JANUARY 2012

tunnels & tunnelling INTERNATIONAL

North America

Both coasts are linked by a need for water and transport that only tunnels can meet

Ventilation

Suspended particle matter removal and flow upgrades to cope with increased use

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Close-up on Crossrail

First machine stands ready at Schwanau

ABU DHABI: SEWAGE SYSTEM WITH STRATEGY.

On the basis of the 2030 master plan, a gigantic new sewage network is being built in the desert metropolis of Abu Dhabi, which will connect new city and industrial areas. The "Strategic Tunnel Enhancement Program", in short "STEP", includes a main collector with a length of 40 kilometers, as well as inflow and pump stations.

Herrenknecht is delivering five tunnel boring machines (EPB Shields Ø 6,130 and 6,950mm) for the project. They are designed to withstand high groundwater pressures of up to 8bar, and they are the first tunnel boring machines of this size in Abu Dhabi. In April 2011, the tunnel boring experts from Impregilo S.p.A. drove the first tunnelling meters, and have rapidly and safely advanced since then. The concrete components for the tunnel lining are delivered by a lining segment production plant installed on site, which was planned, equipped with moulds for lining segment production and put into operation with the help of Herrenknecht Formwork engineers.

The project is well underway with Herrenknecht technology and competent partners from the region. This means that Abu Dhabi will soon have plenty of purified water for the irrigation of the desert city.

ABU DHABI | UAE

PROJECT DATA	CONTRACTOR
S-582, S-583, S-584, S-649, S-654, 5x EPB Shields Diameter: 4x 6,310mm, 6,950mm Installed power: 3x 945kW, 2x 1,200kW Tunnel lengths: 4,885m, 2x 5,320m, 5,325m, 5,380m Geology: clay stone, gypsum, sandstone/limestone	Impregilo S.p.A.

Supporter of:

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contents

comment

Adapt and overcome

It is, of course, traditional at the turn of the year to set out resolutions and objectives for the coming 12 months. The changing of the calendar is a chance to turn over a new leaf, kick a bad habit and take up a new challenge.

It is, of course, traditional at the turn of the year to set out resolutions and objectives for the coming 12 months. The changing of the calendar is a chance to turn over a new leaf, kick a bad habit and take up a new challenge.

Several years ago I lived with the head of eastern European sales for a large tobacco company. He and his staff all took the first two weeks in January on holiday as sales during these weeks plummeted with smokers trying to end their habit. But by the third week sales had returned to near normal levels.

While a great many people set targets for the New Year, few have the perseverance to see them through.

On the front cover this month is a close-up of the first TBM to be manufactured for London's Crossrail project. The cross-London rail line has been more than 30 years in planning and about a decade in design and budgeting. The project has had to adapt itself to the changing political and city landscape but, in March, London mayor Boris Johnson will start the first TBM boring. A core, dedicated team has persevered with this project, understanding its importance and bringing it into construction.

In the T&T Awards supplement accompanying this issue you'll find more stories of project perseverance. Two of the most poignant are the winners of the Overcoming Adversity categories for Endurance and Tour De Force. Sweden's Hallandsas rail project claimed the Endurance prize for its persistence in the face of repeated and often overwhelming challenges. Extremely hard rock in wet ground with tough environmental restrictions has made the project a very complex challenge to overcome. After some 18 years of false starts the project is making solid progress and is advancing the industry through innovative trials and techniques.

The Tour De Force award has been claimed by the Olmas Base Tunnel, which crosses the Andes in South America. The irrigation project is needed to carry water from the water rich east to the desert west. More than a century in the making, this project has had to persevere through squeezing ground and dangerous rock bursting. To face the challenges, the project has relied on a fiercely strong TBM and has devised new support measures to protect the tunnel and miners.

But, for many, the challenges of 2012 are not going to be engineering but financial. Surviving the dip in the western economy will need companies to adapt their skills and move to where the work is. When it was in the depths of the great depression, Franklin D Roosevelt told America: "When you come to the end of your rope, tie a knot and hang on."

Good luck in 2012!

Jon Young

On the cover:
Herrenknecht's first offering to London's Crossrail megaproject is inspected at the manufacturer's works

In the supplement:
The T&T Awards 2011 winners are finally announced. Are you among them?

First Crossrail TBM displayed in Schwanau works

GERMANY

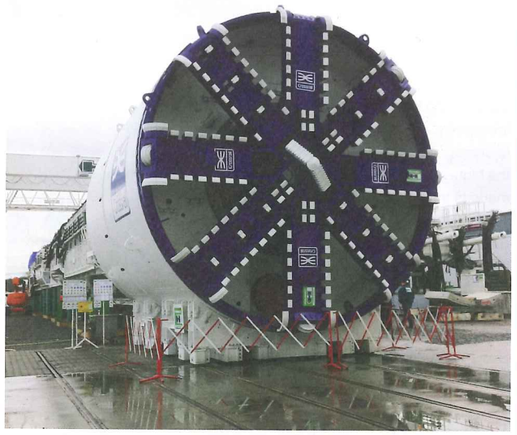
Crossrail's first TBM was fired up last month for guests at Herrenknecht's factory in Schwanau, Germany. The 7.1m-diameter EPBM will be dismantled following factory tests and shipped to London to launch into the rail tunnel drive from the Royal Oak portal in March.

The contracting JV of Bam Nuttall, Ferrovial Agroman and Kier Construction (BFK) was awarded the contract to construct the western tunnels.

Ralph Lickert, a Herrenknecht project manager for Crossrail told *T&TI*, "This is a compact machine. You can see from there isn't much room. It is also very powerful with over 55,000t of thrust and a high main drive torque [of 9,800kNm]. The belt scales are also of the highest achievable quality and are provided by [Australia-based] Control Systems Technology which was the only company able to meet the requirements."

Crossrail chief engineer Chris Dulake said, "Work is continuing across the route to prepare for construction of the major new rail tunnels. Following the March launch, a second launch will occur from Royal Oak a few weeks later. The remainder will be launched from Limmo Peninsula in the Royal Docks heading to Farringdon in late 2012; from Pudding Mill Lane and Plumstead in 2013 and from Limmo Peninsula in 2014."

The first of eight Crossrail TBMs – six EPBs and two slurry machines



Singapore's final DTL project breaks ground

SINGAPORE

Construction has begun on Downtown Line Three (DTL3) in Singapore. The Land Transport Authority (LTA) held the groundbreaking ceremony at Expo Station last month.

An LTA spokesman identified Expo Station as a key project challenge. "It is positioned almost perpendicular to the existing overground East West Line (EWL) Expo Station. This poses significant constraints on the design and construction of the DTL3 station, as the foundation piles of two viaduct columns currently obstruct the construction of the station.

"The two columns will therefore need to be modified, and will first be underpinned with a transfer structure before being integrated with the EWL Expo station's roof slab. As station construction will be carried out beside the operational EWL Expo station, a top down construction method was chosen, with diaphragm walls as a retaining system to minimise ground and structural movement."

The 21km, fully underground DTL3 will complete in 2017. It is planned to run almost parallel to the EWL with 16 stations. Due to challenging Singaporean ground conditions, extensive treatment works were planned before construction is executed.

The LTA also announced that the basic structures of all DTL1 stations have been completed. It will complete in 2013. The DTL2 will complete in 2015. The total 42km DTL will experience a daily passenger flow of 500,000.

HS2 decision delayed

GREAT BRITAIN

The UK Government has delayed its High Speed Two (HS2) decision until mid-January. Transport Secretary Justine Greening will consider the merits of a GBP 500M (USD 782M) tunnel through the Chiltern Hills to the north of London.

The Secretary was expected to make a decision before Parliament's winter break.

The GBP 32bn (USD 50.04bn) project's alignment has attracted criticism for cutting through countryside of 'outstanding beauty'. Lobby group 'Campaign to Protect Rural England' said it welcomed an increased portion of the alignment to be placed in below ground.

The 100-mile (161km) link would be built over 10 years. Construction would begin in 2016. The decision to reconsider the route followed a House of Commons Transport Committee report in November last year.

The Government said that changes to the plan would have to be funded by savings elsewhere along the route.

Shadow transport secretary Maria Eagle said, "By accepting that the current proposals on the table are not right, the government has opened up a real opportunity to get this vital project right.

"It's a welcome start but ministers should now go further, stop being dogmatic and use this pause to finally take up our offer to work together on a long-term strategy for both high-speed rail and aviation."

A Campaign to protect Rural England spokesman added, "We are concerned, by suggestions that the additional GBP 500M (USD 782M) will come from cutting back on mitigation measures elsewhere on the route.

The spokesman added that "Just because countryside is not nationally designated does not mean it should not be valued and protected."

UK Government urges businesses to look east

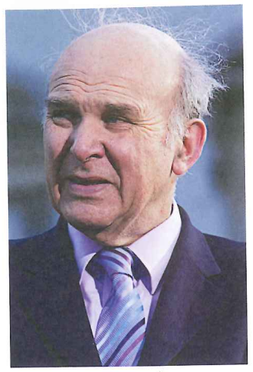
GREAT BRITAIN

UK ministers last month called for more British exports to Asia. Business secretary Vince Cable and foreign secretary William Hague launched a UK Trade and Investment campaign to encourage British involvement in the high-growth and emerging markets in the east. The project will be coordinated with the Royal Bank of Scotland to demonstrate 'key business opportunities' across 12 Asian markets.

The events will be held in February and will focus on China, Hong Kong, India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand and Vietnam. A search will be also launched to find and promote the 'most inspiring' British businesses currently exporting to Asia to set an example. Cable said, "In the last year, our exports to the 12 markets in this campaign were worth GBP 25bn (USD 39.01bn), though we are still well below potential. The Government's recent decision to allocate an additional GBP 45M (USD 70.21M) to international trade promotion will help more medium-sized exporters and will also double the number of small and medium enterprises that UK Trade and Investment supports from 25,000 to 50,000. I urge companies from all sectors to get involved in this campaign, and see what opportunities Asia could hold for them."

Hague added, "There can be no doubt of the importance of Asian markets. By 2030 spending by Asian consumers is expected to be around USD 32tn annually or about 43 per cent of worldwide consumption. So the economic compass of British businesses should be pointing firmly east, and we are determined to support them in their efforts.

"This is commercial diplomacy in action. Around twenty of our senior diplomats with experience in these markets and business leaders who have been there and done it. Together, they will give face-to-face advice to UK firms."



Above: Vince Cable. Photo credit Steve Punter

Crossrail awards Farringdon and Whitechapel

GREAT BRITAIN

Crossrail last month announced its chosen contractors for C435 – Farringdon Station and C512 – Whitechapel Station. Farringdon was awarded to a JV of Bam Nuttall, Ferrovial Agroman and Kier. Whitechapel went to a Balfour Beatty, Morgan Sindall and Vinci JV.

Crossrail programme director Andy Mitchell said, "When Crossrail opens, Farringdon will become one of Britain's busiest train stations served by Thameslink, Crossrail and London Underground. At Whitechapel, the new Crossrail station will be located to the north of the existing station with a new ticket-hall providing step-free access to Crossrail, London Underground and London Overground services.

A Balfour Beatty spokesman added, "The GBP 110M (USD 171.5M) Whitechapel contract comprises demolition of the existing station, construction of a new ticket hall behind the retained station façade, upgrading and extending the Hammersmith & City and District Line platforms and constructing a new station bridge concourse in and over the East London Line cutting. The works will also include the shafts and platforms for the Crossrail tunnels plus related architecture and mechanical and electrical infrastructure.

A Morgan Sindall spokesman said, "Piling will be carried out in-house by Balfour Beatty Ground Engineering and Bachy Soletanche. The mechanical and electrical work will be installed by Balfour Beatty Engineering Services working with Morgan Sindall Professional Services. The project is scheduled to commence in January 2012 and due to be completed in 2018."

A Crossrail spokesman added, "The indicative value of the Farringdon contract is over GBP 200M (USD 311M)."

High-speed rail breakthrough in Galicia

SPAIN

Spanish contractor FCC last month broke through on an 8.13km tunnel for the Das Maceiras-Vigo section of the Eje Atlantico de Alta Velocidad (Atlantic Axis high speed rail).

The project consists of two 9.5m diameter tunnels being excavated by two double shield TBMs. Wednesday's breakthrough at Vigo in the first bore saw the conclusion of two years and eight months of boring through granite rock, with some shale.

A breakthrough in the second tube was expected in December as *T&TI* went to press.

The Das Maceiras-Vigo stretch of high-speed rail is in the Galicia region of Spain and will connect to Portugal.

News in brief

US commuters demand more tunnel improvements
Board members approved a USD 7bn 2012 budget for the Port Authority of New York and New Jersey last month amid complaints by commuters that too much of the money is going to build the new World Trade Center and not enough to bridge and tunnel improvements. The budget is USD 70M lower than that approved in 2011.

Arup wins seam contract
Arup has been appointed to carry out the conceptual design of a 6km tunnel for Australian coal seam gas company Arrow Energy.

Taiwan politician cites tunnel as party success
Democratic Progressive Party candidate Su Jia-chyuan attacked opponents in a presidential debate last month boasting that his party had completed Hsuehshan Tunnel linking Llan with Tapei and also finished Taiwan's first high-speed rail line.

Massive investment potential for UK on the horizon

GREAT BRITAIN

UK infrastructure will receive an approximately GBP 30bn (USD 46.5bn) investment windfall. Chancellor George Osborne announced spending plans last month for the initiative dubbed the 'National Infrastructure Plan'. Some 40 infrastructure projects were outlined as targets, including the Tyne and Wear metro and the Northern Line extension to Battersea.

The UK Treasury said it hopes that two thirds of the total will come from the National Association of Pension Funds and the Pension protection Fund.

Chief secretary to the Treasury, Danny Alexander added, "We're putting in place a new arrangement with private pension funds – the first time this has been done in this country – to try and unlock pension fund money to go into infrastructure."

Alexander said that he was surprised to learn recently that projects in the UK have been funded by foreign pension investment. He cited the Birmingham airport runway extension, which was paid for by the pension funds of Canadian teachers and Australian miners.

Despite Alexander's shock, the opportunity for pension scheme investment of this sort will not be alien to the government. The state sold the High Speed One rail link in November 2010 in an attempt to cut the country's budget deficit. The buyer was a Canadian consortium comprised of Borealis Infrastructure and the Ontario Teachers' pension fund. The price was GBP 2.1bn (USD 3.4bn). The project cost over GBP 5bn (approximately USD 8bn) to build.

The UK Government will invest GBP 5bn (USD 7.75bn) to be paid for by further spending cuts. Alexander said these will come from 'under spend' areas in government, including carbon capture and storage negotiations, as well as a crack down on cases of tax avoidance.

Chairman and CEO of China Investment Corporation (CIC), Lou Jiwei, wrote in London's *Financial Times* that the state-owned investment institution (and China's main sovereign wealth fund) has also been looking to, and will participate in PPP schemes in the UK.

"Local knowledge is essential," said Jiwei. "Foreign investors without this expertise cannot lead a project. Local co-investors and operators can fill this gap. Governments should encourage domestic players to take the lead in infrastructure projects, and attract foreign investment."

Jiwei added that infrastructure in Europe and the US badly needs more investment. "Traditionally, Chinese involvement in overseas infrastructure projects has been as a contractor only. Now, Chinese investors also see a need to invest in, develop and operate projects.

"Infrastructure spending is an important way to boost consumption and it also acts as a spur to economic growth. One need only look at China to see what can be achieved. Between 1979 and 2007, China committed vast resources to infrastructure development. In the wake of the 2008 financial crisis, the government introduced a CNY 4tn (USD 627bn) economic stimulus package, with a large part of the money directed into infrastructure. As a result, China's annual economic growth rose from 6.8 per cent to more than 10 per cent from late 2008 to the end of 2009.

Jiwei continued, "Infrastructure is underinvested in European countries [...] Free of the inflationary pressure that afflicts many emerging economies, the US and Europe should make substantial investment.

"We cannot count on developing countries to deliver a stable economic recovery on their own. China has taken a set of ambitious and effective measures to stimulate domestic demand and consumption. Yet Chinese consumption is still small as a share of the global total. If the world stakes too much on the export-led growth strategy, it may turn out to be a 'zero-sum' game, damaging the world economy."

Trades Union Congress (TUC) general secretary Brendan Barber said the government needs to change course and introduce 'immediate measures to support jobs and promote growth. "The chancellor's economic 'Plan A' has sent unemployment to a 17-year high and the UK's economic outlook is the gloomiest it's been since the end of the recession."

Break-out 'contractors' foiled

BRAZIL

Brazillian police foiled a would-be tunnelled prison breakout, local newspaper *Cidade Verde* reported. Prisoners in the high security Casa de Custodia prison in Teresinha in the country's north purchased a nearby house and contracted builders to dig the escape tunnel.

The excavation was 30m-long and four metres in diameter. It was fitted with electric lighting, ventilation and drainage. A military police chief said, "I was very impressed by their workmanship."

Axes, hoes and shovels were used for excavation.

Muck was transported via a system of sand bags.

Four tunnellers and a female lookout were arrested by the police who are seeking evidence to link them to the bank robbers already in the jail. The tunnel, after one month of work, was only a few metres short of breakthrough to the high security prison's 'C Wing'.

Construction noise mitigation was undertaken by loud gospel music played 24 hours a day. The house cost the project approximately USD 20,000.

Colonel Rubens Pereira of the military police added, "It was like something out of a film, we couldn't believe our eyes. The men had been working there for less than a month, but they had managed to build a structure that any construction company would be proud of.

"They had chosen the house they wanted to dig from and approached the owner, paying the amount he wanted for it. With light and ventilation in the tunnel, they were able to keep digging day and night. If we hadn't come across the tunnel they would certainly have released the prisoners within days."

The prisoners are bank robbers serving a 14-year sentence.

News in brief

Los Bronces complete
Seli announced last month that the 8km-long, 4.5m-diameter inspection tunnel has been completed at the Los Bronces mine in the Chile. Extreme weather was experienced on the worksites at 3000 to 4000m high.

Decision on Mekong hydro dam delayed in Laos
A decision on a controversial plan to build a hydropower dam on the Mekong River in Laos was postponed last month pending further environmental studies.

Strabag results show Eastern European construction resists financial maelstrom

AUSTRIA

Strabag hit double digit growth in its output volume for the first three quarters. Along with its nine-month report released last month, Central and Eastern Europe's largest construction company announced workforce growth of 7 per cent. Half of the new employees were brought in with the acquisition of Germany-based Rimex.

CEO of Strabag, Hans Peter Haselsteiner, said, "The turbulence in Europe caused by the euro debt crisis has so far not affected the output or the expected results of Strabag. While state investment programmes in markets such as Germany had supported the construction industry through the middle of the year, the sector already has several difficult years behind it in countries with lower public-sector spending – such as Hungary – or in the Adriatic region.

The positive results were in part thanks to a milder winter and spring than the previous year, aiding productivity.

News in brief

Toulon subterranean highway fittings award
A JV of Ineo/Axima/Clemessy secured the EUR 19.3M (USD 16.5M) contract (VAT not included) for installation of electrical wiring, ventilation, lighting, control, safety and signaling equipment in the south tube of the Toulon subterranean highway.

