumed in the spring of 2012.

Tie-in intake transition excavation

The tie-in transition excavation was rectangular and approximately 6m by 5m in size, in order to allow for placement of concrete formwork and steel for construction of the transition. Initially, the contractor proposed to perform the excavation work by a pilot and slash method (Figure 5).

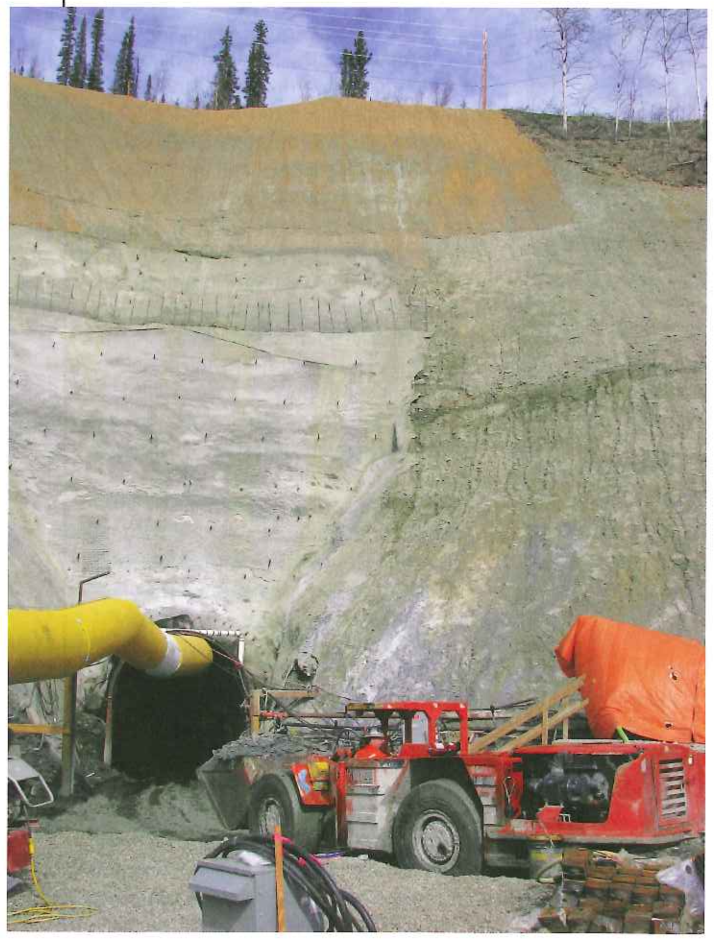
As the work progressed, the blasting operations were re-adjusted to accommodate the overall weak rock structure, and to prevent damage to the existing Mayo A tunnel liner. As the intake could not be dewatered, all tunnel and tie-in work was performed with the intake gate in place and with reservoir



pressure on the gate. Measures taken to address concerns included frequent probe hole drilling, the use of precision electronic detonators, and a specific controlled blasting plan. Mechanical excavation was required near the existing concrete liner. Blast monitoring was strictly enforced, particularly when the tunnel was approaching the tie-in, to determine if amplification of blast vibrations was occurring at the existing concrete intake/tunnel structures.

Above: Figure 5, Tie-in transition excavation sequence (numbered)

Below: View of the completed downstream tunnel path



Frequencies of 50Hz to greater than 100Hz were desirable and were generally achieved. Examples of monitoring data from the existing intake concrete structure, spillway structure, and intake structure bedrock, are presented in Table 1.

Overbreak

The design specified that an acceptable average overbreak be kept to within 150mm. This was considered achievable, provided that light trim charges were used in the perimeter holes. Overbreak occurred mostly in the tunnel crown, often along individual chlorite schist layers, or along weak foliation/shear zones. Deeper overbreak was evident in the areas where the tunnel intersected thin beds of phyllite at an oblique angle, or where the tunnel drive became essentially sub-parallel to the low dip of the bedrock formation foliation, in some cases resulting in wedge fall-out. In these cases, overbreak of 200mm to 300mm was common during the tunnel excavation. Excessive overbreak also occurred at locations where Amex explosive was extensively used. Some areas with significant overbreak were partially infilled with shotcrete to reduce hydraulic abruptness, and losses.

Tunnel shotcrete lining

The final tunnel lining was selected in accordance with the required tunnel hydraulics, as well as for long term tunnel stability requirements. The lining within the tunnel proper consists of 150mm thick, fibre-reinforced shotcrete. Drains were drilled through the shotcrete and into the bedrock formation within the tunnel crown, and within each sidewall, at approximately 5m intervals along the tunnel length. The drains were designed to allow for a reduction in hydrostatic pressure against the shotcrete liner, when the tunnel is in an unwatered condition. Approximately 150 drains were installed, complete with 1.3m long, 25mm diameter slotted Polyvinyl Chloride (PVC) pipes, epoxied into place within the shotcrete portion of the drilled holes.

It was thought that the portal, with its location in highly weathered bedrock, would tend to be more likely to suffer blast damage. Hence, the lining in this portion of the portal was designed to withstand higher anticipated stresses. In addition, a 30m long steel liner, with the annular space backfilled with concrete, was installed within the downstream end of the tunnel, to transition to the steel penstock.

The liner was also designed to mitigate any possible hydraulic fracturing of the downstream portal slope under emergency shutdown and surge conditions. A double grout ring, each ring comprised of eight holes, each hole offset from the others and approximately 2m deep, were drilled into the bedrock and grouted at the upstream end of the steel liner. These were completed prior to installation and final encapsulation grouting of the steel liner. A series of proof holes were also drilled and tested following initial grouting of the two offset grout rings, to verify grouting effectiveness within the bedrock at the downstream transition.

The intake transition (tie-in area) was constructed with 400mm to 600mm thick cast-in-place reinforced concrete, and was designed for full exterior hydrostatic pressure that may occur during tunnel dewatering and inspection. The concrete structure at the intake transition, and the encapsulated tunnel outlet steel liner, were also post grouted after curing, using Fuko injection hoses.

Seepage during tunnelling

It was anticipated that the bedrock units, as observed during the initial site investigations, would not yield significant volumes of seepage during the tunnel drive. Water pressure testing of the bedrock within the tunnel zone, measured during investigation programs, varied between approximately 0 Lugeons (L) to approximately 15 L. The highest water takes were measured at the holes closest to the intake structure/tunnel tie-in and intake rock slope. At the time of investigations, the intake rock slope had not been scaled, and as such, testing of bedrock permeability characteristics could not be completed closer than approximately 30 m down-tunnel alignment from the existing intake tie-in location. At distances of 100 m or so from the intake tie-in, the takes were typically lower and between 0 – 1 L. This permeability variability was also reflected in the static groundwater levels at the exploration boreholes (see Figure3). The majority of the tunnel seepage observed occurred within approximately 50m of the tie-in structure area, being closest to the reservoir. Conventional grout curtains were installed once the excavation was within approximately 40m to 45m of the intake tie-in, as tunnel seepage volumes were increasing.