Stuttgart tunnel tender notice issued for January
Invitation to tender is issued with a deadline of 9 January, for construction of the Heilbronnerstrass dual tube, mono track tunnel. It will form part of the light rail system in Stuttgart. Work period from 27 April to 25 September. Contact Jurgen Hinrichs of Stuttgarter Strassenbahnen, tel: +49 711 7885 2771

Tender notice for Swiss equipment refurbishment
Open invitation to tender notice is issued with a 13 January deadline to refurbish tunnel equipment in Switzerland. The contract runs from 1 March 2012 to 31 December 2013. Contact Astra, email: marchespublics.estavayer@astra.admin.ch

Le Havre sewer award
Arceuil won the contract for water main, sewage outfall and sewerage reconstruction at Le Havre, France.

Sika acquires Axim

SWITZERLAND

Sika of Switzerland last month acquired the global concrete admixture business of the Italy-based Italcementi Group. Its businesses trade under the name Axim and include those controlled by Ciments Francais.

In 2010 Axim had sales of around EUR 61M (79.9 USD), and employs 150 people in six companies operating production and sales unit in Italy, France, Canada, Morocco, Spain and the USA. Giovanni Ferrario, COO of Italcementi Group said, "The agreement will allow the group to capitalise on the value of this business. It will further extend the relationship between Italcementi and Sika, boosting the reputation of both firms as innovators in the field of concrete and cement.

Rick Capka returns to Parsons

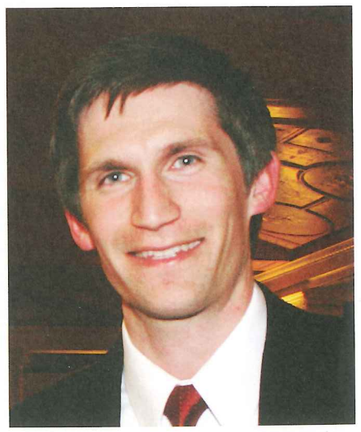
USA

Rick Capka was last month appointed to the Parsons Brinckerhoff (PB) Seattle office, US. He took the role of area manager of construction serives. His responsibilities will include the Alaskan Way Viaduct bored tunnel replacement.

A PB spokesman said, "Capka most recently served as a construction manager for Sound Transit, working on several underground construction contracts associated with the University Link light rail in Seattle. Prior to his employment with Sound Transit, he was a resident engineer for Parsons Brinckerhoff, working on the Beacon Hill tunnel and station of Sound Transit's Central Link light rail."

Capka studied at the US Military Academy at West Point. He earned a degree in civil engineering and is a licensed professional engineer in Washington, US.

Below: Rick Capka rejoined Parsons last month



Jacobs adds Brox to its team of lead associates

CANADA

Dean Brox was appointed as a lead associate at Jacobs. Based in Vancouver, the site of Jacobs' first Canadian branch, he has 26 years of experience as a senior project and design manager on underground projects.

A Jacobs spokesman said, "Brox specialises in underground facilities and tunnels for mining and hydroelectric projects and has performed numerous design and technical review services for such projects in Argentina, Canada, Chile, Greenland, Panama, and also Peru.

He is also highly experienced in the planning of site investigations and preparation of contract documentation for tunnelling and underground projects."

Brox also has experience in accident and damage enquiries for insurance claims.

Steady on Crossrail

Crossrail's current leanness was brought into shape by the 'Project Assure' initiative and is being further trimmed by the 'Optimised Contractor Involvement' process, reports Patrick Reynolds

In his drab autumn statement at the end of November, with its forlorn outlook for the UK economy, Chancellor of the Exchequer, George Osborne, gave more weight to how support for economic activity could come from accelerating major spending, as on construction projects.

Few projects in Britain come bigger these days than the Crossrail scheme in London. However, there is likely no traction to be had by attempting to speed-up this scheme, which has already won significant benefits on cost and schedule from extensive value management scrutiny.

An integrated review – called 'Project Assure' – led to a cumulative saving of almost GBP 1bn (USD 1.56bn) from the official budget, which was going to be bust anyway by more than GBP 2bn (USD 3.13bn), so the savings were even greater. The opening date was delayed by a year to 2018.

Crossrail programme director Andy Mitchell led the Project Assure initiative.

Left: **Crossrail programme director, Andy Mitchell**

While observing that the process was neither 'cheap nor quick to do', and advocating the benefits to be won from reviewing the cost to achieve perceived value in project features, he cautions that there is a window of opportunity to perform the task. Do it too early and the benefit is not secured.

"You can clear barnacles too early and they regrow," he says.

But once main construction procurement takes off, it's too late, he adds. The key is to have sufficiently developed design data for a rapid and meticulous squaring of costs against perceived value in the eye of sponsors and funders. Based on data, they will judge the acceptability of the cost. On Crossrail, the incremental process allowed overall costs to come down, and the programme to be stretched, without swinging a blunt axe to large project features. No stations or branch lines were lost.

The leaner budget plus firmed-up schedule for Crossrail now appears far too locked-in to hold potential for absorbing extra budget, or accelerated spending, especially as the project is well advanced. In approximately six months, the first TBM is due to be launched at Royal Oak Portal in west London. Station excavations are progressing well across the capital – at Canary Wharf the construction of the box structure is almost complete.

While there may not be leeway on Crossrail to gain much from late changes and upset, Project Assure has shown that it is not necessarily too late for value-thinking on large live projects. That success could make a difference elsewhere, not least in a more austere climate where the proof of value-for-money will be more hotly pursued, especially where fresh funding is potentially available.

Climbing costs

When Crossrail achieved Royal Assent in 2005 the plan expected mainline trains to start running through the scheme's 42km of tunnels by 2017. However, in late 2009 the pursuit of that timeline was inflating costs on the public-private scheme, which had an official budget of around USD 15.9bn.

The schedule was reliant on an assumed rate of progress in design development being met, explains Mitchell who joined the leadership team in 2009. He says the rate of progress did not happen.

Because the programme became more challenging, and as a result there was a tendency for decisions to be time-based rather than value-based. "Increasingly, the effort was to try and hold the schedule," he adds.

But the focus on maintaining the opening deadline was leading to escalating costs. Mitchell says that by late 2009, shortly after he joined, the estimated cost had increased to GBP 17.8bn (USD 27.8bn) – 12 per cent more than the official figure. The design was not finished and procurement for construction had not started.

Quickly, he worked with the senior management team to pull the supply chain together for an internal 'comprehensive cost review' (CCR). The initiative was branded 'Project Assure'.

Project Assure

The core idea of Project Assure was to create an opportunity, and an insistence, says Mitchell, to ask: Before we commit to a big spend, are we really sure?

Crossrail's cost-value initiative was not quite a first-of-its kind. Similar processes had been employed on ThamesLink in London and WestRail in Hong Kong, says Mitchell. But this was the biggest, most formal and extensive effort yet. Given the scale, the branded focus was important for communication.

A baseline was needed for the huge task, a way of holding the efforts of the web of organisations involved and the data being generated in a co-ordinated manner. This reference bar would consist of five successive steps of enquiry on the various features of the project – their functionality, specification, design scope, time and cost.

"But these five steps had to be kept aligned, ensuring the data on the different project features stayed linked and matched. This need for alignment within features, and across the project, is what makes the system different to standard value engineering," says Mitchell.

He adds that trying to do value management without the alignment would be 'hellish hard'.

As data came in there were constant iterations of assessment until the numbers firmed on various features and those most likely, or most valuable, were prioritised. They were all checked with sponsors to get the thumbs up – all steps are fine, including cost – or thumbs down – which meant the cost were too much and so the values of the other steps, such as functionality, need to be changed until approval was gained.

"But this can't be done early," says Mitchell. "A sufficient breadth and depth of design data is required."

To drive the process, he led weekly review meetings that ticked off what had been done and issued the next tasks. The teams working on tasks used common templates to lodge and evaluate options, grade them in terms of potential value and also how likely it was they might be adopted. In addition, note was taken of the approval hierarchy for possible changes.

Project Assure also had a risk register in operation, using risk analysis to help cut down on scheduling problems.

The main effort of the initiative ran from late 2009 through to the end of the third quarter of 2010. The rescheduling followed this period of work, and by early this year the Crossrail team was on track – with procurement still underway – to have the budget come in at less than GBP 15bn (USD 23.5bn).

The Crossrail team hopes to deliver for a lower cost still, and notes the Government expects the project to cost no more than GBP 14.5bn (USD 22.7bn), as announced in last year's Comprehensive Spending Review (CSR) and repeated in its annual update on Crossrail for Parliament in July. There is, though, a 'funding envelope' of GBP 14.8bn (USD 23.14bn) agreed following the CSR, notes Crossrail.

Further savings – OCI

With the Government's CSR underway in the latter stages of the Project Assure process, and the hiatus meantime until its future was confirmed, the Crossrail team extended by some months the procurement period for the first main tunnelling contracts. That period and the negotiations on submitted bids also gave rise to further pursuit of cost savings, including suggestions for changing the sequence of construction and also bundling bids.

Above: **Preparation of tunnel eyes at Royal Oak Park portal, west London, for the first TBMs on Crossrail**

From the numbers of large JVs in the prequalification stage – "which allowed for flexibility in our approach to bundling," adds Mitchell – there was a shift on the west tunnels to an approach pitched by a couple of bidders. They suggested a sequence switch to bore with TBMs first and then breakout for station construction; there were also bundled offers for combining tunnel and station works.

The combination was picked in the west, says Mitchell, but adds, "Even that could have been tough to do if we didn't have a schedule we could believe in.' Project Assure had delivered on that front.

Yet another stage of pursuing opportunities for saving costs as well as gaining greater efficiencies was created under the 'Optimised Contractor Involvement' (OCI) process in the 90 days after each contract award.

This is another attempt at refining plans and costs with 'all good ideas on the table', says Mitchell.

Many different opportunities have been identified but some general themes have emerged: improving constructability, collaboration on common scope, improving contract interfaces, logistics, optimising the balance of temporary and permanent works, and also rationalising requirements.

Mitchell cited examples of the good ideas that emerged as including changes to shaft locations, using different materials and changing the construction sequence. He adds that some ideas have impact on more than one contract. Having started with 300 'good ideas' under OCI from the first tunnel contracts, he expects that once all the station contracts are awarded, the total will be approaching 1,000, and which will be whittled to the best.

An example of constructability is given as the enlargement sequence for the station platform tunnels for Liverpool Street and Whitechapel stations, on Contract 510 (C510). The original plan was for rapid enlargement in a confined space but the proposed new method is gradual enlargement to allow for 'safer, more cost effective construction,' says the Crossrail team.

On optimising the balance of temporary and permanent works, Crossrail cites a move made at Bond St station to regain time for the programme: a temporary shaft was sunk to allow SCL works to begin without waiting for access following completion of the delayed eastern ticket hall.

Within contracts, the value engineering clauses urge effort to continue beyond the initial OCI phase, and there is also the motivation of the 50-50 pain-gain share on the target price contracts. Elsewhere in the project, key lessons won from the OCI phases will be used on the remaining contracts, notably improved constructability and logistics, says the Crossrail team.

Beyond Crossrail an approach like Project Assure could see major benefits won – if done at the right time, early in the construction phase says Mitchell. As long as it is not too early.

Case for caverns

Hong Kong pushes key facilities underground and returns land for redevelopment, Patrick Reynolds reports

Hong Kong is not unfamiliar with tunnel projects of almost all kinds, from transport to utility services and deep foundation excavations. But though large, stand-alone rock cavern developments have been rare enterprises, that may be about to change.

The scarcity of expensive surface land, and the opportunity – the chance – to regain pockets for redevelopment, has led the Hong Kong special administrative region (SAR) Government to pursue studies on the strategic transfer of some key facilities and services below some of the hills. The Government's civil engineering and development department (CEDD) is exploring the case for caverns, the efforts being led by its geotechnical engineering office.

Earlier this year, a study carried out by Arup for CEDD highlighted the potential for major cavern excavation to house some public works facilities that could be relocated underground within the granitic and volcanic rocks of the hilly terrain. The work – supported by subconsultants Norconsult and Urbis – reviewed the use of underground space locally and globally, and benchmarked Hong Kong. Suitable areas for possible rock cavern development were identified, and recommendations made to take such developments forward.

In addition, the consultants looked at the challenge of transferring existing services, and three facilities were selected to demonstrate the broad viability of transferring those facilities underground and to explore the main issues involved.

"This was essentially a feasibility study that reviewed the technical and planning aspects of cavern development," says Mark Wallace, Arup director and project manager on the study.

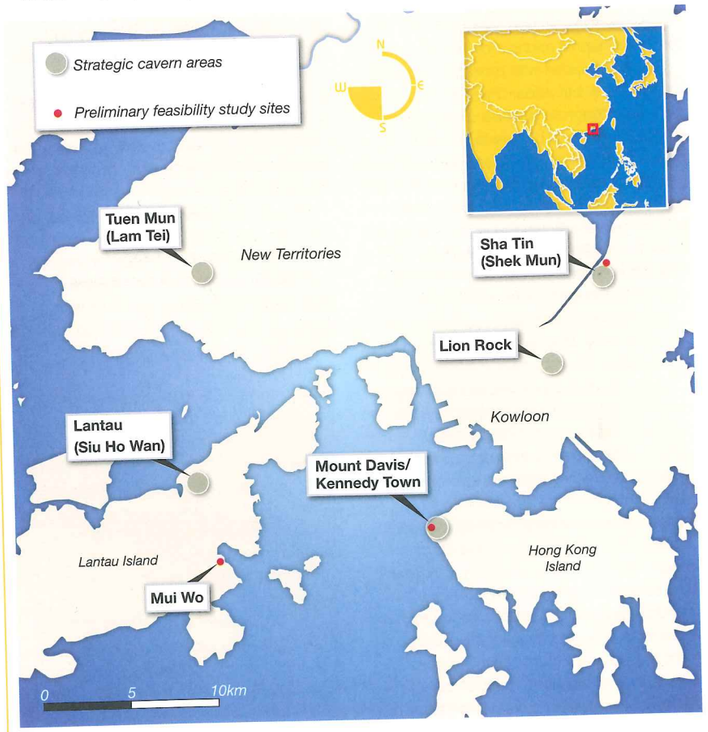
With project sizes dependent on the public works or other processes to be housed underground, the Arup study says smaller cavern schemes might be excavating volumes of 100,000 to 200,000m³ while the largest might be up to 700,000 to 1Mm³.

In terms of support, Wallace adds, "Realistically, a shotcrete and rockbolt approach would be the most cost effective but there may be a preference to consider cast in-situ linings for those facilities where groundwater control and water tightness is of priority. Final lining requirements will depend on the end-user requirements."

Despite the costliness of such major tunnelling schemes, it is expected the cavern schemes will be cost-effective as they would, in effect, be trading relatively cheap underground acreage for more valuable surface land in one of the world's most expensive stretches of real estate.

At the end of June, Arup was awarded a HKD 18.64M (USD 2.4M) consultancy contract by CEDD to follow-up on the initial planning and technical study. The second study is to look at land supply – leveraging the benefits of underground rock caverns as well as looking at reclamation potential. In addition, the contract includes a sizable public consultation element. The work is due to finish by April 2013 and is to explore a further eight prospective cavern sites to re-locate some government facilities.

In exploring the potential for rock cavern projects, Arup's main challenges are to establish an overall strategy and identify opportunities and facilities in a planned manner. "Technical issues are common to any underground scheme," says Wallace, "but all these are dependent on the type of facility to be placed underground."



Underground strategies

Hong Kong's famous congested and spiked skyline is bound in tight swathes around the edges of the hilly terrain of the city and in places around many of the surrounding islands. With a population of about 7.1 million and ever-decreasing availability of flat land to occupy, many of the buildings are high-rise blocks. Every square metre that can be found or recaptured is prized.

Left: Figure 1, Hong Kong's strategic areas for rock caverns and study sites

Much non-residential infrastructure development is underground, especially metro tubes and other transport in addition to the conventional placement of utilities, and much more is planned. Hong Kong, from the start of the last century to 2009 had constructed about 58km of drainage and sewerage tunnels (Pang et al, 2009). Almost the same again – 49km – is either in planning, design or to be constructed by 2019. For rail tunnels it is a similar story – 87km by 2009 and a further 76km planned by 2019. These categories cover approximately 70 per cent of the tunnel projects planned or in construction for the remainder of this decade.

Current tunnel projects include drill and blast excavation as well as TBM boring that is being carried out on metro projects, such as the West Island Line (WIL) extension and the new South Island Line – both on Hong Kong Island. Among other developments have been varied sewerage, road and slope stabilisation tunnels.

The largest project is construction of 26km-long high-speed twin tubes for the Hong Kong section of the Express Rail Link (XRL) to Shenzhen and Guangzhou.

The Government has been clearly supportive of the needs and provisions for underground solutions to infrastructure demands, and no small example is the protection of the XRL corridor out of Kowloon terminus. To this strategic perspective is added the possibility of new caverns being built to take suitable existing public facilities, not least those that may not be too favoured for how close they are to residents and businesses, such as refuse centres or sewage plants.

Earlier this year, just before the second consultancy study was awarded and while visiting some existing underground facilities, Donald Tsang, Chief Executive of the HKSAR Government, said, "Hong Kong needs to create land resources to cope with the demand for housing and development of various industries. However, our land is limited."

Tsang toured the recently completed western salt water underground service reservoirs in Pokfulam, in the west of Hong Kong Island. The caverns are around 16m wide, 14m high and 40m long, and the lining is partly cast-insitu lining with a SCL crown. The site also has covered fresh water reservoirs, following some recent reconfiguration and relocation of the various reservoirs, releasing land for the nearby University of Hong Kong.

Table 1: Major rock caverns In Hong Kong

Type	Dimensions L(m)	H(m)	W(m)	Year
Valve Chamber, W Aqueduct	20	8	20	1984
MTR SubStn (Sai Wan Ho)	18	13	16.5	1985
MTR Station (Tai Koo)	250	16	24	1985
Sewage Plant (Stanley)	130	17	17	1994
Explosives (Kau Shat Wan)	20	6.8	13	1997
Refuse Transfer (Mt Davis)	60	12	27	1997
HKU Saltwater Reservoir	40	15	17	2009

Source: Tunnels & Caverns in Hong Kong, HKIE Working Grp on Cavern & Tunnell Eng (2006)

The Pokfulam site is slightly to the south of where some new, fresh water service caverns might be built, in the Mount Davis/Kennedy Town area, which was identified as a potential project from the consultants' first study. The report also suggested, in outline concept, much larger projects, such as putting the Sha Tin sewage treatment works, northeast of central Hong Kong, underground in an adjacent hillside.

"It is crucial that we think outside the box in creating new land," says Tsang, adding that rock cavern development is an option worth considering.

Caverns – past and planned

Yet the studies are not the first time Hong Kong has looked at strategic rock cavern development. A couple of decades ago, Arup with Norconsult undertook two of the early studies – the Study of Potential Use of Underground Space (SPUN) and the Cavern Project Studies (CAPRO), in 1990 and 1991 respectively.

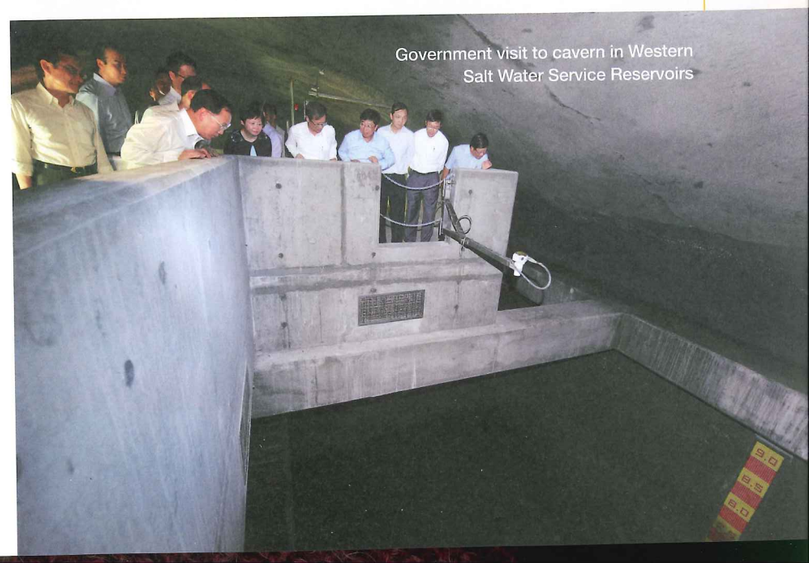
"We have a good relationship with Norconsult and have collaborated on a few projects in other parts of the world," says Wallace.

During the 1990s there were various cavern related studies undertaken by CEDD's geotechnical engineering office, including Cavern Area Studies (CAS) from 1992-98, and which covered Lantau Island, Hong Kong Island and Kowloon Peninsula by identifying potential cavern areas in those areas.

Also, from 1990 until the latest studies began, there were Preliminary Engineering Geology Studies (PEGS) for a variety of government facilities, such as sewage treatment, fuel storage, abattoir and water.

About 60 per cent of the land in Hong Kong is considered suitable for rock cavern development, though addressing land ownership is a separate, and crucial, issue according to the latest studies. Arup concludes there is significant potential for cavern development, especially as many hillsides have shallow rock cover and reserves of good rock mass.

Arup anticipates that future caverns housing transferred public works facilities


Government visit to cavern in Western Salt Water Service Reservoirs

could have dimensions of, typically, lengths of 100m to more than 250m, widths of up to 20 to 25m and heights of 10 to 18m. Access tunnels might be two-way or one-way routes, and could be 10 to 12m wide, and about 6 to 8m high, depending on truck, vehicle and ventilation requirements of each type of facility.

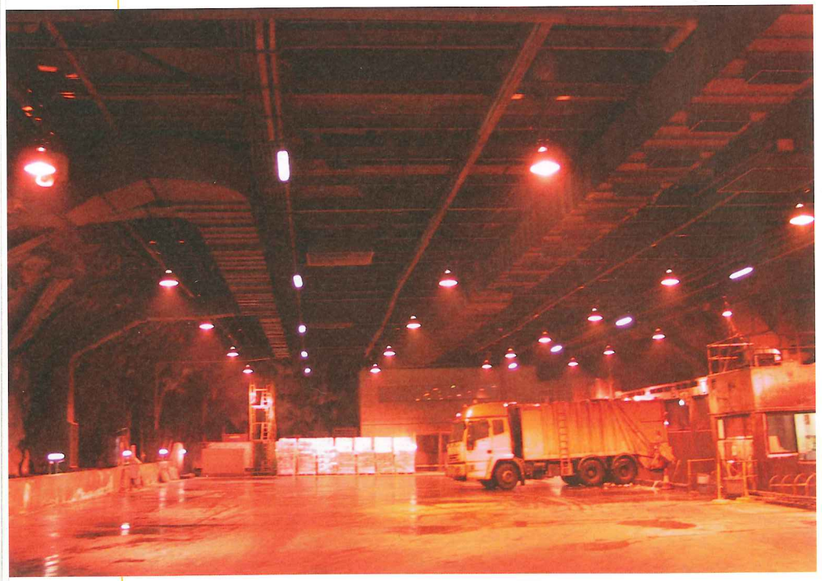
Wallace says that cavern options were considered in the past, and there are some successful examples, such as the Island West refuse transfer station and the Western salt water service reservoir in the west of Hong Kong Island. On the south side of Hong Kong Island, the Stanley sewage treatment plant is housed in a cavern. Underground storage is also used for explosives at the government depot at Kau Shat Wan, on Lantau, while an underground explosives magazine has been successfully constructed for WIL metro project on Hong Kong Island. In addition, MTR's expanding metro network will see more station caverns.

Among other underground, non-cavern related facilities reviewed by the consultants in their first, recently completed study are: the drainage service department's (DSD) Tai Hang Tung flood storage tank and pumping station; Crown Wine Cellars' use of former air raid bunkers on Hong Kong Island; numerous examples of deep excavations, such as cut and cover for metro stations and high-rise buildings, and an underground pumping plant for Stonecutters Island sewage station and various works for the current HATS Two A project.

The longest caverns built so far in the city are for MTR lines with MTR's Tai Koo station still the longest at 250m. Two other cavern stations are being constructed on WIL with similar dimensions to Tai Koo. The cavern for the Island West Transfer refuse station is the widest, built in the late 1990s with a span of approx 27m in the main tipping hall. The highest cavern, at 17m, is the main hall of the Stanley sewage treatment works, higher than Tai Koo by only 1m; the Stanley cavern is half the length of Tai Koo (see Table 1, page 15).

Yet, while there have been numerous tunnelling works in Hong Kong, and perhaps it is a recognised nexus for the industry, Wallace notes that the cost-benefit assessments for public works have not been a level playing field in weighing underground against surface options. He says 'land allocation is not considered as part of the project cost, which tends to support above ground schemes.'

Below: **Cavern hall in Island West refuse transfer station**



Cavern Study: 2010-11

In addition to gaining land, other benefits to be won from going below ground include more stable temperatures and security, though there would be added engineering obstacles to overcome, such as ventilation, lighting, fire safety and evacuation. Matters of land ownership, too, will play no small part in filtering the options for caverns.

To drive forward its latest initiative for rock caverns, CEDD launched the work in March 2010 with the study: 'Enhanced Use of Underground Space in Hong Kong' [Agreement CE66/2009 (GE)] study, which Arup finished in March this year.

Key points covered by the study, in addition to reviewing what had been studied and built before, were to develop a cavern suitability map and identify five strategic cavern areas and potential government sites to transfer underground.

Going into some local detail to showcase how existing facilities could be transferred underground, the study also considered three potential cavern projects and looked into a wider context by placing Hong Kong's caverns and land uses in an international setting. Also in Asia, in a similar manner to Hong Kong, Singapore is considering developing further projects and plans for major underground facilities.

"It appears that Singapore has a similar land supply problem and maybe even a more acute problem," says Wallace. "They have less available steep terrain to enter the ground and hence the majority of any cavern development would involve driving down into the ground, rather than in Hong Kong where the facility could lie close to existing ground level at the portal or to drive up into the steeper hillside areas."

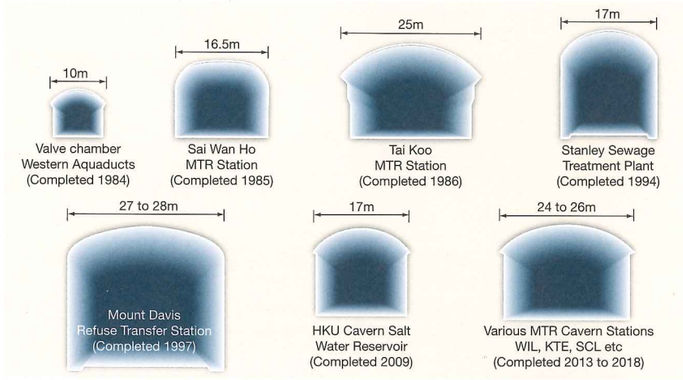
International perspective

The study noted the significant underground facilities for strategic oil, gas and fuel storage built since the late 1970s in South Korea. Recently this has been undertaken in Singapore as well. There are also a variety of facilities in Japan, many of them commercial environments with underground shopping and retail areas. There is also an underground bicycle park and ride complex at a suburban rail station.

Numerous underground space projects are also planned in China, as the study noted from 'The Use of Underground Space as an Unexpected Solution for Promoting Sustainable Development' presentation at a joint UN-ITA workshop in late 2007. The presentation foresees about 60Mm² of underground ground space development by 2020, principally in the Beijing and Shanghai areas and other major cities.

Further afield, underground schemes looked at included a number in northern Europe, including Helsinki, Finland, the first city to completely map its use of underground space.

Wallace says, "The Helsinki underground masterplan is considered by many people as a good example of strategic use of rock caverns and underground space in the world."



Left: **Figure 2, comparative sizes of existing caverns in Hong Kong**
Below: **Figure 3, cavern concept for Mount Davis/Kennedy Town reservoirs**

In the energy sector, there are also questions related to cavern construction and geological competence under examination as well as prolonged debate for the long-term burial of nuclear waste. In Norway, one of the examples cited in the study is the Himdalen waste facility.

Separately in the energy sector, there is also increased use of pre-mined salt chambers for storage of pressurised natural gas.

ITA's Committee on Underground Space (Itacus) Working Group Four collected global data showing that, proportionally, civil applications dominate the use of tunnels with a 45 per cent share. With shares of almost about a third each – 35 per cent and 30 per cent - other categories of use are goods storage and waste disposal, respectively. The remaining 10 per cent of their study identified experimental laboratories as other types of uses, such as the Deep Underground Science and Engineering Laboratory (Dusel) in South Dakota, in the US; as well as the research facilities at Boulby Potash mine in the UK, and the huge particle physics facilities in the Alps.

Map and facilities

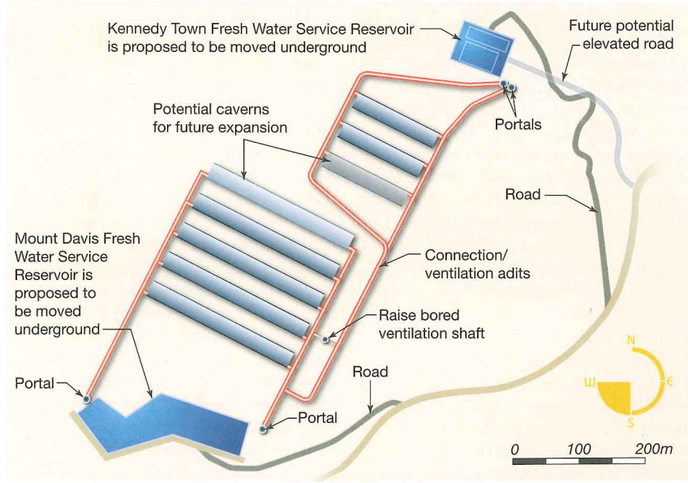
In the study, almost two-thirds of Hong Kong's land area was assessed to have medium-to-high suitability for cavern development based on analyses of set of spatial data, including ground conditions, existing underground infrastructure and other constraints.

A map was developed and it was noted that those government facilities seen as particularly suited to transfer underground are those close to the most favourable zones and others on edges of urbanised areas.

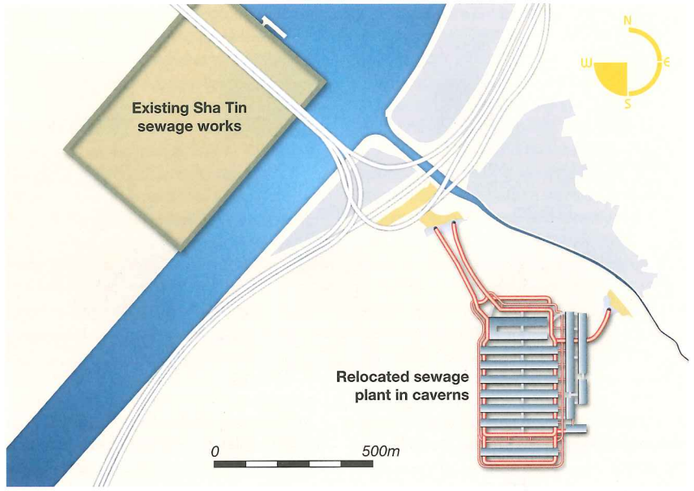
The study looked at more than 400 government facilities and developed a set of preliminary criteria to rank them for potential to be transferred underground.

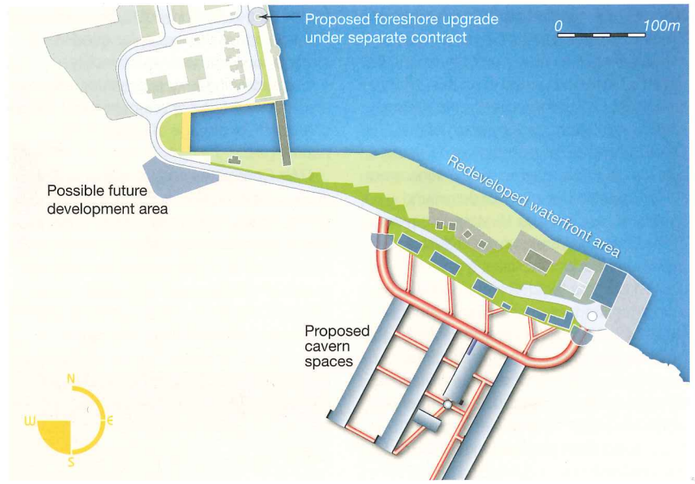
It was noted, however, that developing the rock caverns to take some government facilities underground would require an environmental impact assessment (EIA) – that covered both the construction and operation of the facility.

In looking at land uses with potential for rock cavern development, the study proposed to add a number to those listed already in the current planning guidelines, such as food/wine storage, warehousing, archives, data centres, research



Right: Figure 4, cavern concept for Sha Tin sewage treatment works
Below right: Figure 5, cavern concept for Mui Wo multi-function public facilities





laboratories, science park, bicycle park and ride, car park, crematorium, refuse collection, maintenance depot, underground quarries and substations.

"Another challenge is the location of the portal and the accessibility of the underground scheme to transport networks, although there are many areas where there is good connectivity to nearby roads and highways," says Wallace. He adds, "In Hong Kong, we have a world class approach to dealing with landslide hazards and this will be utilised in mitigating the risk to the rock cavern scheme, in particular at portal locations."

Sample case studies

The first study also considered the challenges of transferring some government facilities to caverns by selecting three to examine on a preliminary feasibility basis.

The existing facilities that were examined in the study were: Sha Tin sewage treatment works; Mount Davis and Kennedy Town water service reservoirs; and, at Mui Wo, a sewage works and refuse transfer station to be housed in a multi-function facility. Relocating them underground into grids of long galleries, as conceptual layouts only, would release a total of approximately 32.5 hectares (0.33sqkm) of land. The selection was made to also look at different ranges of benefits to the wider and local communities, and review the technical challenges, constraints and possible solutions.

Sha Tin

This scheme was chosen to demonstrate the feasibility of moving a major facility underground – in this case a sewage treatment works – from a prime location at the mouth of the Shing Mun River. If done, the transfer of the large facility would release about 28 hectares (0.28sqkm) of waterfront land, reduce environmental and visual impacts and enhance local land value. The feasibility of transferring such a large facility has precedent overseas, and it could be further expanded underground, the report says.

Mount Davis and Kennedy Town

If done, it would see relocation of fresh water service reservoirs to rock caverns, and release about two hectares (0.02sqkm) of prime land. It would improve security and integrity of the water tanks, and also allow future expansion without extensive cutting open-cut works on the hillside.

Mui Wo

This scheme was envisaged as moving a sewage treatment plant, refuse transfer station, bus depot and some other facilities into an integrated cavern complex, releasing about 2.5 hectares (0.025sqkm) of waterfront land with 500m of coastline. Improvements would result for the general environment and appearance of the area.

The key recommendations from first study were to include the cavern option in government project planning, develop a strategy to relocate government facilities underground, protect potential cavern sites from development, and develop a policy for private sector involvement.

Cavern study: next step

The follow-on study, now underway, is 'Increasing Land Supply by Reclamation and Cavern Development' [Agreement CE 09/2011]. CEDD said the 21-month study is a 'major milestone' in the strategy to identify potential reclamation sites outside Victoria Harbour and also suitable rock caverns.

In parallel with the study, there will be a two-stage public consultation, the first to start before the end of this year and lasting six months, and the second to commence in the third quarter of 2012.

Following the two stages, the process will deliver, by early 2013, a list of 18 publicly accepted sites – eight rock cavern sites, seven reclamation sites and three handling sites for contaminated sediment.

From sea to shining sea

Demand for tunnels in North America is strong to meet public transportation and water conveyance needs. Nicole Robinson highlights projects in the region

The US and Canada had different reactions to the global recession. While both took a hit, Canada's economy didn't suffer nearly as much as its southern neighbour's. Looking specifically to the underground construction industry, both countries are seeing strong demand for tunnels—from multi-billion dollar transportation infrastructure programs to smaller sewer conveyance projects.

1) Alaskan Way Viaduct Bored Tunnel Replacement

Seattle Tunnel Partners (STP), a joint venture of Dragados USA/Tutor Perini, is the design build contractor for this USD 1.35bn highway tunnel of 17.7m diameter. STP will use a Hitachi Zosen TBM to excavate the two-level, 2.7km tunnel, starting this year.

2) University Link Light Rail Extension

Three TBMs launched last year on this light rail extension in Seattle. The twin bore tunnels, each of 6.5m diameter, are being constructed under two separate contracts. The JCM U-Link joint venture of Jay Dee/Coluccio/Michels is using a Hitachi-Zosen machine for a distance of approximately 1.85km, while a joint venture of Traylor/Frontier-Kemper is using two Herrenknecht TBMs, each executing a 3.4km drive.

3) Second Avenue Subway

TBM excavations completed last year on both bores for the running tunnels of Phase One on New York's Second Avenue Subway line, each roughly 2.4km in length. The new line will have three new stations, two of which are being constructed by drill and blast. A joint venture of Schiavone/Shea/Kiewit is working on the cavern for 72nd Street Station, and a Skanska/Traylor joint venture is working on the 86th Street Station.

4) Lake Mead water intake number three

Providing additional drinking water capacity for the Las Vegas area, the Southern Nevada Water Authority is building a new 4.5km tunnel under the lake and intake structure. Contractor Vegas Tunnel Constructors (VTC), a joint venture of Impregilo and its subsidiary SA Healy, will use a 7m diameter Herreknecht TBM for the job.

5) Water Treatment Plant Four

Two separate contracts have been awarded to build a water treatment plant worth USD 508M in Austin, Texas. A joint venture of Southland/Mole will excavate the 10.5km Jollyville Transmission Main, which will have a final diameter of 2.1m. Austin Hill Country Constructors, a joint venture of Obayashi USA/Manson Construction Company, is building the raw water system, which includes a 2.7m diameter raw water intake tunnel of 1.3km in length and a 2.1m diameter raw water transmission main 1.1km long.