A series of nine overlapping grout curtains were emplaced, each installed by drilling a pattern of up to 12m long grout holes at specific angles into the tunnel face, as the tunnel excavation advanced to the tie-in. When approaching the tunnel tie-in area, and as noted during project investigations, reservoir-equivalent pressures were measured in the grout holes, indicating that open and reservoir connected fractures in the rock structure were present.

Many of these zones were successfully grouted during the advancement of the tunnel.

The amount of grout take for each hole was dependant on the joint conditions, and emplaced grout was allowed to set for a shift, or more. The following day (or shift), probe holes were drilled to examine the effectiveness of the previously completed grout curtain, prior to blast pattern drilling and loading.

In the event that seepage inflows from probe holes exceeded approximately 10 L/min to 15 L/min in total, additional grout holes were drilled and grouted prior to any further drilling and blasting. Overall, relatively minor seepage was observed in the tunnel proper (between the tunnel tie-in and downstream portal). Seepage was usually concentrated in rock bolt and probe/grouting holes, and was grouted as required, prior to advancing the next blast round.

Tunnel survey and mapping

Throughout the project, KGS utilised Topcon GR-3 survey grade receivers, Topcon total stations, and a Leica HDS C10 scan station to laser scan the inside of the Mayo B tunnel. Survey control established at the downstream tunnel portal was brought into the tunnel to allow for 3-D tunnel scanning using the Leica equipment, producing scans with a point density of 10mm to 15mm with an accuracy of 5mm to 8mm. Data from the tunnel scans was used to produce volume calculations, confirm alignments and tunnel geometry (particularly in 3-D space at the tie-in), produce as-constructed information, and to assist with field-based design modifications.

The KGS site engineer completed mapping of the tunnel geology after each blast. The geological sheet developed for the project represents a developed cylindrical view of approximately a 3m interval of tunnel. Each mapping sheet summarizes the component RMR values, including rock type(s). The collection of this data by KGS was primarily related to compilation of the as-built record of the tunnel for YEC. Golder Associates performed mapping for PKI for determining and identifying all initial tunnel support requirements.

Review mapping of the tunnel as a whole, prior to final shotcrete installation, was completed at the end of the first construction season (November, 2010), and also during final construction phases of the tunnel during 2011. The compiled as-built tunnel condition mapping provides YEC a record that subsequent tunnel inspections may be compared to, even though the completed tunnel is lined with shotcrete.

CONCLUSIONS

The Mayo B hydroelectric project provides additional electricity to the Yukon Territory, hence displacing diesel generation that would otherwise be required to meet the various increasing electricity demands. Operation of the Mayo B facility offsets as much as ten million dollars in annual diesel fuel costs, and eliminates approximately twenty five thousand tonnes of greenhouse gas emissions per year.

Planning and executing a construction project in remote regions of the Yukon Territory is challenging, primarily due to the cold-related short construction season and other logistic hurdles, such as the timely availability of equipment and material. Recognizing these challenges, YEC and KGS proceeded to engage the construction Contractor at the early stages of the project. The owner (YEC), designer (KGS and their subconsultants) and contractor (PKI, and their subcontractors) are credited for completing the project without significant overall delays or injuries. Careful planning, the use of precision survey tools, and input from subject matter experts in control blasting and grouting were key factors in the successful completion of tunnel tie-in.

Mayo's "alliance model" contracting experience could prove useful while planning other projects, in similar challenging environments. The project was designed and constructed in less than two years between preliminary design to first power. This schedule was only achievable due to close, continued communication and cooperation between YEC, KGS, PKI, and the various subcontractors and subconsultants involved with the project

The writers would like to acknowledge the important contribution of a number of individuals from YEC, KGS Group (and their subconsultants Knight Piésold and Amnis/HDR), Peter Kiewit Infrastructure, and their subcontractors (Procon/Na-Cho Nyak Dun joint venture/Golder Associates, Burnaby, BC) participating in this project. Specialist input from Gord Revey for controlled blast designs, and from Peter White (Multiurethanes) for tunnel grouting, when approaching the intake tie-in, were essential to the success of the Project. Special thanks to Yukon Energy Corporation for approving this paper and for their assistance throughout the project

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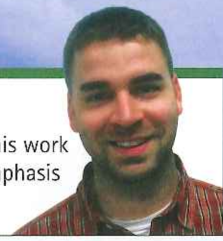
Yukon Geological Survey - Map Maker Online *http://mapservices.gov.yk.ca/YGS/WebMap.aspx*

Jesse Schneider
Jesse is a mechanical engineer, and his work in heavy civil construction has an emphasis on equipment and system design



Tony Dell
Tony is a civil engineer with more than 40 years of experience, and involved in the full range of project services

HARTBEAT

Updating the John Hart Generating Station requires a new underground powerhouse. **Jesse Schneider** of *Frontier-Kemper Constructors, ULC*, and **Tony Dell** of *SNC Lavalin Power*, discuss the proposed design and construction approach for the project

THE JOHN Hart Hydroelectric project is located on the Campbell River and close to the town of Campbell River on Vancouver Island, British Columbia.

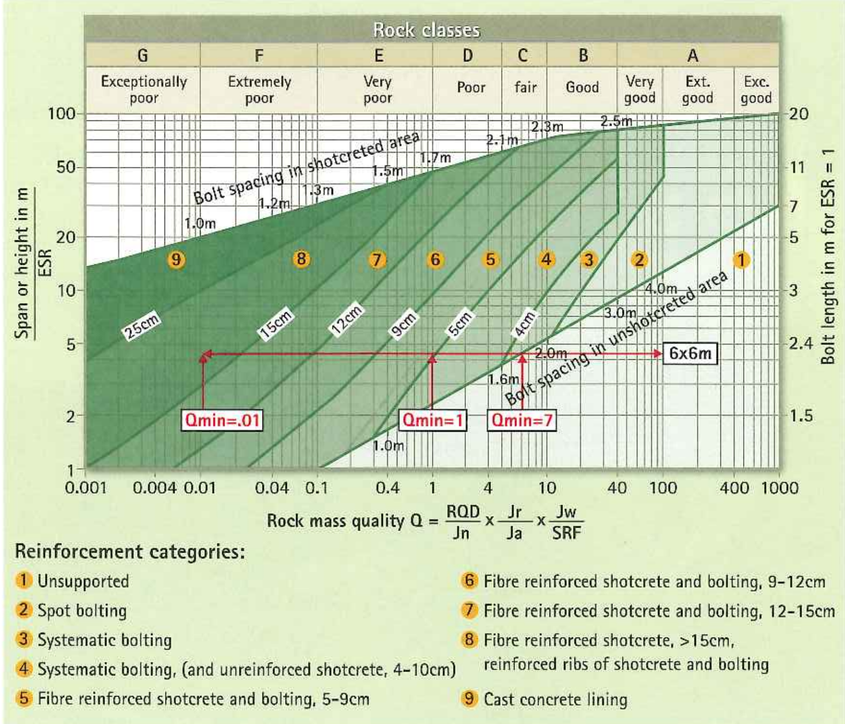
The project team of SNC Lavalin, Aecon, and Frontier- Kemper Constructors have been selected to carry out this design-build project. The underground powerhouse is a concept that provides many benefits to the area, in particular the small project footprint, as the project is situated adjacent to a Provincial Park.