6) Waller Creek Tunnel

To protect the city from dangerous flooding, Austin, Texas, is working on a 1.7km tunnel ranging in diameter from 6.2 to 8m. The USD 146.5M project is being delivered in four contracts to construct the tunnel, inlet and outlet structures. S.J. Lewis was awarded a contract for the tunnel portion, worth USD 49.5M last year.

7) Port of Miami Tunnel

Excavation of the 12.86m diameter tunnels started in November for the highway tunnel at the city's port. The 1.1km twin tunnels are being constructed by contractor Bouygues Civil Works of Florida, part of the Miami Access Tunnel (MAT) concessionaire.

8) Toronto-York Spadina Subway Extension (TYSSE)

Contractor Aecon started two TBM drives on the TYSSE last year. OHL/FCC will be using two more TBMs to tunnel 6.6km on the project's second major contract. All four CAT Tunneling (previously Lovat) machines were owner-procured.

9) Eglinton Scarborough Crosstown LRT

Running across the entire length of Toronto this light rail project of 25km will include 19km excavated by TBM. Twin tunnels 5.75m in diameter will require at least four machines, and perhaps as many as eight. Owner Metrolinx hasn't finalised the exact number of construction contracts, but expects to have the first package awarded early this year.

10) Toronto sewer tunnel

Strabag has a USD 296M contract to build a 15km wastewater tunnel in the Toronto area, including 16 shafts, in August 2011. Four Caterpillar Tunneling TBMs with diameters of 3.6m, will be used to mine the tunnel. Construction is expected to finish in August 2015.

11) Ottawa Light Rail Transit

The City of Ottawa is selecting a consortium to deliver the Ottawa Light Rail Transit project—a 12.5km line that will include a 2.5km tunnel through the city's downtown. The RFP process is scheduled close in July for the three shortlisted consortia. The winning proposal will be announced at the end of the year.

12) Evergreen Line Subway

A total of 11km long, the City of Vancouver's new Evergreen line will include a 2km tunnel. Three shortlisted teams (EL Partners, Kiewit/Flatiron Evergreen Line and SNC-Lavalin) will submit technical submissions for an April deadline.

13) San Francisco Public Utilities Commission

The SFPUC is undertaking a USD 4.6bn improvement program to update its water system. Significant components include the 5.6km New Irvington Tunnel, 4m in diameter, and the Bay Tunnel of 4.6m diameter and 8km long. The Bay Tunnel will see the first TBM to excavate under the San Francisco Bay.

14) North-South Tunnel

Atlanta's proposed 11km tunnel would connect Interstte highways to relieve congestion. Initial studies suggest using a 12.5m diameter TBM for excavation. The Georgia Department of Transportation proposed the project as a toll road, but has met some resistance from local residents. Based on 2008 costs, the estimated price of the tunnel project would be USD 3.74bn.

15) DeKalb Tunnel

Dekalb County, east of the Atlanta area, is planning the Interplant Storage and Conveyance System (ISCS) or DeKalb Tunnel for transfer and storage of wastewater between treatment plants in the county. Design is still underway for the approximately 25ft (7.6m) diameter tunnel, with an length between 7 and 8km.

16) Central Subway

The San Francisco Municipal Transportation Agency awarded a USD 233M contract to SA Healy/Barnard in June 2011 that includes two single-track tunnels of 2.7km, excavated by two TBMs of 6.4m diameter. There are three underground station contracts yet to bid.

17) Euclid Creek Tunnel

A joint venture of McNally/Kiewit secured a USD 198.6M contract to excavate a 5.5km tunnel with a 7m diameter by TBM in Cleveland, Ohio. The storage tunnel includes a 900m stretch below Lake Erie.

18) OARS

Measuring 7km in length and 7m in diameter the first of three deep tunnels for Columbus, Ohio's, USD 5.4bn Wet Weather Water Management Plan is being constructed by a Kenny/Obayashi joint venture. Two more tunnels on the east and west side of town—the 21km Alum Creek Relief Tunnel and the 18km Olentangy Relief Tunnel—will be constructed to relieve sanitary sewer overflows in 2014 and 2018, respectively.

19) Lower Mill Creek Tunnel

The Metropolitan Sewer District of Greater Cincinnati is proposing a 1.9km-long tunnel with a 9m diameter worth USD 244M to reduce combined sewer overflows. Design is in the preliminary stages. Construction should be completed in 2018.

20) East Side Access

Connecting the Long Island Rail Road to Grand Central Station, this New York project completes tunnels either side of a 2.6km long existing stretch at 63rd Street. A Dragados/Judlau joint venture is constructing the 2.2km Manhattan Approach Tunnels. In Queens, a joint venture of Granite Construction Northeast/Traylor Bros/Frontier-Kemper is using slurry TBMs for 3.2km of tunnels.

21) South Hartford Conveyance and Storage Tunnel

In Hartford, Connecticut, the Metropolitan District is planning the 4.1km South Hartford Conveyance and Storage Tunnel of 8m diameter. This is part of a total 8km of tunnelling and microtunnelling for the city's Clean Water Project.

22) Midtown Tunnel

The Virginia Department of Transportation has partnered with Elizabeth River Crossings (ERC), lead by Skanska Infrastructure Development and Macquarie Financial Holding Limited, to build a new two-lane immersed tunnel crossing the Elizabeth River. The PPP expects to reach financial close on the project in late February/March.

23) Blue Plains Tunnel

To tackle its CSO problems, Washington, DC has hired a joint venture of Traylor Bros/Skanska/JayDee for design and construction of the 7.2km-long Blue Plains tunnel with a 7m-diameter. There is also the 3.8km Anacostia Tunnel, which should start construction in November 2013.

24) Gateway Tunnel

Amtrak announced its proposed rail tunnel to connect Secaucus, New Jersey to New York's Penn Station in February 2011. This would take the place of the cancelled Access to the Region's Core (ARC) tunnel. Amtrak estimates the project could be completed by 2020 with an USD 13.5bn price tag. The US Senate approved USD 15M for design and engineering work in November 2011.

25) Deep Rock Tunnel Connection

The City of Indianapolis' USD 280M Deep Rock Tunnel Connection of 5.5m diameter will be 12.7km-long and help solve the city's CSO problems. The project is slated for completion during 2017.

26) Delta Tunnel

California is looking to build a USD 12.7bn tunnel to bring water from the San Francisco Bay, south to the Sacramento-San Joaquin Delta. A report issued in late 2010 found a 8km single bore tunnel, with a 8.8m i.d., connected to another 56km dual bore tunnel with 10m i.d. would be the best option.

27) Delware Aqueduct Tunnel

A 4.8km bypass tunnel is under design to repair the leaking Delaware Aqueduct in New York. Under the plan, the USD 1.2bn tunnel will be built around a portion of the aqueduct experiencing the most significant leakages. The project includes four access shafts ranging from 213 to 274m deep at 4.6 to 6m in diameter. The 6.7m diameter TBM should begin excavation in 2015.

Out with the old and in with the NIT

Keeping the water flowing is the soul objective of the New Irvington Tunnel as the old struggles against the constant threat of a major earthquake. Nicole Robinson was on site in San Francisco to see the roadheader excavating the 3.5 mile (5.6km) of tough and changing geology drive

In 1928 construction started on the Irvington Tunnel to help deliver water to residents of the San Francisco Bay Area. Since its completion, the region's population has grown so much it hasn't been possible to take the tunnel out of service for repairs—doing so would severely impact the water supply.

Now it's 2012 and the tunnel hasn't been inspected since 1966.

Located on the southeast side of the Bay, near the city of Fremont, the tunnel is framed by the Calaveras fault to the east and the Hayward fault to the west. With one major earthquake the tunnel would be rendered useless.

The Irvington Tunnel is not alone in reaching the end of its useful life. The San Francisco Public Utilities Commission (SFPUC) is embarking on a USD 4.6bn improvement program to upgrade its entire aging Hetch Hetchy system. As part of this infrastructure program a new tunnel has been designed to replace it, and to withstand a major earthquake.

When the New Irvington Tunnel is complete, it will carry 320 million gallons of water, but it will have little effect on capacity as it replaces the old tunnel. The purpose of the project, and all projects in the program, is to provide a seismically reliable water transmission system that's capable of sustaining an earthquake, able to carry water within 24 hours and able to return to maximum service in 30 days.

SFPUC put the project out to bid in January 2010, and announced a joint venture of Southland Contracting and Tutor Perini as the lowest bidder at USD 226.6M in April. Construction work began in

Left: The Vargas shaft; photo by Sue Bendenarz, Jacobs Associates

Right: Figure 1, work sites along the tunnel's alignment

September of last year, and completion of the tunnel is expected in May/June of 2014. Hatch Mott MacDonald is providing construction management services for the project.

The lay of the land

The contractor will construct the 3.5 mile (5.6km) New Irvington Tunnel parallel to the existing tunnel. On average the distance between the two is between 150 to 200ft (45.7 to 61m). Initially URS Corporation and Jacobs Associates had designed the tunnel for TBM excavation. The TBM would start at the Alameda West Portal, the primary work site, and do the 3.5-mile (5.6km) drive for the tunnel, finishing at the Irvington portal.

However, during the design period, boreholes gave unexpected results.

"By about 35 per cent design, they got additional boring/ground data that convinced the design team that it would be wiser to go through conventional type construction," says David Tsztoo, senior project manager with the SFPUC. "We started thinking in terms of roadheaders and some limited drill and blast. So there was a major shift in the scope of the project at that time to convert the design from TBM to one that would be roadheaders."

Once the design team knew the tunnel would be excavated by roadheader rather than TBM, another portal was added to the alignment at Vargas Road (Figure 1, above right). "They developed the concept that the contractor can do more tunnel headings from the Vargas shaft as well as from any of the portals," Tsztoo explains.

Working from two headings at once, the Southland/Tutor Perini JV has the option to run three roadheaders if necessary. Adding the Vargas portal also reduces the construction activity at the Irvington portal, which is located in the middle of a neighborhood of about 100 households. At this site, only up to 500ft (152m) of tunnelling is allowed if needed.

"From the most basic level, the tunnel is designed to have the most minimal activity as possible at that one tunnel site, given the community," says Betsy Rhodes, Sunol Regional Communications Liaison, SFPUC. "It's tight. It's crowded. Literally the people's backyards look right out at the job site. The majority of the tunnel construction will happen from the intermediate Vargas shaft and the main work shaft at Alameda West."

Tucked into part of a cloverleaf exit/entrance ramp for the 680 Freeway, the Vargas work site is shaped much like a teardrop. Comprising roughly 2.5 acres, operations above ground in this small space are tight. The contractor completed excavation of the 120ft (36.6m) deep shaft, with a 41ft (12.5m) diameter, in late March last year.

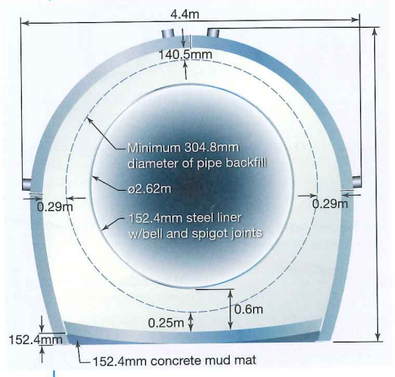
In total the tunnel will be 18,660ft long, and there is a distance of roughly 14,440ft (4.4km) between the Alameda West and Vargas portals. For the majority of the alignment the grade is 0.125 per cent with an increase in the last 2,000ft to 2.95 per cent. There are several gentle curves, one vertical, and three horizontal.

The new and the old

The New Irvington Tunnel will be between 30ft (9m)—at the portals—to 700ft (213m) below the surface. Geology in the area varies and difficult ground conditions are expected, ranging from very weak to strong rock. The alignment crosses seven zones of seismic secondary faults where squeezing ground is anticipated (Figure 2, page 24). Geology along the alignment includes Briones Formation (Tbr, as indicated on the geologic profile of Figure 2), Cretaceous-age sandstone and shale (Ks) and Tice shale (Tt). Near the Vargas shaft there are areas of Claremont formation sandstone and siltstone (Tcs) and shale and chert (Tss).

"Part of the reason for going to conventional tunnelling was because it can handle different types of ground better, including probing, grouting the ground,

Right: Roadheader and drill and blast methods were chosen to better cope with the different types of ground



Above: Figure 3, The tunnel will have a steel pipe lining

mapping the ground," explains project manager Michael Cash, of the Southland/Tutor Perini JV. "We'll know exactly where the faults are. Going with the roadheader and drill and blast approach enables us to handle all of those conditions."

Another factor that highlights the need to change from a TBM to roadheaders is that high groundwater inflows are expected. "There are very detailed records from when they built the tunnel starting in 1928, and so they knew at what precise points they had flushes of water, which has been very helpful in designing," Rhodes adds.

For the construction, dewatering facilities are being set-up to control groundwater in flows ahead of tunnel excavation. At the same time it's a large concern for the SFPUC, which owns the subsurface easement through which the existing and new tunnels go, but underneath private property relying on groundwater wells.

"Initially there was distress resulting from previous tunnel construction where there was significant ground water loss," says Francis Zamora, public outreach consultant with the project.

The SFPUC has developed individual ground water management plans for 33 property owners within the project area explaining what would happen in the event of groundwater loss as result of the project. "Out of 33 there are only seven that we feel really are going to be impacted," says Dan McMaster, project construction manager at Hatch Mott MacDonald.

Pre-mitigation measures are planned for those seven properties including setting up additional tanks on the surface for which water can be trucked in to fill on a daily basis. "Once the tunnelling underneath the valley is done we hope some of the ground water will come back, but as soon as we get that final lining in then the water table will start rising again."

The contractor is excavating the tunnel to a 13ft (4m) diameter in a modified horseshoe pattern. The interior diameter of the tunnel will be 8.5ft (2.6m). While the contract had been bid with several options for the final lining, at the time of *T&TI's* visit to the New Irvington Tunnel's work sites, final negotiations were underway for an alternative.

One of the options in the contract was a cast-in-place lining with one steel pipe in the seven sections of the fault zones—this would be about 3,000ft (914m) of welded steel pipe. Other options include reinforced concrete pipe with the welded steel pipe in the fault zones and a pre-stressed concrete cylinder pipe lining.

During the bidding process the contractor asked if welded steel pipe could be used throughout the tunnel, but needed to wait until after the project had been awarded to see if it was feasible, at the client's request. Since then the Southland/Tutor Perini JV has proposed a welded steel pipe option all the way through the tunnel, which would provide an impermeable lining with welded joints (Figure 3, above, left). Negotiations were finalised in April and steel pipe supplied by Northwest Pipe will be used throughout.

Alameda West

In late March last year an Antraquip AQM 150 began excavation at the Alameda West Portal. The largest of the three worksites; workers moved about the staging area, surrounded by water supplies and ventilation awaiting installation. It was a sunny day but hot on the heels of a few record-breaking rainy days.

The JV had the option of lining the tunnel with shotcrete or using steel ribs, which it has chosen and is installing 4ft (1.2m) apart. Shotcrete is applied to the face only if it is going to be left for any time

For pre excavation grouting there are two probes out in front at all times. The contractor can probe up to 150ft (45.72m) but a 20ft (6.1m) bulkhead must be maintained at all times. "And then if we do encounter water, if it's over 20gpm [75.7L], they can grout with microfine cements along the perimeter to reduce the inflow of water into the heading and also for some ground modifications if we hit bad ground," McMaster explains.

It's too early to tell what lengths will be probed and it will also depend on the type of ground. It won't be until late this summer that Southland/Tutor Perini reaches the first of the seven fault zones.

Located in Sheridan Valley, it's about 3,500ft (1.06km) away from the Alameda West Portal. How the contractor will handle these zones depends on the water. In the event of badly fractured ground, the support spacing will be reduced from four to 2.5ft (1.22 to 0.76m), explains Cash. On average he expects the project will see rates of 20ft (6.1m) per day, but tough geological sections will be much slower.

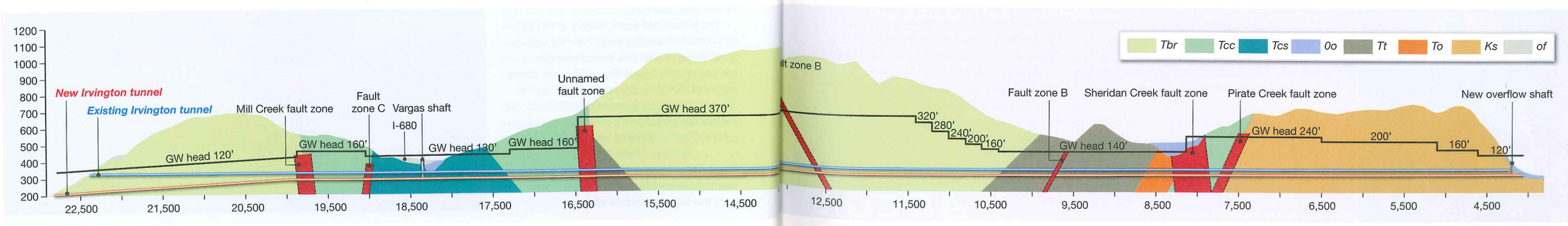
The AQM 150 has gathering arms that pull spoil onto a conveyor, which empties into muck cars. Once the material is out of the tunnel and loaded onto trucks it is taken to designated dumping areas.

All equipment specified in the contract is explosion proof because there is a potential for both methane and hydrogen sulfide in the tunnel. The contractor is monitoring the gas as required for tunnels classified as potentially gassy. In the event the tunnel is reclassified, not having permissible equipment could have halted the project three to four months for retrofitting, explains McMaster—who notes construction work in the 1930s on the existing Irvington Tunnel encountered gas as well.

Another roadheader, a Mitsui Miike S200 was launched from the Vargas shaft having arrived from Japan the first week of May. Tunnelling operations will be the same at the Vargas as the Alameda portal, except that a 160t crane is being used for muck removal. A 50,000lb excavated the Vargas shaft and a concrete was floor laid. Construction started in late 2010 on the 120ft (36.58m) deep shaft made up of 67 secant piles. "We surveyed every single pile to guarantee that it didn't diverge from where it was supposed to be," Cash says. "It's actually very accurate. We didn't have to re-drill any piles at all."

The JV used a special sonar survey, he explains. "We backfill the hole with water and probe down the center and it will sense each pile's case before we pour the concrete. It sensed where that casing was and gave a measurement at different points to tell how far it deviates from the surface."

By monitoring the divergence during the shaft excavation, the contractor could drill down to relieve any water pressure behind the secant piles. The shaft excavation was about 27 to 29m of rock. Instead of using drill and blast, a rock hammer was used on the excavator that chipped out the rock.



Below: Figure 2, alignments of the existing and New Irvington Tunnels

Looking back

The old Irvington Tunnel is 3.45 miles (5.55km) long, conveying water east to west from the Alameda West Portal to the Irvington Portal. The 10.5ft (3.2m) diameter tunnel is lined alternately with concrete and gunite with an average thickness of 18 to 21in (0.46 to 0.53m). It was excavated from 1928 to 1931 with an average of 10ft (3.05m) per day.

Irvington tunnel was constructed as part of the 25.1-mile (40.4km) Coast Range Tunnel, which started construction in 1927. According to the SFPUC, project engineers kept earthquake threats in mind when designing the tunnel, and used innovative techniques for the time such as flexible joints on some sections of the concrete-lined Coast Range Tunnel.

"The New Irvington Tunnel project is fascinating to me in a way that affirms my awe in the achievements and tenacity of men and women to build great things," says Michael Cash, project manager for the Southland/Tutor Perini JV.

"Our tunnel is being built parallel to the original and the close proximity is a daily reminder of the pioneering spirit of the men and women who originally constructed the tunnel in the late 1920s and early 1930s. The original construction was well documented and we have made a special effort to post photos of the original construction throughout site offices to remind us of the historical context."

Above: Construction work on the original Irvington tunnel in 1931. © *San Francisco Public Utilities Commission; Horace Chaffee*

Lakeside risk

Challenging soil combined with strict deadline requirements to spur the City of Portland in Oregon, US, to award a non-standard contract. Construction on the much needed sewer relief project completed late last year as Nicole Robinson reports from site

Marking the centennial anniversary of their famous trek, the Lewis and Clark Exposition in 1905 attracted people from all over the world to Portland in Oregon, US. Visitors crossed wooden bridges to an island in scenic Guild's Lake to attend.

Old black and white images show still waters surrounding an elaborate entrance building, which would be taken down after the show. The lake would be filled in with anything and everything in only 15 years.

As the City of Portland wraps up a 20-year program to control combined sewer overflows (CSOs), it's exploring the geological history of the city's northwest side while constructing the Balch Consolidation Conduit.

The 8,500ft (2.6km) pipeline will carry combined sewage and storm water runoff from the Balch Drainage Basin via the existing West Side Big Pipe to the Columbia Boulevard Wastewater Treatment Plant. With the completion of the tunnel and the program late last year, CSO volume emptied into the Willamette River, which passes through the city, has been reduced by more than 94 per cent.

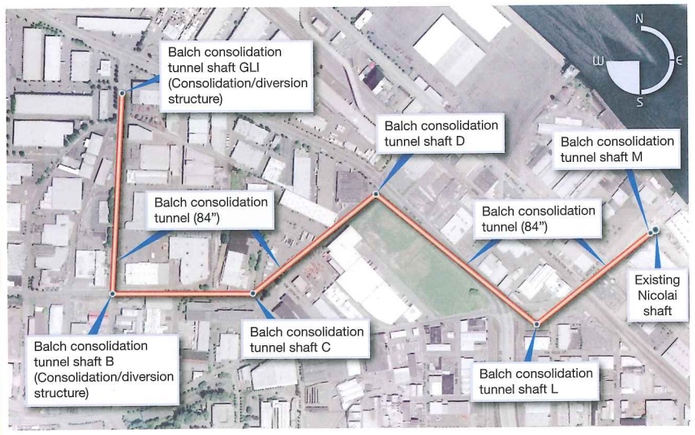
Design work began in 2007, when the city put out a consultant services request for proposal (RFP) in January, which was awarded to a JV of Kennedy and Jenks Consultants, with Staheli Trenchless Consultants and Shannon & Wilson.

Guild's Lake's demise

Ground conditions along the Balch alignment were less than ideal, partly because of the former lake. "This pretty good sized lake was filled in with man-made materials and our project had to navigate through all these different features associated with the lake," says Jerry Jacksha, lead geotechnical design engineer, who is a senior associate with Shannon & Wilson. Of all the projects the City of Portland has undertaken in its CSO program, he says, "It's fair to say we probably have a wider range of subsurface conditions than any of those."

This varies from very soft lake sediments, which are unique to the whole west side of Portland; red sand materials that were man-placed; wood trestles from railway beams that ran through the lake and sluiced gravel from the nearby West Hills.

"In order to provide a cheap way of getting fill into this lake area from the West Hills, they used high-pressured water and they turned this native material into a kind of fluid, sluice material that flowed down into the lower areas," Jacksha explains.



Left: Figure 1, the tunnel alignment and location of the six shafts

This sluice material made its way to the lake shortly after the 1905 exposition finished when the area began to see new development. Scott Clement, project manager, with the City of Portland's Bureau of Environmental Services, explains, "The Portland Regional Dock Authority was also doing navigation work on the Willamette River where they would dredge and then dispose into Guild's Lake. The City of Portland also had an incinerator on site where local trash was burned, and then deposited as landfill, which was also going in the lake."

As different organisations used Guild's Lake as a catch-all, it was filled in and was developed over during the 1920s-40s. But that's not the only challenge for the Balch Consolidation Conduit. In terms of the native materials Alluvial deposits are predominant, Jacksha says. "These were deposited from up to an estimated 40 flood events. They're called Missoula floods—a lot came from that part of the country [the city in western Montana] when the big ice dams would break and send huge amounts of water down the Columbia River Gorge into Portland, and then they would move down toward the ocean."

There are also gravel, cobbles and boulders along the alignment. And there is a material unique to Portland, a cemented gravel called the Troutdale formation. "And that was something we really had to consider with this micro TBM—hitting this cemented gravel and how it would respond. It could be rock material and in other places it could be partially cemented," Jacksha explains. "And of course all of this area is below the water table, and our shafts had to deal with ground water and other things related to ground water."

Contracting for risk

When it came to the alignment, the City gave heavy consideration to the geology, along with public right-of-way and public impact. "We looked at those on a cost basis and overall just trying to keep our microtunnelling drives on the order of about 1,500ft [457m] plus or minus," says Brad Moore, technical director of the Kennedy/Jenks consultants design team.

That led the design team to the preferred alignment, with six shafts and depths ranging between 40 to 75ft (12 to 23m). There were two existing diversion points where the tunnel needs to pick up flow before delivering it to the west side Nicolai shaft or shaft M (see Figure 1, above).

Originally the tunnel was to be delivered in a standard design-bid-build route. Design plans were 30 per cent complete when the City of Portland started looking at the schedule and the risks associated with the project, and decided to look at alternate forms of contract delivery.

"We chose the Portland method, which is similar to CM/GC [Oregon's Construction Manager/General Contractor], but it doesn't restrict the prime contractor to perform a limited amount of work," Moore says. "It also doesn't have the guaranteed maximum price. The restructure is based on a reimbursable cost, plus a fixed fee. That was the vehicle for completing the design."

The city issued an RFP for the project's contractor and selected James W. Fowler, which came on board in November 2008 when the design was about 60 per cent complete. "We had the contractor, the designer and the city at the table to complete the design of that project," Moore says.

"Through that process we found many innovations to improve the project in terms of cost, environmental and societal issues. At the end of the PSA [pre-construction service agreement] phase—when the contractor was on board to participate in the completion of the design—we entered a second contract with the contractor for the construction and that began June 2009." The contract was worth USD 57.3M, and the project's total budget was USD 74.4M.

The 84in (2.1m) diameter tunnel is approximately 6,980ft (2.1km) long and is being mined by a Herrenknecht AVN2000D slurry machine. The TBM arrived at the site in November 2009 and was later launched in spring 2010. "During the pre-construction—from 60 per cent design completrion to the final design—that was a period that allowed the contractor to also look at early procurement of equipment in terms of the micro TBM," Moore says.

CSM shafts

Five shafts needed to be constructed, GLI, B, D, C and L, and the sixth existed, but needed major work (see 'Shaft dimensions', right). Project plans called for secant or sheet piles to build the shafts, but in the end cutter soil mixing (CSM) was used instead, by suggestion of the contractor.

"They proposed that to us initially as a cost saving measure that was anticipated to save us USD 600,000 to USD 1.2M," Clement says, "And also as a schedule saver because we wouldn't be subject to the drilling subcontractors providing these services."

The City of Portland was reluctant to try CSM because it was untested in the project's unique soil. "We relayed that back to the contractor, and they ended up coming back to the city with a proposal from the manufacturer of this equipment saying, 'if we're not successful, the city wouldn't incur the full cost of it'," Clement says. "Sort of an incremental purchase—they would prove successful at one site we would pay for so much; prove successful at a another site we would pay more."

Contractor JWF worked with Jacobs Associates on the CSM, and with the city relieved of its concerns over the risk, a USD 4.5M CSM machine manufactured by German company Bauer was sourced through its Bauer Pileco office in Texas. The machine went through a test program at different sites in Portland to see how CSM would perform, particularly with the area's gravels.

"The gravel alluvium is an open network

Shaft dimensions

GLI
Rectangular shaft, 28 by 20ft (8.5 by 6.1m), about 30ft (9.14m) deep

B
Rectangular shaft, 45 by 31.5ft (13.72 by 9.6m), about 45ft (13.72m) deep

C
Round shaft, 36ft (10.97m) inside diameter, about 60ft (18.29m) deep

D
Round shaft, 23ft (7.01m) inside diameter, about 63ft (19.2m) deep

L
Round shaft, 29ft (8.84m) inside diameter, about 75ft (22.86m) deep

M
Rectangular shaft, 27 by 16ft (8.23 by 4.88m), about 65ft (19.8m) deep

of cobbles and I would classify it as boulders," Clement explains. "It's basically like a bag of marbles. There is nothing there to hold it. As soon as you release one or release the bag they just run everywhere."

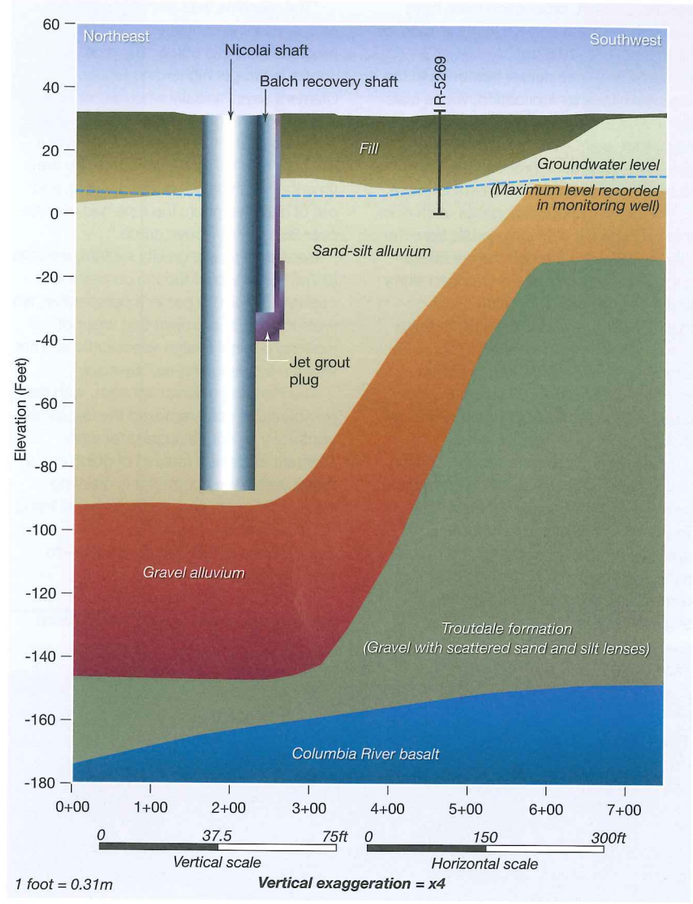
And that's what was to happen at shaft L. The contractor needed to go at depths of 35 to 55ft (10.7 to 16.8m) to pre-grout the perimeter of the shaft while the CSM panels were drilled into place.

"We did our research throughout the world of CSM projects, and the kind of material that they ran into in various places around the world," Jacksha says. "And to our knowledge, this is the only place the machine has ever worked with this amount of gravels or cobbles, and this kind of formation with very little matrix or no matrix."

In the end the City of Portland is happy with the results. "It's been very successful, and it came with some added benefits that we hadn't originally considered," Clement says. "One of those was, this methodology proved to be watertight. So at shaft B we didn't have to deal with the contaminated water. It also proved to greatly reduce the amount of waste product that had to be hauled off. So there are additional savings there in just the construction of the support of excavations."

Construction for shaft M, or the Nicolai shaft, had originally been part of a previous contract, by a different contractor who had multiple failures excavating the shaft before abandoning it. "They had sand boils anytime they had removed enough of the overburden in the bottom of the shaft," Clement recalls.

Together the contractor, designer and city discussed three options for shaft M, and chose one proposed by JWF to drill down into the existing jet grout fail, trying to supplement that with additional grout to seal the leaks (Figure 2, above). After several attempts the contractor was successfully able to excavate down to grade without a failure on the bottom.



Above: Figure 2, the complex geology at the Nicolai Shaft

Diverse drives

The MTBM has a 102in (2.6m) outside diameter and is just under 50ft (15.24m) long with 10 disc cutters and 12 carbide bit picks on the face. There is also a 54in (1.37m) diameter drive from shaft B to the Nicolai shaft using a smaller machine through the sluiced West Hills material. Altogether the sequence of drives is: B to GLI; C to B; C to D; B to Nicolai (54in); L to M and then L to D.

The first drive, from B to GLI, was in the project's softest ground and required CSM panels along the alignment to support the machine's weight. These panels were placed approx. 15ft (4.57m) on centres for just over 400ft (121.92m). "That assured us that we wouldn't lose grade or the machine wouldn't sink, and we finished that drive within specifications for grade," Clement says.

The project elected to purchase an optional second articulated joint with the MTBM for additional steering in the softer grounds. Along with the first drive, this was also used for the second, the C to B drive. A 9in-thick reinforced concrete jacking pipe, poured locally by Cascade Concrete, is being installed, with neat cement grout injected through pores in the pipe. JWF has been typically running two 10-hour shifts with downtime for maintenance in the

second. By shift, production rates have been between 2.5 and 3.5 joints of pipe, or 25 to 35ft (7.62-10.67m).

After slurry lines deliver bentonite to the machine's face for lubrication, waste lines carry spoil and bentonite back out to a separation plant. "We have a fairly elaborate separation process that allows us to reuse the bentonite," Clement explains.

The separation plant consists of shakers that segregate the finer materials from the liquids, which go through the centrifuge and clarifiers to produce a cleansed slurry that can be reused for mining. Finer materials, sands and gravels go through shakers and come out to one of three bins: a mud bin that's still very fine or liquid, a sand bin or gravels bin. The project is reusing more than 7,000t of the sands and gravels for backfill on the shafts.

In the third run, C to D, around 460ft (140m) into the drive the MTBM hit what is believed to be a boulder on top of the Troutdale formation, and the whole machine rotated 13 degrees. The operator was able to move the machine past the object, but that caused it to go into negative pitch.

"The machine was starting to plow, and as the machine continued to slowly progress past this object, the pipe continued to get higher and higher," Clement says. "Initially when we went over this object, the pipe was online and grade. Once we hit it—the machine went over it—we were 5in (127mm) over grade. By the time the machine got out of plowing, and out of negative pitch, the pipe had risen to over 26in (0.7m) above grade."

Because this is a gravity system, the 26in (0.7m) hump would reduce conveyance capacity. "From an owner's perspective, we were looking at a project that was not meeting original design specifications. That was a major issue for us," he says.

The Portland method contract, with the reimbursable cost, removed the risk for the contractor of not being paid for work, Clement explains. "Instead of going into a mode where the contractor is claiming changed conditions and the owner is trying to refute that, we all sat down—the designer, the owner, the contractor—to discuss a solution."

Being able to discuss the options together the project could move forward quickly, and that helped avoid a rescue shaft. That's particularly significant as this section of the alignment is under landfill.

Jacksha explains, "The jacking pressures got to be tremendously high during that run and it really pushed the limits of that machine. But everything performed way better than expected." Clement adds that, had this been a low-bid contract, it's likely that the contractor would have claimed changed conditions and waited for a response. That process would have allowed the jacking forces to increase to the point the only option was to construct the rescue shaft.

"We evaluated the modelling and the hydraulics and found that although it's not optimal," he says, "A system with 26in (0.7m) high hump will meet the flow conveyance requirements for CSO events."

After tunnelling from C to D the machine's face was refurbished and its disc cutters were replaced.

During the drive from L to M the face became gravel bound about 25ft (7.62m) into the drive. An optional airlock had also been purchased with the MTBM, and was then used for an entry under pressure to remove material by hand.

"The most difficult and aggressive soils, gravel alluvium basalts and quartzites from the Missoula floods deposits—we've run into them between L and M and L to D," Clement says. "Quartzite is one of the hardest natural minerals you will find, and coupled with the basalts and the open network makes it a unique tunnelling run."

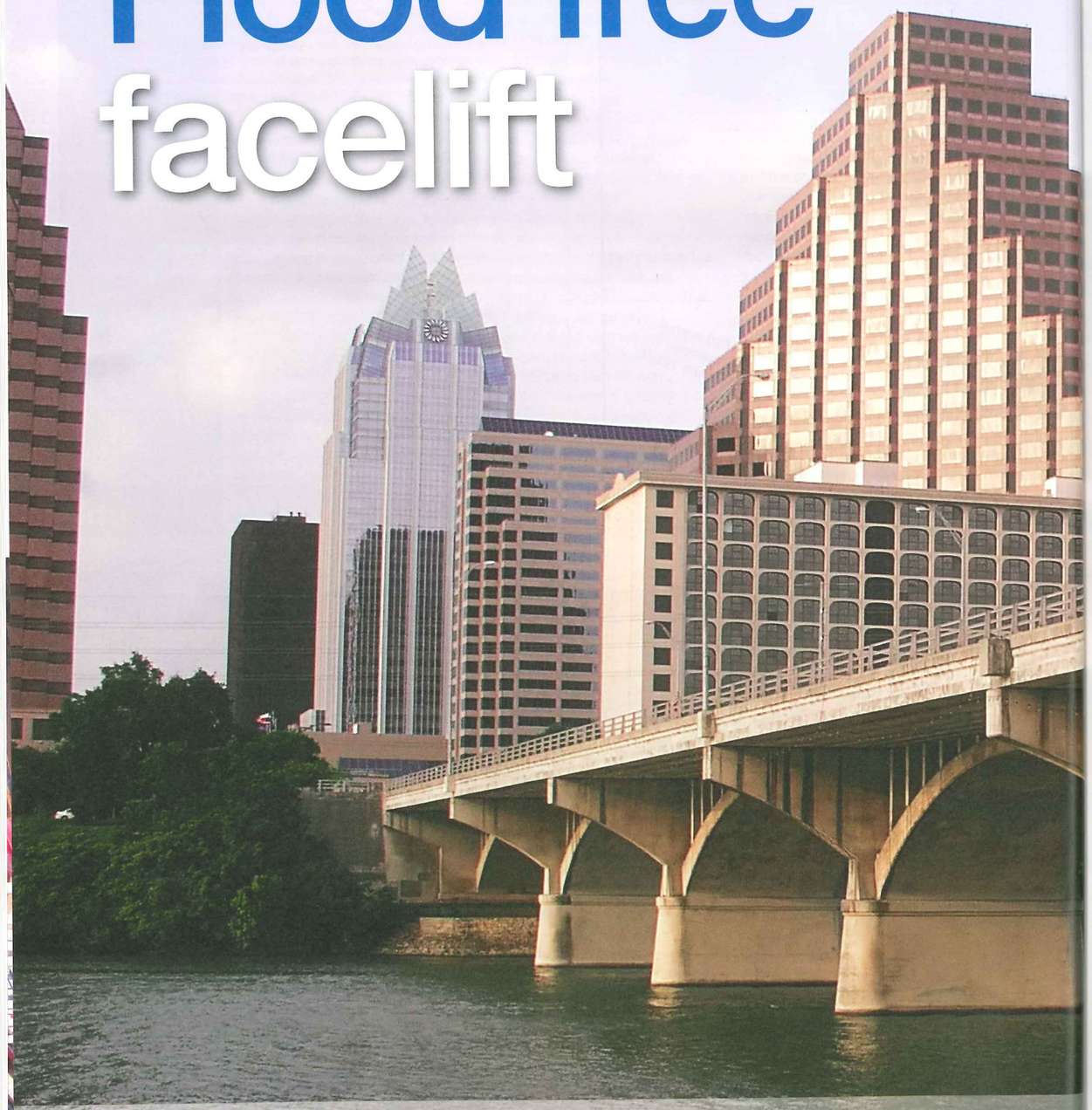
Even once cleaned, the head still wouldn't rotate and when the machine was started up it became gravel bound again. The project team needed to find a way to stabilise the material in front of the face without locking up the machine. "You would lock up the machine if you were to do ground improvements with cementitious grout or concrete," Clements explains. "We ended up using a chemical grout to try to bind up those open network gravels."