Combined with the efficiencies of modern drill and blast technology, the underground powerhouse will make the John Hart Generating Station Replacement Project (JHGSRP) a safe and cost effective alternative to traditional surface penstock and powerhouse options. The underground powerhouse is located where the rock cover is sufficient to prevent hydrojacking, thus obviating the need for approximately 700m of steel lined tunnel.

The underground excavation and support portion of the contract is scheduled for a duration of approximately three years. The entire generating station including power facilities, turbine installation and commissioning of the project is scheduled to be completed in approximately two additional years, for total project duration of five years.

GEOLOGY

The only lithological type encountered in the John Hart area is basalt (a mafic volcanic rock) from the upper sequences of the Karmutsen Formation, which is late Triassic in geological age (about 200M years old). Most of the basalts in the area have undergone low grade regional metamorphism.



Above: Figure 1. Empirical Support for Service Tunnel

Below, left: Existing John Hart facilities including the steel penstocks and surge towers

A variety of original scale geological faults have been mapped in the region, but none appear to cross the study area. The closest previously mapped original scale geological fault occurs 1km to the south of the study area, it strikes west-northwest--east-southeast.

In spite of the observation that the closest "previously mapped geological fault occurs 1km to the south of the study area", there are fault zones which include zones of damaged rock, which are weaker than the rock mass outside of the fault zone and may contain polished or slickensided discontinuities and microfractures.

The bedrock along the tunnel alignment is expected to consist of basalt that has been subjected to low grade metamorphism, but is generally fresh.

Minor alteration (e.g., carbonate, epidote, and chlorite) is common within and adjacent to faults zones, but does not extend far from the fault boundaries. The altered rock, where present, generally exhibits lower strength and reduced rock mass quality values.

A cap of slightly weathered rock typically 0m to 3m thick was noted at the surface. Where present, this rock exhibited slightly lower strength.

Cognizance has been taken of the possibility that fault(s) may intersect the powerhouse and additional support allowed for this contingency.

In summary, the rock mass is relatively good quality, strong (UCS ave 122 MPa; Intact Modulus ave 64GPa) basalt with two sub-vertical joint sets, and the sub- flow contacts – described where encountered in borehole core as "welded".

With regard to the faulting: five "major" faults and several "minor" faults are anticipated.

The existing project consists of an intake structure in the John Hart Reservoir; surface penstocks (woodstave for the low pressure section and steel for the high pressure section) to a surface powerhouse with six units.

DESCRIPTION OF REPLACEMENT PROJECT

The JHGSRP consists of the following:

- A new intake through the existing concrete dam;
- A 6.5m diameter intake shaft;
- A power tunnel (8.1m by 8.1m, "D" shape);
- An upstream surge shaft: 4m diameter; 109m deep;
- An underground powerhouse 23m x 39m x 93m;
- A gate house structure;
- A downstream surge system;
- A tailrace tunnel;
- A tailrace outlet structure;
- Two access tunnels; and
- Various construction adits, from 6m x 6m to 9m x 6m.

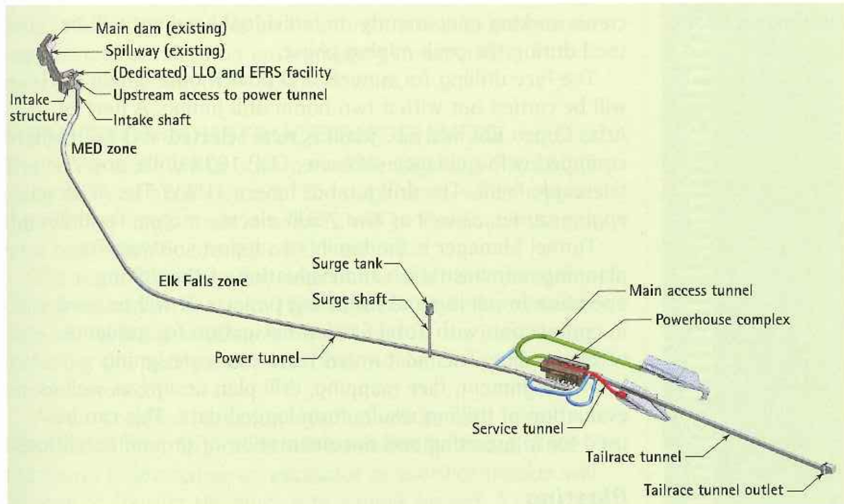
DESIGN ASPECTS

The design life of the power tunnel and powerhouse is 100 years, so all rockbolts are corrosion protected.

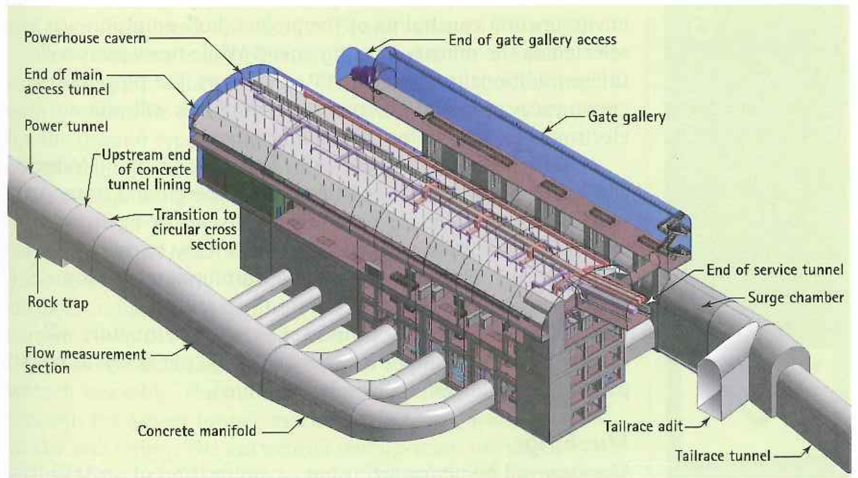
Twenty-one exploratory boreholes were drilled during the investigation of the proposed JHGSRP. All of these boreholes were logged and some were surveyed with optical and acoustic televiewers. In addition to the boreholes, surface mapping of the exposures of rock along the gorge between the dam and the existing powerhouse was carried out.

A further three boreholes are planned, specifically to investigate the major fault along the tunnel alignment and the powerhouse. The boreholes planned will all be logged and surveyed with an acoustic televiewer. The holes used for the investigation of the powerhouse will also be subjected to hydrojacking tests. The borehole logs and the surface mapping were used to assess the rockmass characteristics along the tunnel alignment and assign proportions for the various rock mass classes (Class I, Class II, Class III and Class IV) to the power tunnel. One borehole was drilled in the location of the powerhouse and this borehole was used in the preliminary design of the underground powerhouse.