This grout program was used for 20 to 30ft (6.1 to 9.14m) in front of the face, before the contractor mucked out the chamber and started mining again, successfully finishing the drive. Again, JWF replaced teeth and rotator cutter discs on the TBM before moving on to the final drive, L to D, completed in early June.

"One of the things that was so unique about this project was the learning of how to microtunnel in these gravels and cobbles," says Jacksha. "Throughout the project Herrenknecht provided machine operators. They had never encountered gravels and cobbles like this before."

Herrenknecht operators said they had never encountered such gravels and cobbles before

Flood free facelift



Constructing a mile-long tunnel in downtown Austin, Texas, will provide flood protection at Waller Creek, and an environmental regeneration, Nicole Robinson reports

Downtown Austin, Texas, and Lady Bird Lake

The City of Austin has seen devastating flood damage near Waller Creek too many times to list. Along with expensive repairs to property, hundreds of lives have been lost to flooding over the city's history, the most recent in 2007.

Located in the flash flood alley of central Texas, the city sees heavy downpours due to moisture coming up from the south from the Gulf of Mexico, meeting colder air masses coming up from the north. That clash creates significant amounts of rainfall and heavy storms.

Contributing to that is the city's geographic location, explains Joe Pantalion, deputy director of the Watershed Protection Department for the City of Austin. "We are at the edge of the Balcones Fault system where we have the Edwards Plateau creating some very steep slopes. And it's a limestone rock formation as well, so we have a lot of thin soils and a lot of exposed rock outcroppings—that really doesn't allow the rain to soak in."

Run-off in these heavy rains becomes a big problem for Waller Creek, particularly the lower mile (1.6km), which is on the eastern boundary of Austin and in a highly urbanised area. The 100-year flood plain for Waller Creek encompasses an area of one million square feet (304,800sqm), and inundates 42 structures and 12 highway crossings. In some places the flood plain is as much as 800ft (244m) wide.

For decades the city has discussed flood protection for the Waller Creek area, deciding to build a 5,600ft (1,707m) tunnel and awarding the project's first construction contract, worth USD 49.5M, last spring.

The project has been divided into four contracts to take advantage of the current bidding climate, says Pantalion, but also to coordinate each part finishing in and around the same time to be operational in 2014. SJ Lewis Construction had notice to proceed last spring for the tunnel construction. The first inlet project was awarded to Oscar Renda for a total cost not to exceed USD 28.5M. In a statement the council contracts department says, "Due to the potential for unknown conditions that could be encountered during underground tunnel construction, a 2.5 per cent contingency in funding has been included to allow for the expeditious processing of any change orders."

Construction began late last year and should be completed in summer 2010. The other two contracts for the outlet and the 8th Street creek side inlet were expected as *T&TI* went to press. The total cost of the project so far, including engineering and real estate acquisition, is USD 146.5M.

Consulting on the project is a joint venture of Kellogg, Brown and Root (KBR) and Espey Consultants, which is supported by a multitude of local firms, particularly Brown & Gay Engineers, and Jenny Engineering of New Jersey.

Underground downtown

The tunnel idea dates back to the 1970s—the bicentennial of 1976 in particular, which triggered efforts to beautify parts of Austin, including the Waller Creek corridor. The city acknowledged that to be able to preserve the area, there needed to be a solution in place for the problematic flooding. Widening or channelling the creek had been considered, and deemed financially infeasible because of the commercial development alongside the creek.

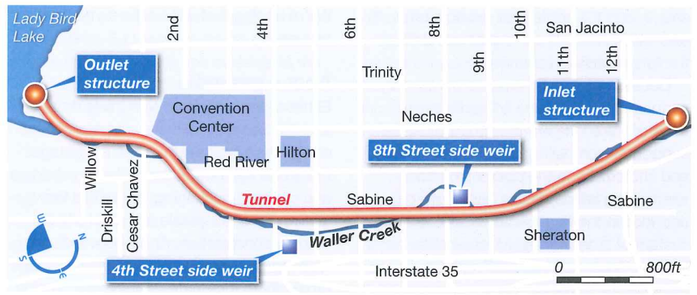
In 1998 the city passed bonds for USD 25M to fund the tunnel project and the consulting joint venture started preliminary design in May 1999. At the end of preliminary design the price tag was around USD 60M and the project sat dormant until a funding source could be determined. The city brought the joint venture back on the project in late 2007 for design, bid and construction management services.

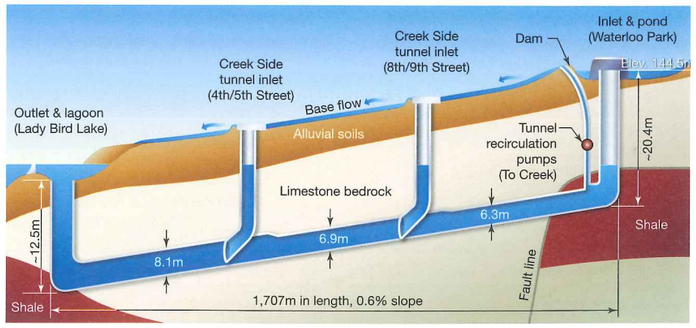
Trying to locate the tunnel within the city's right-of-way, proved quite difficult in the downtown area. The final alignment has both the inlet and outlet located on city-owned parkland, and primarily follows Sabine Street, which closely parallels the creek.

"That really limited the amount of real estate we had to acquire," Pantalion says. "But that also created a challenge in that we were really focused on designing a tunnel inlet and tunnel outlet that could be seen as amenities or blending into a parkland setting."

The tunnel outlet structure is located at Waller Beach, where water will be discharged into a lagoon on Lady Bird Lake. The tunnel's inlet structure is at Waterloo Park, about one mile north of the lake (see Figure 1, below). Two smaller creek side inlets at 4th and 8th Streets will convey additional flows into the tunnel. Designed as an inverted siphon, the diameter of the tunnel will start at 20.5ft and increase to 22.5ft and then 26.5ft (6.2m, 6.9m and 8m), with a 0.6 per cent grade (see Figure 2, below).

Tunnel depth will range from 60 to 70ft (18 to 21m) putting the alignment primarily in limestone, with some of the excavations in shale. "The geology, starting from oldest to the youngest is Del Rio clay shale, Buda limestone, the Eagle Ford shale and then





Top right: Figure 1, a map of Waller Creek and the tunnel alignment going through downtown Austin; Bottom right: Figure 2, the alignment

Above left: Waller Creek today, courtesy of Daniel Herrera; **Above right:** Flood damage at Waller Creek circa 1915, courtesy of Austin History Center

we've got the lovely Austin limestone, which is generally where the tunnel horizon is," says KBR's Matthew Crow, project manager for the consulting joint venture.

The contract didn't specify means and methods for excavation, but leaned toward conventional tunnelling, either roadheader or drill and blast. SJ Lewis decided to use two refurbished roadheaders and is in negotiations for securing them. Excavations will be done in a modified horseshoe shape, and the contractor expects rates of 8 to 14ft (2.4-4.3m) per eight hour shift, as the tunnel varies in diameter.

Detailed design did provide the primary support and secondary lining. Because most of the alignment is in good rock, the support system will consist of rock dowels and shotcrete. "In the poorer limestone we're using lattice arches and shotcrete and then in the Eagle Ford shale there is a system of steel arches, which enable the lining to squeeze in on itself with the potential for swelling," Crow explains.

For the secondary lining SJ Lewis will install a 12in (305mm) thick cast in-place concrete lining with a conventional rebar reinforcement on 12in (305mm) centres. The lining doesn't have a waterproof membrane so grouting will be imperative.

"We're next to a pretty sizeable body of water, Lady Bird Lake, so we've got forward probing, and then if need be tunnel grouting to control ground water ingress," Crow says. "We've also got grouting to minimise water inflows in the completed lining."

Probe holes will be 80ft (24m) long, with a minimum overlap of 20ft (6.1m).

Pantalion adds, "We are currently constructing wastewater tunnels here in the city in the same formation. These are down into the rock structure, and groundwater has not been a significant issue for them. We're hoping that will be the same for us as well."

Above ground

Either of the two creek side inlets on 4th and 8th Streets could be used as a drive shaft. The 4th Street inlet has advantages in the grand scheme of the project's schedule and contract packaging, as well as the availability of a suitable and level site for staging construction. Another benefit of working out of a 4th Street shaft is its close proximity to Interstate-35 for muck hauling, especially with the project's urban location.

The Waller Creek project held a ceremonial grounding breaking in April 2011 and in the summer was working on setting up the site. The shaft is 70ft (21m) deep with about 35ft (11m) in soil. Dimensions are 31ft (9.4m) in the soil burden and then 30ft (9m) in rock. Excavations in the soil will be supported with ring beams and steel liner plates. In the rock the contractor will use rock bolts with fiber-reinforced shotcrete, as needed.

Table 1: Soil permeability

Soil	Suggested permeability
Alluvium (clayey, silty, sand)	0.001 cm/s
Alluvium (gravel)	0.01 cm/s
Austin Limestone	1×10^{-5} cm/s
Eagle Ford Shale	0.0001 cm/s
Buda Limestone	1×10^{-6} cm/s

While the impetus for the Waller Creek tunnel was flood protection, Austin does have concerns for drier seasons. At times in the summer, the creek can become stagnant and experience low or no flows. Designed as an inverted siphon there will be water in the tunnel at all times, allowing the city to pump out the tunnel at the inlet facility to allow lake water to flow down the creek. At the same time this will prevent water in the tunnel from becoming septic in the dry seasons.

"By having this base flow we are really able to promote an environmentally-stable aquatic habitat year-round. There is just a tremendous benefit for the environment," Pantalion says.

The USD 32M inlet contract being bid this summer includes underground work to build the 20ft (6m) diameter inlet shaft and a stub tunnel, among the 20,000sqf (6,096sqm) surface level facility, rakes, screens and mechanical and electrical work associated with those features.

A massive, reinforced concrete morning glory, or spillway, will be built to bring water down the shaft into the tunnel. Groundwater is not expected to be an issue on the inlet contract as this aspect of the Waller Creek project is the furthest north of the lake.

It goes without saying it's a completely different story at the other end of the alignment. Construction for the outlet facility will include a stub tunnel, outlet shaft, and an outlet lagoon and spillway to

Top right: Figure 3, the inlet structure in Waterloo Park where water will enter the tunnel; **Bottom right:** Figure 4, the outlet to Lady Bird Lake

convey water into the lake.

The average velocity of stormwater in the tunnel will be 20ft/s (6m/s), and the outlet structure, and in particular the 40ft (12m) diameter outlet shaft, is designed to dissipate this energy to minimise lake shoreline erosion. From an aesthetic point of view, the city and design team heard many concerns about the appearance of outlet facilities. One of the initial proposals included a lot of exposed concrete with an amphitheatre and other structures

"As the project went through the public input stage we just heard an overwhelming response from the public that anything along Lady Bird Lake should really respect the character of the natural shoreline," Pantalion says. "The outlet lagoon really tries to take on, as much as possible, the characteristics of the natural shoreline that exists there now."

To construct the outlet, a shaft will need to be sunk within a cofferdam in the lake. In his presentation at RETC last June, Dorian French, senior vice president at Brown & Gay, explained the complex geologic formation at the outlet site. Even with grouting it will be a challenge to keep water out, he says.

Excavation through the alluvium and overburden soils consisting of clay, rubble and typical river deposits, between 4.5 to 28ft (1.4 to 8.5m), shouldn't experience significant difficulty. Going deeper into the limestone and shale strata will be more challenging. At this point in the alignment, tunnel excavations are in the Austin limestone, 13 to 28ft (3.9 to 8.5m) deep, and the Eagleford shale between 34 to 74ft (10 to 23m) deep.

According to the paper French authored with Brian Reis, vice president of Espey Consultants, a floating dike system is planned to serve as a cofferdam on Lady Bird Lake to impound at least 16ft (4.9m) of water. On top of that, "5 to 25ft [1.5 to 7.6m] or more of saturated cohesionless alluvium will require seepage cut-off (particularly beneath the cofferdam impounding the lake), dewatering and stablisation."

Significant groundwater is expected in the lower portions of the alluvium, which has higher permeability. Meanwhile a groundwater head of at least 16ft (4.9m) in fractures in the bedrock strata is expected to be problematic, the paper says. The design team developed presumptive field permeability values (Table 1, below, left) for cost-estimating purposes.

Outlet construction is scheduled to finish in early 2014. SJ Louis will install bulkheads in the tunnel at the inlet and outlet (and the 8th Street inlet), which will be removed in April 2012 by the contractors who build those structures.

"The biggest challenge is really timing the other projects," says Lizan Gilbert chief engineer with SJ Louis. "We've got schedule constraints—they are aggressive—but we'll meet them. The challenge is how the other two projects are coordinated with ours."

For example, part of SJ Louis' contract is to build an ecological weir in Waller Creek upstream of the 4th and 8th Street inlets, and at the main inlet structure.

These strategically-placed limestone boulders will create channels that replicate the natural currents and pools that can occur in bedrock stream habitats of the Texas Hill Country.

"That weir will essentially back up water behind it and the result of that will be a flooded tunnel. We can't construct that until the tunnel is operational," Gilbert says. "So that's where we've got this one last, pretty big component of the job in terms of how it works, how it is presented, that we can't begin on in any meaningful way until those other projects are connected."

For the city, one of the biggest influences on the schedule is financing. Funding for the tunnel will be generated from an increase in property values in the area adjacent to the creek using a tax increment reinvestment zone, established in 2007.

"We would like the tunnel to be completed as soon as possible to provide a higher level of flood protection, which we hope would lead to significant redevelopment within this corridor," Pantalion says.

And for the citizens of Austin, who will no longer need to worry about their safety, nor property damage, in the event of a flood, there is the added bonus of beautifying their city. Among the new facilities to keep trash out of the creek, there will be new park trails as part of the project.

"We're going to have a cleaner creek, one with water year-round, and we're going to be able to restore the banks with native landscaping," Pantalion explains.

"We're really excited about recreating a stream that you might see in the hill country of Texas, right here in the heart of downtown Austin."

Toronto starts digging the line

Last year the Eglinton-Scarborough Crosstown LRT project in Toronto expanded, adding 8km of tunnelling. Nicole Robinson discusses the design changes and progress on the city's major east-to-west link with Jack Collins, vice president of rapid transit implementation for Metrolinx

Toronto skyline

A little over year ago, Toronto elected Rob Ford as mayor. He ran on a campaign promising, among other things, better transit, better roads and more subways.

By the end of March, a revised transit plan had been announced for Toronto that favored more underground options than previously planned. The entire Eglinton-Scarborough Crosstown LRT would become a single line running mostly underground for 25km. Rather than tunnelling for 11km, the project will now see 19km excavated by TBM.

Ontario's minister of transportation Kathleen Wynne called the project their 'top regional priority' and by the end of summer construction had started on the launch box for the project's first TBM.

Design work is still underway on the no-longer surface level portion of the line, particularly in the Don Valley, where it will cross the Don River.

Metrolinx, an agency of the province of Ontario and owner of the Eglinton-Scarborough Crosstown LRT, is responsible for planning and funding commuter rail and rapid bus transportation in the Greater Toronto-Hamilton Area, which has a population of more than three million. The Toronto Transit Commission (TTC) is Metrolinx's agent for the project and will operate the line following completion.

Ontario is funding 100 per cent of the CAD 8.4M (USD 8.48M) project, and it is the largest investment in transit the province has made in history.

Hatch Mott MacDonald is in charge of tunnelling design, with numerous design teams from the Greater Toronto-Hamilton Area handling station design. There will likely be 26 stations in total. A joint venture of URS and Parsons Transportation Group is in charge of systems design.

Project and construction management is being carried out by the Transit Expansion Department of the TTC, with the assistance of a number of consulting firms.

Adjusting Eglinton Avenue

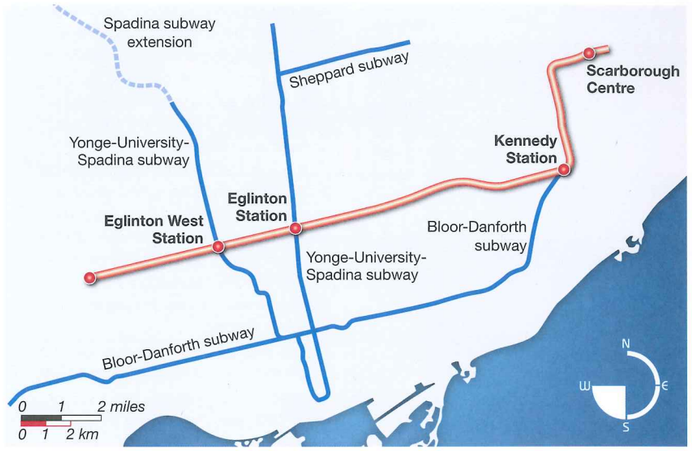
As it transverses the entire length of Toronto, Eglinton Avenue is a key east-to-west roadway. At the same time it's somewhat diverse as it changes from a downtown corridor with storefronts and parking spots to a suburban arterial road.

Two primary bus routes currently serve Eglinton Avenue and they are heavily used, says Jack Collins, vice president of rapid transit implementation for Metrolinx. "They carry approximately 66,000 daily weekday riders. The existing Scarborough Rapid Transit line, which is going to be totally retrofitted to larger vehicles, is carrying 45,000 daily weekday riders. That's what's being carried along this corridor."

Collins continues, "When we looked at our travel demand forecast with the TTC, by 2031 we're coming up with ridership in this corridor that reaches 100 million annual riders."

The Eglinton-Scarborough Crosstown line will connect with three subway stations and future commuter rail transit hubs. There are also several local transit lines that intersect with the project. Moving the line underground for most of its length will significantly reduce the number of buses that currently run on Eglinton Avenue.

The original plan called for the project to have 11km of tunnelling in the congested downtown area where Eglinton is a narrow four-lane road. Another 6km, the Scarborough Rapid Transit portion Collins previously mentions, is already grade separated and just being upgraded to larger vehicles. With the revised plan, all 25km will be grade separated, nearly doubling the amount of tunnelling to be done.



Above: **Figure 1, map of the Eglinton-Scarborough Crosstown alignment**

"The primary reason for grade separating the entire line was to minimise the impact on traffic, but it also speeds up the travel times," says Collins. He adds that the City of Toronto is updating its official city plan, and is looking at making changes to public land uses along Eglinton Avenue that will complement the investment being made with the Crosstown project.

The 19km will be divided into several tunnelling sections, and contract packages are still being finalised for all of the line. Portions of the originally planned 11km underground line was due to bid as *T&TI* went to press.

With the new plan for the line, Metrolinx and its design team is facing a new challenge on the east side of the project in the Don Valley, which includes a river crossing. "When we were at surface it was fairly easy and cost effective to do, and now we're looking at tunnelling beneath that, which needs to be really deep. So that's a huge challenge for us," explains Collins.

"But, in our environmental documents that we're updating, we're looking at another alternative that would put us on an elevated guideway running down the center of the street or off to the side of the street to get across the Don Valley.

"So that's an option that we're seriously looking at as a result of this change."

Getting underground

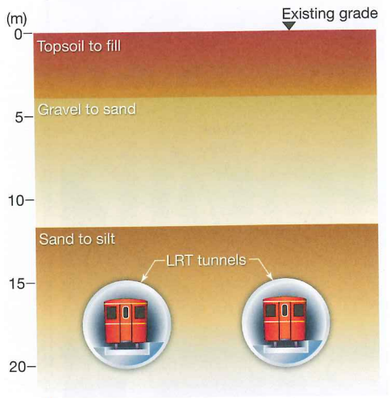
The Eglinton-Scarborough Crosstown LRT line will comprise twin tunnels of 5.75m diameter, excavated by TBM directly under Eglinton Avenue in the road's right of way (see Figure 1, above). With the Don Valley area of the project, off-road sections are being examined for an underground alternative, in addition to the aerial alternatives being considered for this portion of the line.

TBMs are being furnished by the owner, and a contract for four EPBMs had been awarded to Lovat, now Caterpillar Tunneling Canada, in summer 2010. Precast concrete segments will be used to line the tunnels, and local manufacturer Munro, will be supplying the project.

Chris Smith, Munro's tunnelling specialist for the Eglinton-Scarborough Crosstown project, says each ring will be 1.5m long and consist of five segments plus a keystone. The segments will have a tapered, universal configuration with two trapezoidal segments and four parallelogram segments. They will be reinforced with standard high-yield steel reinforcement cages, structurally welded. All segments, a total of 14,775, will be produced at Munro's facilities and delivered as required to the Toronto job site. Production started in November last year on the segments and should last about two and a half years.

The depth varies throughout the entire 25km project, but typically the alignment will be 15 to 30m deep (see Figure 2, overleaf). The geology of the area is soft ground, generally consisting of glacial till and interglacial granular, with a mix of sand and clay with some small boulders to be expected. "There is bedrock in some areas, but we're above the bedrock along the entire alignment, or at least trying to stay out of it," explains Collins.

The water table is reasonably high in this area, he says. "There may be some areas of loose, running sands that we'll do some



Above: Figure 2, typical geology of the Crosstown alignment

pre-grouting on, probably from the street level down in advance and along the path." Otherwise tail grouting will be used on the TBMs; however the design team doesn't expect much settlement.

The revised plan didn't really affect the 11km of tunnels originally planned, located on the west end of the line, where the first phase of tunnelling will start. At the time of publication Metrolinx hadn't finalised the exact number of tunnelling contracts for the first section, and is still investigating how and where to extract the TBM. Collins says 3km drives are being considered.

"At approximately 3km we'd like to be pulling the machines out and then relaunching them, after we check them out, for another drive. The plan right now is to take that 11km and have four TBMs, two running from west to east and the other ones on the eastside running west. Eventually they would meet each other somewhere in the middle."

The plan depends on which alternative is chosen for the Don Valley, which will also determine how many TBMs will need to be added to the project. However, whether the alignment is underground or elevated in the east, after crossing the valley, there is still tunnelling to be done over to Kennedy Station.

"So we are looking to use at least four machines, possibly two extra for overall schedule considerations, and if we tunnel under Don Valley we'll need another two for a total of eight TBMs," says Collins.

Metrolinx plans to have design for the first contract package completed, with the bid advertised as *T&TI* went to press. The first tunnelling package is hoped to be awarded in spring of this year with the first two TBMs arriving on site in the summer and excavation in early autmn.

Right now, local contractor Kenadian is building the west launch shaft, from which the first tunnelling contract will start. The Eglinton-Scarborough Crosstown line is scheduled to be completed by 2020.

Station location

The alignment passes under two subway lines and ties into existing Kennedy Station, on a third line. "Our thoughts right now are that we'll extract the machines just shy of the subway tunnel and then put a launch shaft at the opposite side. And then have a very careful excavation underneath the actual subway line," explains Collins.

For the other stations on the Eglinton-Scarborough Crosstown line, exact location is still being finalised; however their development should not affect the tunnelling schedule.

Each station will be approximately 140m long and design plans call for a headwall strategy to prep the alignment for station excavation.

"We'll put a headwall at each end and run the machine through that. It will be lean soil/cement so the machine will just excavate right through and you have a tight seal through the liner and the end of the station," he explains. "Then when the station is actually excavated from the top down by the station contractor they will pull the liner out when they come down to the bottom of the station and then pour concrete.

"That way we get the tunnels done and out of the way rather than [deal] with the risk associated with one of the stations falling behind in terms of construction and you can't get through. So the philosophy here is we're just going to 'blow and go' and get the tunnelling done."

Stations will be built using cut and cover. The design team is looking at techniques used in Los Angeles for the Hollywood extension on the Red Line and the Pasadena Gold Line extension where top-down excavations using precast deck beams have been used to allow traffic flow during construction.

Beyond Eglinton

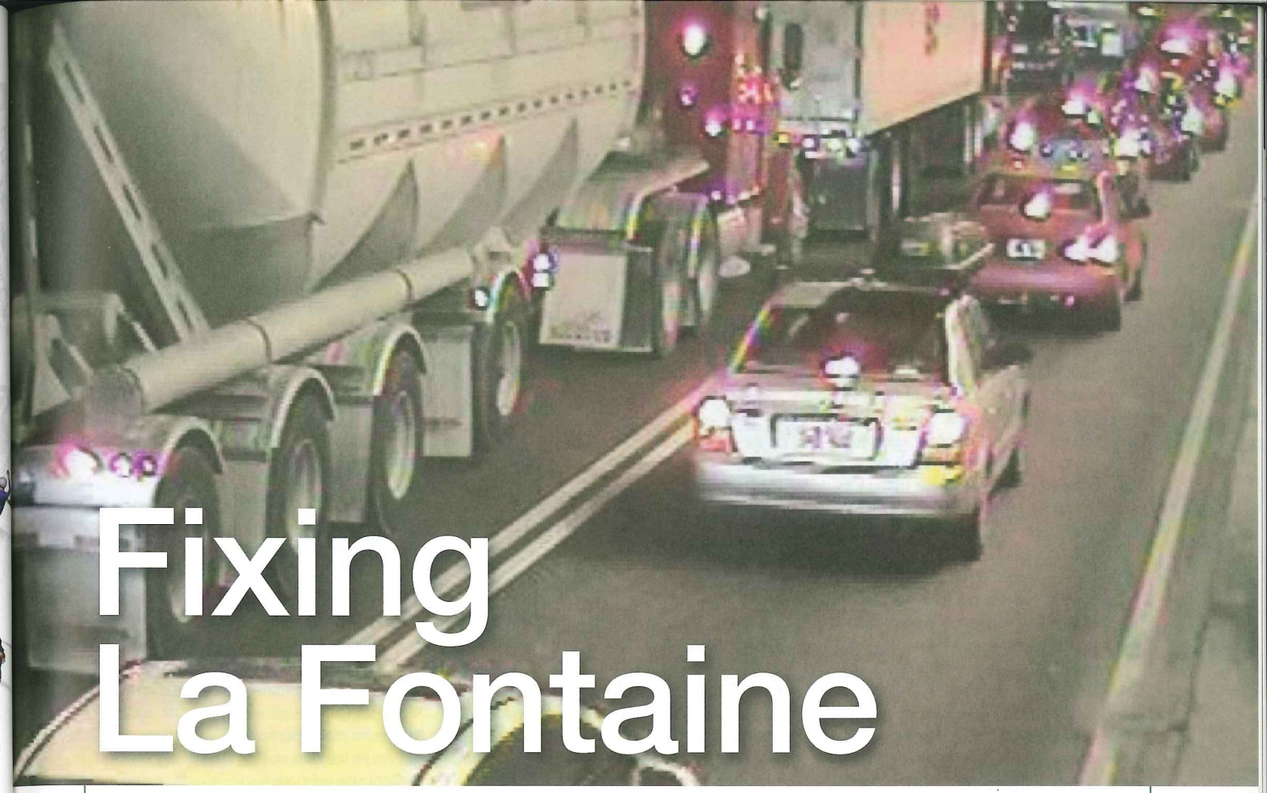
Metrolinx recently finished its overall transportation planning document 'The Big Move 2020', which covers more than 50 transportation improvements that will be implemented over the next 20 years.

Collins points out one of the impacts of bringing 9km from surface level to underground is the increased cost of tunnelling. To cover this, Metrolinx and the TTC are looking at deferring other projects being planned for surface light rail in the Finch West area.

Instead, an enhanced bus service will be introduced until future funding becomes available at a later phase in the city's transportation development program.

The main reason for choosing to use owner-furnished TBMs is to stay on schedule and complete the project by 2020. Collins says, looking at the larger plan for the Greater Toronto-Hamilton area when the contractors turn the machines back end at the end of the project, Metrolinx will likely have additional projects for which they can be redeployed.

Below: One of the TBMs being manufactured for the Crosstown line



Fixing La Fontaine

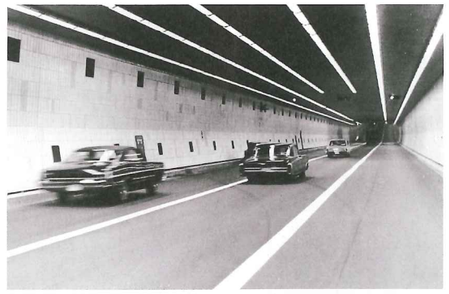
Since commissioning in March 1967 the La Fontaine highway tunnel that links Montreal Island with the South Shore of the St Lawrence River in Montreal, Canada, has had to accommodate rapidly increasing traffic flows (now up to 130,000 vehicles a day), as well as criticism of the adequacy of its ventilation system. Plans for refurbishment to better airflow and emergency provisions are underway, and seem likely to feature a new type of jet fan reports Maurice Jones

The Lafontaine Tunnel in Montreal, or the Louis Hippolyte Lafontaine Bridge-Tunnel to give the crossing its full name after the first Canadian prime minister of Lower Canada, is an immersed tube tunnel under the St Lawrence River main shipping channel. It is made of prestressed concrete box sections carrying two main tubes with room for three lanes in each. There is also a central service tube. The tunnel's immersed length is 768m, plus connecting sections on the shores making 1,471m. This makes it the longest underwater vehicular tunnel in Canada. Its height is 7.84m, overall width 36.75m and depth down to 27.5m.

The immersed tube is set on an incline of 0.25 per cent, with the ramps at each end at inclines of 0.45 per cent.

The tunnel's ventilation is semi-transverse with twin double exhaust fan towers with diffusers at both the Longueuil South Shore end and the Montreal end. The structures also incorporate an intake for the force fans. There are 16 fans installed (eight normally for fresh air and eight for exhaust) but these are reversible. Powers range from 125hp (93.2kW) to 200hp (149kW) each.

Following a tunnel fire elsewhere in Montreal in 2001, and concerns expressed by fire fighters to the Transport Quebec (MTQ) about ventilation adequacy, MTQ sought the advice of the National Research Council Canada (NRCC) to evaluate tunnel ventilation. Amongst other measures, biannual tests were conducted in the La Fontaine Tunnel overnight. Ventilation, together with electrics, lighting, surveillance and fire protection were upgraded in the early 2000s, and additional repairs were carried out in 2009. Major refurbishment including repaving is scheduled for 2014.

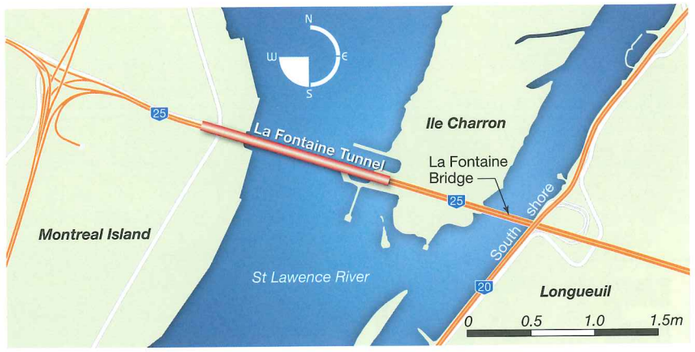


Top: **Figure 1, typical traffic in La Fontaine Tunnel in 2009**; Above: **Figure 2, typical traffic in 1967**

Risk analysis

Existing urban road tunnels can be narrow, leaving little space for additional ventilation equipment to upgrade the system. A study by Mosen suggests that there is a way of providing significantly more aerodynamic thrust where space is limited.

The tunnel is currently operated normally with one-way traffic is each main tube to handle vehicles at a maximum speed of 70mph (112km/h). Lanes are 12ft (3.66m) wide with a vertical clearance of 4.53m. Vehicles carrying hazardous materials are banned and other trucks are restricted to the central of the three lanes due to less



Right: Figure 3, location of the La Fontaine Tunnel on the bed of the St Lawrence River, Montreal

clearance on the left and right lanes.

The central service tube of twin corridors is designed for use by service employees and emergency personnel. The corridors are also used for ventilation air supply, drainage and as a refuge or evacuation in an emergency. Fresh air to the traffic tubes normally passes through frequent openings in the side of the service tube.

The general principles of the safety plan is to use the central service tube as a refuge in the event of a minor incident or fire, but also as emergency egress in the event of a major fire.

The feasibility of a tunnel safety and ventilation upgrade depends on refitting the service tube, aimed at increased user safety in the event of a major incident in the traffic tubes. In this case the design fire would be of 30MW heat-release magnitude, equivalent to a burning semi-trailer carrying non-hazardous materials. As far as location is concerned, the worst-case scenario is for the fire to be at the centre of the tunnel where air velocity is very low.

A study was commissioned by Alexandre Debs of MTQ to consider the methodology of risk analysis, as well as the particular mitigation measures required.

The methodology adopted was firstly to establish a tree of safety functional needs incorporating operational and maintenance needs and the minimum requirements of standards such as the US National Fire Protection Association NFPA 502.

Next the worst-case scenario was identified as above followed by the establishment of performance criteria for this case. There followed a brainstorming and creativity workshop to optimise the potentially 'best' solutions. Finally a value analysis was conducted to choose the optimal solution.

The tree of safety functional needs includes functions classified under regulations, safety and flexibility. Those within the overall function of ensuring safe mobility of people and goods, were:

- Ensure traffic fluidity
- Ensure traffic safety
- Protect users in incidents
- Protect the infrastructure
- Communicate with users
- Control the smoke
- Ventilate the tunnel
- Optimise maintenance
- Optimise operations
- Winter viability
- Ensure water pumping
- Ensure ice removal
- Optimise lighting
- Comply with standards

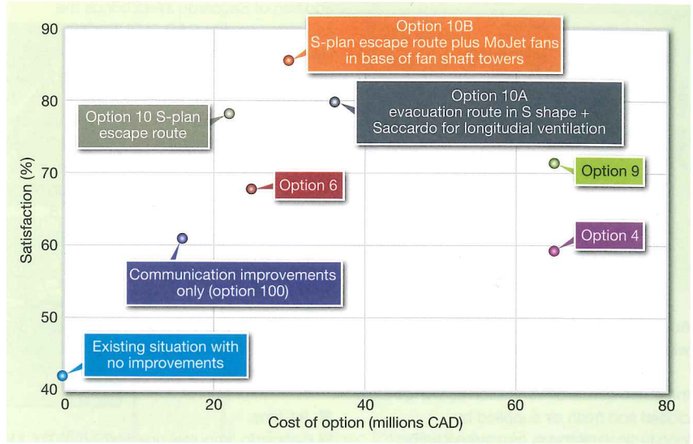
Within a performance analysis of the existing tunnel arrangements working under normal conditions, these functions were marked according to how much flexibility the tunnel operator had in meeting them (score F0 for no flexibility to F4 for more flexibility), and according to how well the conditions had been meet (out of ten).

There was very little flexibility allowed in all the functions listed, as all ratings were either F0 or F1. 'Achievement' scores range from as little as 3/10 for communicating with users to 7/10 for six of the listed functions. At 4/10 the functions of 'protect users in incidents', 'winter viability' and 'comply with standards' also scored lowly.

Table 1: Performance Criteria

Weight	20.0	7.9	8.7	7.1	8.1	7.3	6.7	7.4	6.0	10.0	
Option	Safety	Comfort	Emergency egress	Constructibility	Operability	Maintainability	Technological risk	Life cycle	People evacuation	Traffic management	Overall performance (per cent)
Existing with communications improvements etc	6	7	4	10	7	1	6	7	6	7	61
Existing – no improvements	5	7	2	1	4	4	7	7	4	1	42
Option 4	10	9	6	1	1	1	6	4	7	7	59
Option 9	10	10	8	4	4	4	6	4	10	7	72
Option 6	7	7	4	8	9	7	6	8	4	7	68
Option 10	8	9	8	8	9	8	6	7	8	7	78
Option 10A	9	8	8	7	10	7	6	8	8	7	80
Option 10B	10	8	8	7	10	6	5	8	10	10	85

Right: Figure 4, graph relating cost of refurbishment solution to satisfaction/performance ratings



As for tunnel users, many stay in their vehicles and are asphyxiated by smoke because they lack the appropriate knowledge of how to behave in such situations. Other car drivers enter the tunnel despite red signals and it is also assessed as due to lack of appropriate knowledge.

Regarding ventilation, fresh air supply contributes to destratification of the smoke and backlayering is observed where the air velocity was practically zero.