As indicated, two more boreholes will be drilled and this information will be used to confirm or refine the design of the powerhouse support.



Top: Layout of the John Hart project



Bottom: Figure 2. 3D Rendering of Underground Powerhouse.

General design process

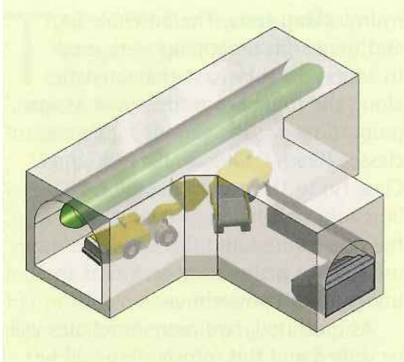
The design process for all the underground structures uses the following general procedure:

- Break the tunnels into sections with a range of rock mass characteristics, as defined by the Q1, RMR2 and/or GSI3 rock mass rating systems.
- Use the empirical Barton – Grimstad method (Grimstad et al. 1993) moderated with experience in other similar projects to get a preliminary support system. The support system would be for a given range of rock mass characteristics. For instance: for the power tunnel there would be four "Support Classes" – ranging from spot bolts only to pattern bolts and shotcrete to lattice girders and thick shotcrete support. See Figure 1.
- Consider the joint sets and make sure any wedges/blocks are adequately supported by the support system.
- Use finite difference (FLAC) and/or finite element (Midas GTS) methods to ensure that the rock mass and elements of support, the shotcrete, rockbolts and lattice girders are not overstressed.

Design of the powerhouse

A 3D rendering of the underground powerhouse is shown in Figure 2. The power tunnel can be seen approaching from the right; the rock trap can be seen at the extreme right, the manifold with three bypass valves and three intakes, the gate chamber and the tailrace tunnel. Sections of the two access tunnels can also be seen.

The location of the powerhouse was chosen so that the rock cover is sufficient to prevent hydrojacking of existing joints. Two criteria were used to evaluate this. The first was the Norwegian criterion: the factor of safety used was effectively 1.6. The second criterion will be used to confirm the location, which is a hydrojacking test



carried out in a borehole. The factor of safety against hydrojacking for this test is 1.3.

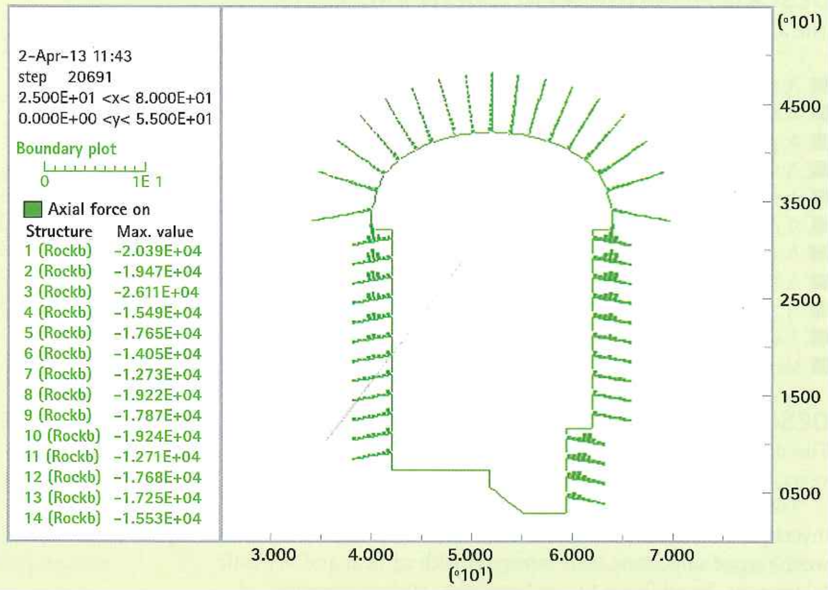
Since only one borehole was available at the preliminary design stage, the borehole data was evaluated and a design value chosen for the tunnel and the same general method of design was used as described for the tunnels. However, some conservative assumptions were made to allow for the following eventualities:

- The rockmass is poorer overall. In this case, heavier support is required – a thicker layer of shotcrete and longer, more heavily loaded rockbolts; and
- A fault runs directly through the powerhouse parallel to the main axis. For this case some additional support was required, particularly in the sidewalls and locally adjacent to the fault.

The FLAC analysis showing the loads in the rockbolts for the design case is shown in Figure 3. Where appropriate, FLAC 2D was used for the stress and deformation analyses of the tunnels and powerhouse. Where 3D analyses were required, for instance for the analysis of seepage between the power tunnel and the powerhouse and the analysis of the large span of the main access tunnel at the intersection with the gate chamber, Midas GTS was used.

Assumptions have been made regarding the hydraulic head losses, based on the roughness of the power tunnel. As head loss is a critical aspect of the project, measurements will be made, using precise survey techniques, of the crown of the powerhouse as the pilot drift is being driven to determine the overbreak characteristics.

These measurements will then be extrapolated to the power tunnel to calculate the head losses in the tunnel. If the head losses are too high, the dimensions of the tunnel can be adjusted to reduce these head losses to acceptable values.



Above, left: Figure 4. And example of the muck bays.

Above:, right Figure 3. FLAC Analysis showing loads in rockbolts.

METHOD OF CONSTRUCTION - TUNNELS

Tunneling will start with a single crew working on the L40 heading, which will function as the service access for the powerhouse, and continue into the powerhouse crown. Shortly after the L40 heading is started, the L20 portal, serving as the main underground access, will be prepared and ready for tunneling to commence with a second crew. Three crews working concurrently on individual headings will be used during the peak mining phase.

The face drilling for tunnels and powerhouse crown level will be carried out with a two boom drill jumbo. A fleet of Atlas Copco Boomer E2C jumbos were selected and will come equipped with guidance software, COP 1838 drills, and 7.1m telescopic feeds. The drill jumbos have a 115kW Tier 4i diesel engine carrier, as well as two 75kW electric motors for drilling.

Tunnel Manager is the family of support software for planning, administration and evaluation of the drilling operation in mining and tunneling projects. It will be used in conjunction with Total Station navigation for guidance of the jumbos. The most noted features are designing tunnel alignment, face mapping, drill plan design, as well as evaluation of drilling results from logged data. This can be used for interpreting and documentation of ground conditions.

Blasting

To ensure costs were minimised while complying with the strict environmental constraints of the project, bulk emulsion was selected as the primary blasting agent. While most areas will utilise traditional non-electric LP detonators, the powerhouse crown excavation and power tunnel trim holes will utilise electronic detonators for precision blasting.

A Normet Himec/Charmec series Explosive Charging Vehicle and Personnel Lifter will be utilised for underground transport and loading of the explosives. These units will be equipped with a bulk emulsion pumping system for easy transfer.

Due to the sensitive nature of the surrounding existing structures that are still in operation, there are strict requirements on blasting controls. Electronic detonators will further assist the team in minimising charge per delay, as peak particle velocities will be closely monitored.

Mucking

Mucking will be performed using a combination of an LHD (scoop) and mine truck. The Atlas Copco ST14 scoops were selected with a heaped capacity of 7m3, which will carry approximately 14 tons of material. A Cummins 250 kW Tier 3 diesel engine powers the scoops.

For mine haulage, Atlas Copco MT42 trucks were selected. These trucks have a heaped capacity of 21m3, which will carry approximately 42 tons of material. Cummins 388 kW Tier 3 diesel engine powers the trucks.

For the first few hundred meters of tunnel, solely the scoops will be used for mucking and hauling. Once the tunnels are advanced far enough, muck bays will be developed every 250m of tunnel. An example of a muck bay is shown in Figure 4. This will allow for quick mucking away from the face by moving the muck a limited distance. This clears the face quickly for ground support activities to occur simultaneously with the rest of the muck cycle. The scoop loads up to three heaped bucket loads into a mine truck at the muck bay for delivery to the surface.

Ground support

The ground support regime consists of shotcrete, rock bolts, and lattice girders depending on ground type classification.

The contractor plans to use an in-cycle shotcrete approach, applying shotcrete as the primary ground support immediately following mucking and hydro-scaling. Shotcrete mix design will use admixtures that achieve early strengths approaching 1 MPa in the first hour, while maintaining long term strength requirements per contract. Bolting can be performed with the jumbo, providing primary ground support for miners to access the face safely. A double corrosion protection type bolt will be used, in which an expansion anchor can be set during initial installation. This provides increased robustness to the ground support regime, allowing post-grouting to occur later in the cycle simultaneously with other activities.

METHOD OF CONSTRUCTION - SHAFTS

The intake shaft will be sunk conventionally from the surface using drill and blast methods. The surge shaft, which replaces the existing surge tower structures, will be developed using a raise bore machine located on the surface.

The 6.5m diameter, 60m deep intake shaft is situated in close proximity to the John Hart Reservoir and the existing dam and spillway structures. For this reason, the blast design, including the peak particle velocities will be closely controlled and monitored.

An air-powered tophammer jumbo will be used for all blasthole drilling. Explosives will be manually loaded. Once the round is detonated, an excavator or overshot mucker will be used to transfer the muck into a muck bucket. A crane will hoist the muck bucket to the surface, where it will be offloaded and then transferred to a haul truck and removed from site.

Once mucking is complete for that round, the ground support regime will commence. This consists of rock bolting with the possible addition of 50mm thick shotcrete as required for the ground type classification. The intake shaft will be completed before the power tunnel excavation reaches it.

The surge shaft will be excavated by a raise boring machine located on the surface. To begin this, the power tunnel excavation must reach the location of the surge shaft. The 350mm pilot hole will be drilled by the raise drill from the surface, connecting down to a stub tunnel off the power tunnel. When the pilot hole breaks through underground, the pilot drill bit will be removed with a specialized hydraulic wrench assembly. The 4.3m diameter cutterhead is brought in through the power tunnel, assembled in place, and connected to the drill string. The cutterhead will up-ream the shaft, letting the muck fall to the bottom. The muck will be removed with the scoop.

Once the shaft reaming is complete, the raise bore machine and cutterhead will be removed from the shaft collar. The ground support regime will commence, applied from a crane hoisted work platform. A combination of 75mm thick shotcrete, as well as patterned rock bolts will be installed as required for the ground type classification.

THE POWERHOUSE

The powerhouse will be constructed by driving a pilot tunnel along the alignment of the top of the crown of the powerhouse. When the L40 tunnel is driven down to the powerhouse, it will continue through the powerhouse as the pilot tunnel. This will be a 6m x 6m cross section tunnel. The remainder of the crown of the powerhouse will be excavated in the next pass of drilling and blasting.

Once the powerhouse crown is complete, the prime civil contractor will install the crane rails and the remainder of the powerhouse excavation can continue. It will be taken in bench blasts, approximately 6m - 7m deep per round. A muck pass will be excavated from the bottom of the powerhouse where the L20 intersects, up to the powerhouse crown section. The raise climbing method will be employed. Muck haulage will be primarily through the L20 tunnel during this phase of construction.

A construction adit will be driven towards the tailrace tunnel's intersection with the Surge Chamber. From here, slot raises will be installed from the Gate Chamber down to the Surge Chamber level. The draft tubes and bypass tubes connect from here into the powerhouse, and will be driven in that direction.

CONCLUDING REMARKS

At the time of writing of this paper, the underground works are undergoing final design. Tunnelling is scheduled to commence in November

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The writers would like to acknowledge the contributions of Steve Redmond and Matt Kendall from Frontier Kemper and Tim Hao and Mehdi Yousefi of SNC Lavalin to this paper.

TIED TOGETHER

Tie-in works of a tunnel twinning project in northern British Columbia required drill and blast excavation of access tunnels leading to interconnection tie-in chambers that were excavated in hard rock to within 3m of the existing pressurised steel lined penstock. **Mark Kellaway** and **Dave Young** of Hatch and Hatch Mott Macdonald and **Gordon Revey** of Revey Associates, Inc., explains the geometrically complex excavation undertaken during a limited shutdown period when the penstocks were depressurised

Mark Kellaway
Mark is currently working for Hatch as a chartered senior engineering geologist

Dave Young
Dave is a vice president and deputy tunnel practice leader with Hatch Mott MacDonald

Gordon Revey
Gordon is an independent blasting consultant providing design, training and risk management

THE TIE-IN works comprised the excavation by drill and blast methods of two new 6m diameter access adits from a surface platform to 8m diameter tie-in chambers approximately 80m below ground level. The tie-in chambers were excavated to leave a 4m thick pillar of which approximately 1m comprised prepacked concrete backfill between the tie-in chamber and existing 1950s pressurised penstocks to allow excavation of two new 4m diameter penstock connection tunnels from the tie-in chambers to a new guard valve chamber located approximately 100 to 60m away.

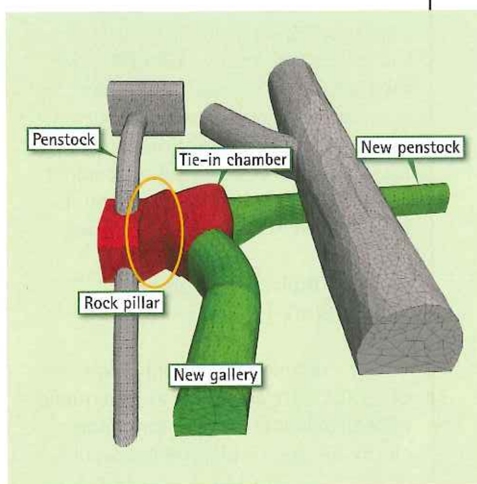
Through further design analysis when the geological conditions were better understood the pillar width was subsequently reduced to 3m to assist the construction schedule while the penstocks were still pressurized. The 3m pillar was then removed once the rest of the tunnelling had been completed and the penstock was depressurised.

The design needed to consider the geometrically complex proposed tie-ins as well as passing below an existing access adit, with a maximum of 5m middling. Coupled with limited information on the condition of the 1950s penstock pipe and thickness and surrounding pre packed concrete backfill, added to the complexity on the type and nature of the constraints and the development of practical blasting criteria that could be successfully implemented by a contractor.

The rock mass typically comprised strong (125MPa) blocky locally very block and seamy Granodiorite where intersected by dykes and altered shear zones. An average rock mass rating, RMR89, value of 65 and typical Geological strength index, GSI, values ranging from 60 to 80 were recorded at the Tie-In Chamber locations.

Below, right: Figure 1, A 3D model of one of the proposed tie-ins

Below: Checking of hole-depths and layout to finalise blast plan



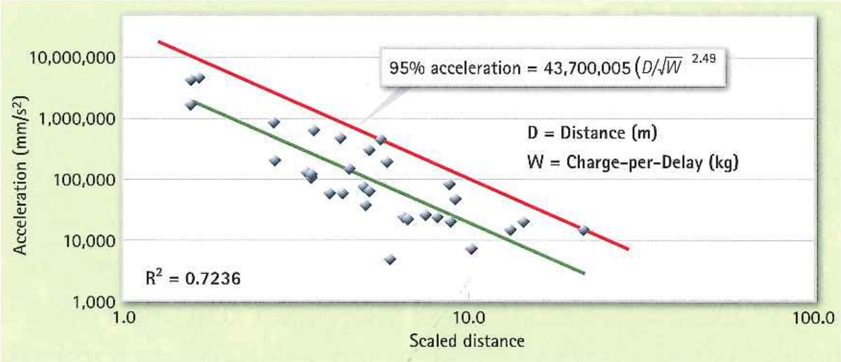
Development of the drill and blast criteria that would allow a contractor to successfully excavate and support the tie-in chambers, while the penstocks were still pressurised, and subsequently remove a pillar of rock and packed concrete backfill to expose a depressurised penstock to allow the tie-in works to be undertaken, within a very tight construction window, without damaging the penstock pipes, was a key challenge. Consideration was given to blasting effects, predicting the vibrations and the amount of strain on the pipe and the amount of control that could reasonably be placed on the drill and blast excavation methodology to reduce the risk.

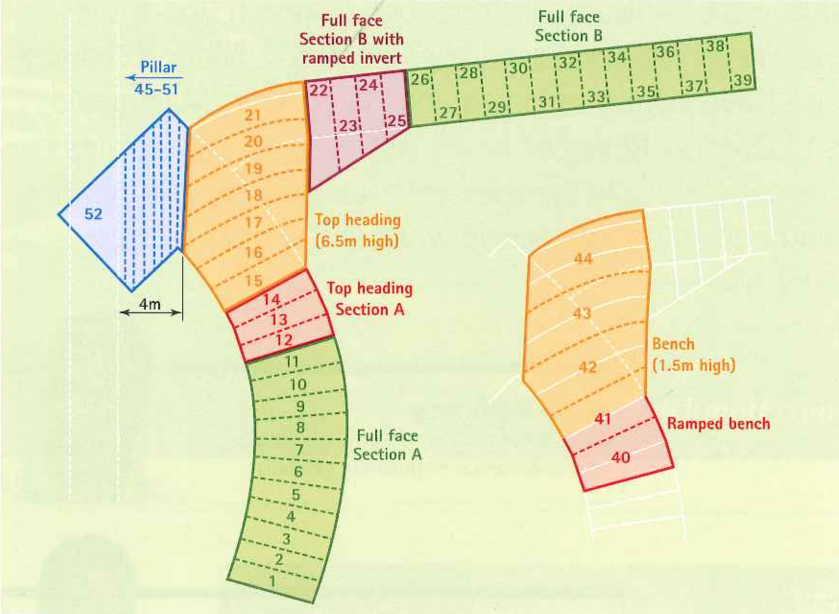
Standard industry damage criteria and 'safe levels' of ground motion are generally based on peak particle velocity (PPV) and frequency of motion. General safe PPV limits for pipes generally range from 76 to 127mm/s. Since blasting needed to accomplish this work would occur within a metre of the pipes, calculations of PPV for minimum practical charges indicated levels would exceed 2,500mm/s. This motion seems extremely high and at first glance pipe failure would be expected.

Particle velocity values should not be confused with ground displacement. For instance, if a measured peak particle velocity for very near-field blasting is 2,000mm/s, the ground has not moved 2,000mm because ground particles disturbed by blast vibration waves will oscillate back and forth many times in a second. This is why frequency of motion is important because, unlike earthquakes where frequency of motion is quite low, cycles of ground particle shaking (frequency) caused by careful blasting in hard rock at distances of 1 to 5m usually occurs between 100 to 1,000Hz. Since the ground particles are shaking back and forth or up and down so quickly, similar to running in place, they do not move very far. At any given PPV, the amount of elastic particle displacement is inversely proportional to frequency (f). With the sinusoidal motion created by blast-induced vibration, displacement can be approximated by the formula below where 'f' is motion frequency.

Peak Displacement (mm) = PPV/(2πf) [1]

For example, a seemingly high PPV of 2,000mm/s occurring at a frequency of 500Hz would cause a temporary elastic particle displacement of only 0.64mm [2000 / (2 x 3.14 x 500)]. To





Above: Figure 2, Typical blast sequence for a tie-in correction

Top: Figure 3, Acceleration data and upper 95 per cent curve

convince other engineers reviewing the risk of the work that blasting could be accomplished safely while working outside typical PPV limits, microstrain in the pipe was modeled based on blast-induced ground displacement. While considering the unknown conditions of the penstocks and potential for adverse rock mass conditions, a reasonable factor of safety was established if peak ground displacement at the pipe did not exceed 1mm. Since vibration monitoring equipment cannot directly measure displacement, and velocity transducers could not handle the high frequency and PPV ranges, accelerometers with a 500g and 1Hz to 3kHz range were used to perform primary measurements of ground motion. Displacements were estimated using sinusoidal motion relationships.

When explosive charges detonate in rock, they are designed so that most of the energy is used in breaking and displacing the rock mass. However, some of the energy can also be released in the form of transient stress waves, which in turn cause temporary ground vibration. Detonating charges also create rock movement and release of high-pressure gas, which in turn induce air-overpressure (noise), airborne dust and audible blast noise. In the very-near zone, if holes are filled with bulk explosives or tightly tamped charges crushing usually occurs in the rock around the charge. The extent of this compressive and shear failure zone is usually limited to one or two charge radii (half the diameter of the charge). Beyond the plastic crushing zone, the rock or ground is temporarily deformed by elastic strain waves. For some distance, tangential strain intensity exceeds the rock's strength and new fractures are created. The magnitude of dynamic strain and particle

Table 1. Project specific blasting limitations close to sensitive structures

Zone	*Charge-per-delay (kg)*	*Hole depth (m)*	*No. of rows*	*Charge dia. (mm)*	*Hole dia. (mm)*	*PPV (mm/s)*	*Peak displace--ment (mm)*	*Scaled distance ($m/kg^{1/2}$)*
1-3m	0.19	2	2	Detcord	≥38		1	3
3-5m		2		≤32	≥38		1	3
5-20m		4			≥38	≤125	1	1.6

Source: Authors

motion decrease as distance from the charge increases. Radial cracks are created in rock around detonating charges as a result of induced strain that exceeds the rock's tensile strength. These cracks for fully-charged holes generally do not extend farther than 13 charge-diameters. For instance, if the diameter of the charge is 38mm, radial cracks might extend 494mm into adjacent rock. Direct rupturing or overbreak of rock beyond the desired limits of a blast area might also occur if ground is weak or jointed and or poor perimeter control methods are used for blasting. For this work, much less radial cracking was expected in the packed concrete due to the discontinuities at the boundaries and varying properties of aggregate surrounded by weaker cement. This result was later confirmed when exposed concrete was very cohesive and showed little crack damage.

Early on, it was decided that the expected concrete with a thickness of 1m (+/-) around pipes would be excavated by mechanical methods. Hence, the blasting done near the pipes had to be designed to assure blast- induced pressure would not cause direct rupturing of the penstocks.

Charge decoupling and relief

With the understanding that direct rupturing of ground or high gas pressures occurring near the pipes would cause damage, all charges placed near the pipes were designed with excellent relief so blasted rock can easily move toward open rock faces and away from the existing pipes. When holes are fully-charged with explosives that fill or nearly-fill the hole, rock or concrete around the charges is crushed and fractured because the explosion generates pressures as great as 400,000 psi (2.75 x 106kPa), which greatly exceeds the strength of rock and concrete. The physical properties of concrete are generally consistent so blasting results are more predictable.

Since the borehole pressure of fully-coupled charges exceeds the dynamic strength of rock or concrete, the size of charges used in holes located at and near excavation perimeters and the penstocks were reduced to control damage. Similar to controlled blasting methods like Pre-splitting and Smoothwall blasting, borehole pressures were reduced by using extremely decoupled charges. For the very close-in blasts, a series of decoupled charges were used to lightly slash rock away from surfaces where clean break was desired., Fast millisecond delay timing was also used to create a cooperative cleaving effect within each row of very lightly-charged holes.

Blasting limitations

At the outset of the work, very specific limitations regarding minimum scaled distances, maximum charge weights, hole-diameters, charge diameters, PPV and maximum calculated displacement were specified at locations where blasting took place within 20m, 3m to 5m and 1m to 3m of existing structures. These limitations are summarised in Table 1.

In addition, in the 1m to 3m zone burden distance for all charges was set to not exceed 0.5m and the delays set to assure best charge relief. Holes were to be orientated on vectors away from or tangential to the penstock pipe. These limitations would typically be developed by a contractor to comply with PPV and frequency limitations as part of their working methodology. Specifying these limitations together with the input of a blasting specialist in the development of the project provides more control and assurance to owners when blasting close to their existing assets and assist in the managing the risks at the design phase.

COMPLIANCE MONITORING

Triaxial accelerometers were grouted into the toe of boreholes drilled to locations centered about the tie-in excavations about 1.5m above each penstock. Since all blasts would have varying proximity to the closest section of pipe and the measurement points, extrapolation calculations based on site-data-curves were used to predict the intensity of motions at the closest part of the pipe. Conventional PPV measurements were also done at other more distant points of concern.

As blasting progressed towards the pipes, regression curves were continuously updated to establish site- specific relationships between the dependent variables of distance and charge-per-delay; and frequency of motion, PPV, acceleration and predicted

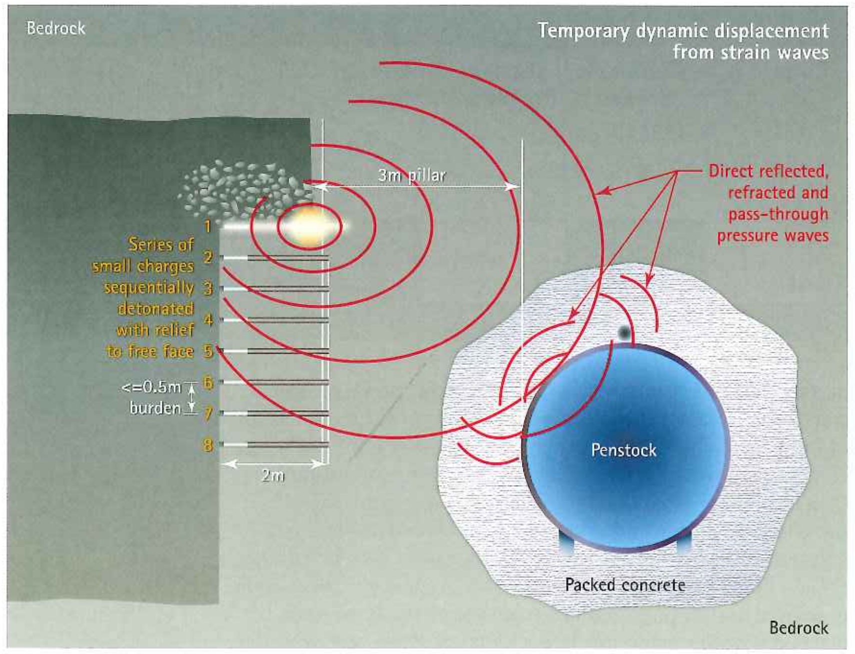
Below: Layout of blasts on 3m pillar face (red dashed lines represent approximate location of penstock)

displacement. Upper 95 per cent confidence curves were used to establish the compliance of all blasts with the 1mm displacement limit at the pipes and with other PPV limits for existing openings and other facilities.

High frequency geophones were also used as a back up to verify the blast data from the triaxial accelerometers. The high frequency geophones were mounted on the walls to as close as possible to the blasting with protective plates. Measurements of wall-mounted geophones typically recorded higher motions in directions normal to the wall surfaces. This was attributed to a greater degree of freedom due to the open wall surface. The location of each instrument was surveyed so the distance to the blast and the nearest structure or penstock could be determined before each blast.

The raw blast data was analysed using advanced software to identify the dominant frequency, which may or may not have been related to the peak acceleration or velocity and to discount any erroneous readings such as impacts of fly rock to wall-mounted velocity transducers. The results of each blast were reviewed by the project team and the results were compiled into a working spreadsheet continuously updating curves based on respective acceleration, PPV and predominant frequency measurements. With further information being made available from geological face mapping of the advancing excavations and laboratory testing of core taken at the location of the tie-in chambers to confirm the ground conditions it was possible to review the blasting limitations and progressively relax some of the limitations based on measurements and results. Agreements by all parties to the work were confirmed before implementing changes to specifications or relaxing blasting limitations. The first relaxation was given to reduce the scaled distance for zones 1 to 3m and 3m to 5m as well as allowing drilling orientations to be directed in the general direction of the penstock pipe, with a number of quality control conditions such as establishing an appropriate survey control.

Control was implemented on site by setting out each hole by survey and orientation and depth guides were surveyed and demarcated using paint and ribboning to allow the jumbo operator and miners sight in the drilling of each hole. In addition, holes were then checked upon completion of drilling to ensure there were no deviations and allow the contractor to finalise their blast plan. It was critical



Above: Figure 4, Schematic of the controlled blasting concept

that the drill hole-depths were carefully controlled to avoid any unnecessary over excavation that could have exacerbated the depth of potential geological over break in the pillar face while the penstock was pressurised. Given the orientation of the main discontinuities, geological over break in the form of face wedges were foreseen through kinematic analysis and were going to be difficult to control.

This was considered by the design when considering the safe pillar width and the over break that occurred in localised wedges up to 0.6m deep were within the permissible tolerances set out by the design and did not lead to any destabilisation of the pillar while the penstock was still pressurised. By comparison, with similar jointing but generally better ground, less over break was witnessed on the second tie-in chamber pillar. These better results occurred despite allowing reduced scaled distances and increased charge weights.

As works progressed in the 3m to 5m zone the results from the blast monitoring indicated that the charge weight per delay and scaled distance could be further relaxed for the 1m to 3m zone that were predicted not to adversely affect the penstock pipe. Advance planning and discussion also meant that the contractor was also prepared for such relaxations and had procured appropriate materials to allow them to blast four rows at once and help control vibration. This allowed a significant saving to the construction schedule to be afforded. Such a relaxation remained conditional on the importance of quality assurance and quality control on the drill depths, amount of burden and survey data that were required to be put in place.

Due to the complex geometry of the tie-in locations, some blasting was done above and below the penstock pipes. To create needed relief, the contractor chose to use a Brokk excavator equipped with a hoe-ram to carefully excavate rock and concrete located within a metre of the pipes. Vibration by the Brokk excavator was very low and caused no damage.

SUMMARY

The unique challenge of excavating by drill and blast methods in very close proximity to the penstocks, with a very tight excavation schedule in hard rock required the use of special methods, measurements and controls. The approach dealt with the risk, made the project viable, and allowed significant reductions in the excavation schedule

The writers would like to thank Rio Tinto Alcan for their permission to publish this paper and the cooperative efforts of the project team members representing Hatch, VK MASON (Kiewit-and-Partners) and Bechtel, who were critical to the successful completion of this work

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Rates, series bookings and dimensions available on request

What's on

2015

George A. Fox
27 January 2015
New York, New York
In recognition of his accomplishments, the UCA of SME holds this annual one-day conference.
www.smenet.org

Shotcrete conference and exhibition
29-30 January 2015
Tyrol, Austria
Wolfgang Kusterle and his team welcome you to the Conference and Exhibition Shotcrete 2015 at the Alpbach Conference Centre. Knowledge and experience do not help, if they remain hidden. This platform has gathered shotcrete specialists for 25 years.
www.spritzbeton-tagung.com

ICETUS 2015
3-5 March 2015
Subang Jaya, Malaysia
Following the successful International Tunnelling and Trenchless Technology Conferences held in Malaysia in 2006 and 2011, the Tunnelling and Underground Space Technical Division of The Institution of Engineers, Malaysia, is holding its third conference to coincide with KVMRT developments.
www.icetus2015.iemtc.com

ISRM Congress 2015
10-13 May 2015
Montreal, Canada
Held in conjunction with the CIM Convention for 2015, the International Symposium on Rock Mechanics is an international conference every four years. A one-day symposium on "Shale and Rock Mechanics" is planned.
www.ISRM2015.com

World Tunnel Congress 2015
22-28 May 2015
Dubrovnik, Croatia
WTC 2015 heads to the Dalmatian Coast as the event returns to Europe. Further details to be confirmed.
www.wtc15.com

RETC
7-10 June 2015
New Orleans, Louisiana
The Underground Construction Association's biennel confrence.
www.smenet.org

49th US Rock Mechanics / Geomechanics Symposium
28 June-1 July 2015
San Francisco, California
The 2015 program will focus on new and exciting advances in rock mechanics and geomechanics and encompasses all aspects of rock mechanics, rock engineering, and geomechanics. Field trips and technical tours are planned.
www.armasymposium.org/

Eurock 2015 & 64th Geomechanics Colloquium
7-10 October 2015
Salzburg, Austria
The Austrian Society for Geomechanics has the pleasure to invite you to the ISRM Regional Symposium EUROCK 2015 Future Development of Rock Mechanics, to be held in conjunction with the 64th Geomechanics Colloquium in Salzburg.
www.eurock2015.com

25th World Road Congress
2-6 November 2015
Seoul, South Korea
The World Road Congress has been held every four years for more than 100 years. Since the first meeting in Paris in 1908, it has toured the member countries of the non-government organization, Permanent International Association of Road Congresses (PIARC).
www.aipcrseoul2015.org

RETC
14-18 March 2015
Sendai, Japan
UNISDR is facilitating the process of developing a post-2015 framework for disaster risk reduction. This process will culminate at the 3rd United Nations World Conference on DRR
unisdr.org/we/coordinate/hfa-post2015

Stuva Conference
1-3 December 2015
Dortmund, Germany
Held every two years, this conference sees 1,500 participants and visitors from about 20 countries. It is numbered among the world's leading get-togethers for underground construction experts.
www.stuva-conference.com

2016

World Tunnel Congress 2016
22-28 April 2016
San Francisco, USA
WTC 2016 heads to the Golden State as the event heads to North America. Further details are to be confirmed.
www.wtc2016.us

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. Regular BTS monthly meetings are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month. In recent years, the BTS Young Members have also begun hosting a programme of evening lectures.

Debate - This house believes that Regulation and the accompanying Compliance culture is stifling Innovation and Creativity within the tunnelling industry
11 December 2014
This year's traditional pre-Christmas debate looks into innovation within our industry and the factors which promote or stifle it. Speakers include Bob Ibell, London Bridge Associates, and Bob Cummins, Hollins Consulting, (For); and Kevin McManus, London Bridge Associates, (Against);

BGA John Mitchell Lecture: Going Underground? The Past, the Present and the Future.
13 January 2015
Colin Eddie will present his own perspective on the tunnelling industry. He will start by looking at the utilisation of underground space and the development of increasingly sophisticated construction techniques. He will examine some of the challenges encountered when tunnelling beneath urban areas before turning to the future and considering the challenges that will be faced by the upcoming major projects proposed for London and how the UK tunnelling industry can overcome them and maintain their position in the international market. Prior booking is required for this event.

If you have a topic or project you feel would be suitable for a BTS evening presentation, please contact either:
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