Another performance analysis was conducted for the worst-case scenario, obviously with low flexibility in all functions. Scores for acceptability ranged from zero for 'ensure traffic fluidity' to 6/10 for control of smoke and ventilation. Traffic safety and user protection was only 2/10.

This analysis therefore identified functions to be improved including ventilation and smoke control, communications with users, user protection in case of fire, and protection of the infrastructure.

Communication measures include education of users on behaviour expected in case of fire, and real-time communication during an incident. For protection, barriers were to be considered to avoid jams of vehicles, and rapid self-evacuation was to be encouraged. For infrastructure protection automatic fire-fighting systems were to be considered as well as better fire detection.

Not all performance criteria necessary for refurbishment design are of equal importance, so weighting was applied to each (see Table 1, left).

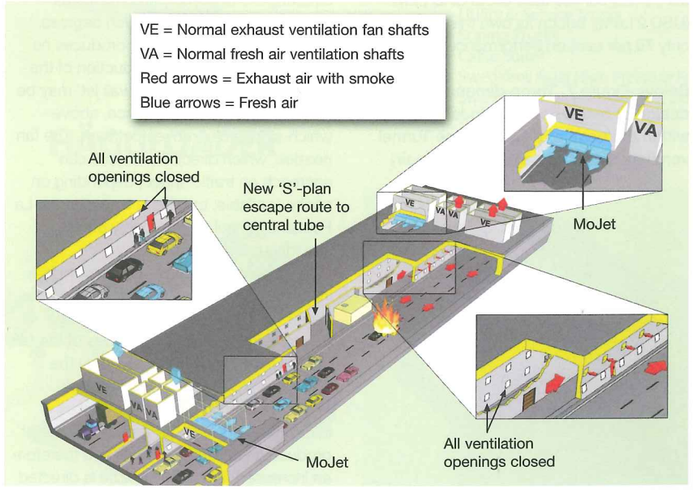
Ventilation options

Improvements to ventilation suggested by analysis included the need to protect the evacuation route from smoke, as well as means to avoid destratification of smoke and backlayering. Following the analyses, brainstorming sessions were conducted to assess all available options for improvements to performance criteria (main results shown in Table 1). Of the options involving ventilation improvements, some required major construction works, thus reducing their 'constructability' assessment compared to other options involving little or negligible construction work.

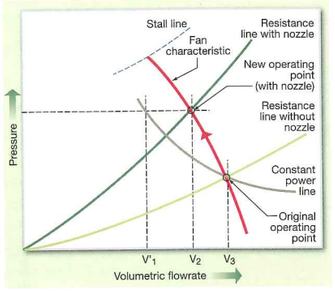
Overall the preferred option on the basis of performance was Option 10B involving the construction of an 'S'-plan escape and refuge corridor in the service tube from the centre of the tunnel, plus the installation of MoJet fans at the bottom of the existing main exhaust fan ventilation towers.

Of the other options assessed to be amongst the top performers, Option Nine involved the creation of two floors in the central service tube with a mid-tunnel division for longitudinal ventilation. This scored well for evacuation safety and comfort but low on constructability, operability, maintainability and life cycle.

Option 10 involves the 'S' escape route as with the MoJet option, but improves ventilation by the installation of more powerful exhaust fans for existing longitudinal ventilation. The upper ventilation openings near the fire are opened to allow the smoke to be extracted via the service tube at a high level, but at



Right: Figure 5, diagrammatic representation of worst case scenario using Option 10B solution including MoJets installed in base of exhaust ventilation shafts



Above: **Figure 6, characteristics of a jet-fan with and without MoJet nozzle**

the traffic queue all ventilation openings are closed and fresh air supplied by longitudinally through the parked traffic.

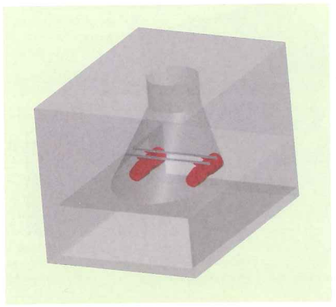
Option 10A is very similar to Option 10B but involves construction of Saccardo ducts at both ends of the tunnel to aid airflow instead of installing MoJet fans. All vents in the service tube near the fire are opened to extract smoke, but all those adjacent to the tunnel users and vehicles are closed for an escape route in fresh air.

Of course cost also has to be taken into consideration as well as performance. The cheapest, but least effective option is to simply install better communications such as better signs and signals. Other suggested measures taken include this.

Options including the construction of extra floors within the central tube, whether for longitudinal or semi-transverse ventilation, were the most expensive at an estimated CAD 65M (USD 63.9M).

Of the three Options 10, the provision of an escape route from the transport tubes to the central service tube costs CAD 22M (USD 21.6M), but on its own this scored only 78 per cent on performance. The addition of Saccardo inlets brings the estimated cost to CAD 36M (USD 35.4M). However, to use MoJet jet fans instead of Saccardo vents costs only CAD 30M (USD 29.5M) and scores 85 per cent on performance. Other forms of jet fan are not nearly as practical in the La Fontaine Tunnel due to minimal headroom, and lower aerodynamic performance. Installation of MoJets, together with installation of 'S' escape routes, is the preferred option.

Below: **Figure 7, Three-dimensional design of two proposed MoJet fans within the base of a La Fontaine Tunnel ventilation shaft (Image by Systemair)**



MoJet and others

Within the arguments presented by Mosen, the developers of the MoJet, it is stated that longitudinal ventilation of tunnels can be achieved by:

- Jet-fans.
- Saccardo (impulse) nozzles).
- Ventilation shafts (for example, push-pull ventilation).

Jet fans are generally preferred for shorter tunnels (up to about 3km long) since they do not require ventilation shafts and buildings. They move air in the axial direction with a discharge velocity of 30 to 40m/s. Their efficiency is influenced by the Coanda effect (eddy currents caused by interaction with tunnel surfaces and other objects), and also the installation position. The installation efficiency ranges between 0.85 for ceiling mounting and 0.73 for corner mounting. Saccardo nozzles were patented in the UK in 1898. Comprising fan inlets in the tunnel crown with a discharge angle of 30° or less, they produce a jet velocity of around 30m/s.

A version of the jet-fan is the Banana Jet, which improves installation efficiency by directing the air jet towards the tunnel centreline at an angle of seven degrees. But, according to Mosen, it produces no additional thrust beyond reduction of the Coanda effect, and also a 'wall jet' may be generated on the road surface, above which smoke can move upstream. The fan nozzles, which direct the air jets, can encroach on traffic space, depending on space available, but this is limited in the La Fontaine Tunnel and probably others requiring refurbishment.

An alternative means of improving fan installation efficiency is to use deflection louvers but these can generate a large pressure drop on the outlet sides of the fan.

MoJets are claimed to combine the advantages of jet-fans and Saccardo nozzles. They have convergent nozzles installed on one or both ends of a fan that produce an accelerated flow, and therefore an increased thrust. The nozzle is directed towards the tunnel centre-line, enhancing the installation efficiency. Mosen has applied for patent protection for the MoJet in the UK, Europe, Japan, Australia, the US, India and various Middle East countries.

The fan thrust is developed according to the equation:

$$T = \eta_i \rho A V_j (V_j - V_T) \cos\theta$$

in which:

T = aerodynamic thrust (N)
η_i = installation efficiency (-)
ρ = density (kg/m³)
A = jet-fan area (m²)
V_j = jet velocity (m/s)
V_T = tunnel velocity (m/s)
θ = jet angle (deg)

Figure 6 (above, left) shows the fan characteristic for a jet fan with and without a MoJet nozzle showing that a nozzle leads to a reduction in mass flow through the fan. The fan characteristic is preferably steep enough so that the reduction in mass flow is compensated for by increased air velocity. The enhancements in thrust are due to:

- Increase in jet velocity (typical thrust increases of 7-20 per cent are available).
- Improvement in installation (providing thrust increases of 18-37 per cent).

The overall thrust increase is multiplicative, so up to 64 per cent increase may be available. This increased thrust characteristic can be used in various ways:

- There are reduced power requirements per unit of thrust.
- Smaller diameter fans can be selected for the same installed thrust as conventional fans, so saving space.

The spatial design of a MoJet can be used to avoid encroachment into the traffic envelope, including installation positions very close to the tunnel walls and soffits. Desired ventilation effects can be achieved by MoJets installed at portals or with reduced spacing between fans, thus saving on cabling costs.

In the case of the La Fontaine Tunnel the proposal is to install MoJets within the base of the ventilation shafts so that ventilation is enhanced without encroaching on the traffic envelope (Figure 7, left)). The fans, installed in pairs, would be of 1,250mm diameter with 10-degree silencer outlet nozzles but no inlet nozzles. The fire rating of the fans is up to 250°C for two hours.

Ventilation and climate – part two

on a 53km Andean base tunnel

Concluding the edited paper by Andrea Krpo from the December 2011 issue, this article describes ventilation concepts, including fire control, for the proposed Corredor Bioceanico Aconcagua (CBA) rail base-tunnel through the Andes. The paper is co-authored by Mattia Ferrazzini, Michael Flueckiger and Peter Reinke, all of HBI Haerter of Berne, Switzerland.

During normal operation, the piston effect of the moving trains lead to an air movement inside the tunnel and controls the air quality, temperature and humidity levels. Thus, the fans for the tunnel ventilation and the shaft tunnel ventilation are not used to supply fresh ambient air to the tunnel during normal operation. If the climate inside the tunnel reaches a non-acceptable level (for example, too high temperature), forced mechanical ventilation will be applied during normal mode of operation as well.

Design verification: Only freight trains will pass through the tunnel during Phase One, with a maximum speed of 100 km/h. Achievement of tunnel ventilation objectives during the normal mode has been verified for both summer and winter. Only the results related to the summer (December, January, and February) are presented here but similar results can be observed in winter.

Pressure deviation and air velocity: The trains running in the tunnel cause temporal variations of the pressure along the tunnel. The history of the deviation from normal pressure in the tunnel is shown in figure 6 for the two positions along the tube with the maximum positive and negative deviations from normal pressure.

Figure 7 (below, left) shows the maximum positive and negative deviations from normal pressure along the tunnel. It is derived from the pressure v time curves for every location along the tunnel.

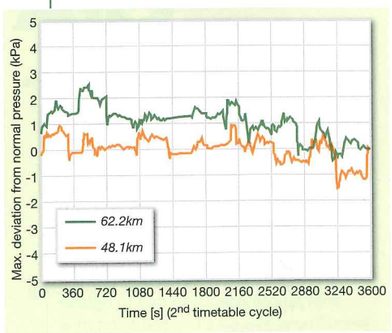
Due to the limited train velocities, the maximal positive and negative train-induced pressure fluctuations are small compared to high-speed rail tunnels and range between two and 3kPa.

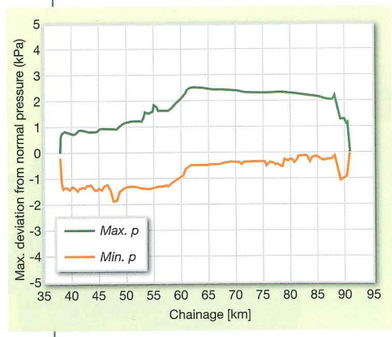
Similarly to the pressure deviations Figure 8 and Figure 9 (far left, top and bottom) indicate the maximal and minimal train-induced air velocities along the BT. In Figure 8 the abrupt air velocity changes from negative to positive velocities and vice versa within a short period of time are due to passages of trains at that position. The mean velocity indicated in Figure 8 shows a predominant air flow from the portal Chile in direction of the portal Argentina. This behaviour is linked to the natural draft effect and leads to a full air-exchange within 24h for typical meteorological situations in summer (as sshown in the specifications in Table 1 in part one *T&TI* December 2011, page 30).

Local air velocities in the immediate vicinity of trains might be substantially larger due to three-dimensional effects.

Dry bulb temperatures: A prognosis of the tunnel climate was undertaken using numerical simulations in order to examine the impact of the factors of the tunnel climate. In order to exclude the long-time climate the results are given for simulations after six years of tunnel operation.

The predicted maximum dry-bulb temperature in summer reaches 32°C, which is below the limit value of 35°C (see Table 1).





Above, left: Figure 6, pressure history at two locations along the tunnel with maximum positive and negative deviation from normal pressure. Distances are rail chainages and not distance in tunnel; Left: Figure 7, maximum positive and negative train-induced deviations from normal pressure along the tunnel during a complete cycle of the train timetable

Congested operation

The specific ventilation requirements for the congested mode of operation need to be specified at a later planning stage. These are considered to be covered by the tunnel ventilation system (TVS) as designed for the emergency mode of operation.

Maintenance operation

Fan operation has to provide every tunnel portion under maintenance with a longitudinal air flow. Fresh air has to be provided in order to remove polluted air and provide adequate working conditions. In order to control the air flow in the maintenance zone, rail tunnel doors must be installed at different tunnel locations. For example, the characteristics of the maintenance operation mode for a tunnel segment located between the Chile Multi-functional Station (MFS) and the Argentina MFS are illustrated in the original paper; in particular, the positions of open and closed rail tunnel doors. Tunnel stretches between a portal and an MFS are treated similarly by correctly opening or closing the rail tunnel doors and operating the axial fans at the ventilation stations.

The amount of fresh (with respect to exhaust) air that has to be supplied (as opposed to removed) in case of maintenance is smaller than the one needed during the emergency mode of operation. Thus, no specific ventilation requirements are specified for the maintenance mode of operation.

Emergency operation

In an emergency a train shall always try to leave the tunnel. As a second option, the train should try to reach the nearest MFS and passengers evacuated through the access tunnel. If the train cannot reach an MFS, it stops within the tunnel. In any case, the TVS design must take all possible emergency scenarios into account.

At every MFS two extraction points located above the main and the passing track are foreseen. Due to the larger number of escape ways, a train on fire shall always be directed along the main track. However, the occurrence of a fire-related incident on the passing track shall not be excluded, so two extraction points located above the main and the passing track are considered. In this way all possible fire locations are covered.

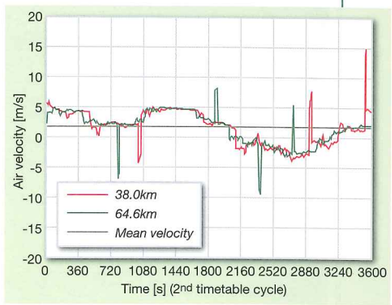
During Phase One, only freight train traffic is foreseen. This aspect must be taken into account for the TVS design in order optimise the ventilation.

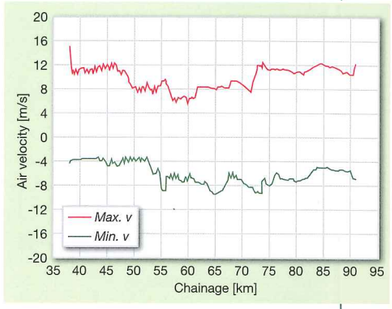
In an emergency the fire location must first be identified. During a second phase, the switching damper corresponding to the appropriate extraction point must be activated. The ventilation system should be kept as simple as possible in order to minimise the risk of incorrect operation.

In case of fire in a stretch of tunnel, the ventilation system must always be able to achieve the critical velocity in both directions. In each case the evacuation of passengers will be arranged in the upstream direction of the fire.

A summary of the designed ventilation system during emergency operation for a fire in different tunnel sections is given in Table 3 (overleaf). For every train location, the TVS is designed to carry the smoke in either direction, if required. The proposed values of the flow rates are derived from the knowledge acquired from other base tunnel projects with comparable length (for example, Gotthard Base-tunnel (GBT), Lotschberg Base-tunnel (LBT), Brenner Base-tunnel (BBT)). In addition, a typical freight train fire has been taken into account with a maximal heat release rate (HRR) of 250MW.

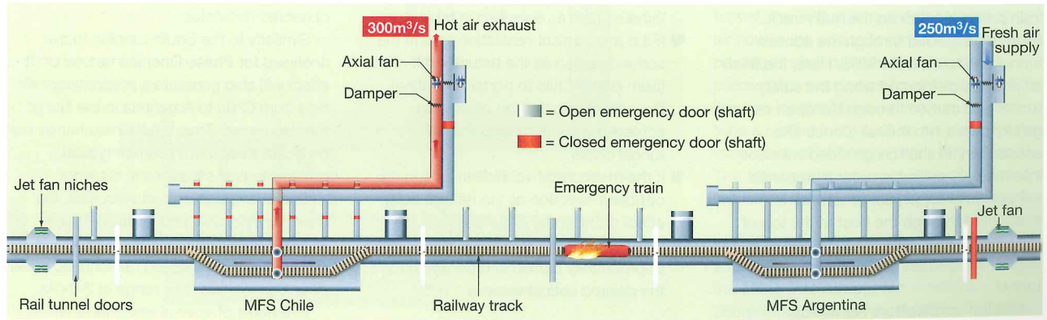
As an example Figure 10 (below) illustrates the emergency ventilation system for a train on fire located between the MFS Chile and the MFS Argentina. A 'push-pull' ventilation system is considered with a longitudinal airflow from portal Argentina to portal Chile. Rail tunnel doors must be appropriately closed in order to counteract the predominant natural draft effect from portal Chile to portal Argentina. The supply fan is set to 250m³/s and the exhaust fan to 300m³/s. The rail tunnel door in the direction of portal Argentina is closed in order to counteract the





Top: Figure 8, velocity history at two positions along tunnel with maximal positive and negative velocity based on one-dimensional simulations

Above: Figure 9, maximum positive and negative train-induced air velocities along the tunnel



Below: Figure 10, emergency operation with train on fire stalled between the MFS Chile and the MFS Argentina

Table 3: Description of the TVS for a train fire in a stretch of tunnel

Description	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Position of the train in fire						
Train stalled between portal Chile and MFS Chile	x	x				
Train stalled between MFS Argentina and MFS Chile			x	x		
Train stalled between MFS Argentina and portal Argentina					x	x
Ventilation mode						
Mechanical ventilation in direction of portal Chile	x		x		x	
Mechanical ventilation in direction of portal Argentina		x		x		x
Supply of 250 m³/s at MFS Chile through doors	x			x		x
Supply of 250 m³/s at MFS Argentina through doors	x		x			x
Extraction of 300 m³/s at MFS Chile through openings		x	x		x	
Extraction of 300 m³/s at MFS Argentina through openings		x		x	x	
Additional civil measures						
Closed rail tunnel doors	x		x		x	

predominant natural draft effect from portal Chile to portal Argentina.

In case of an accident in a MFS, the TVS must be able to maintain the escape ways, such as the cross-passages and the central safety tunnel, free of smoke, for which air velocities of 2-11m/s shall be achieved.

In Figure 11 (far right) the emergency operation in an MFS is illustrated, with the train on fire located on the main track. Fresh air is guided through the access tunnel and toward the MFS. Here, the fresh air shall be distributed along the safety tunnel and carried through the open escape gallery doors into the rail tunnel. The access tunnel shall be provided with one intermediate ceiling in order to separate exhaust and supply air. Smoke/air is evacuated through the duct at the top of the tunnel cross-section, and fresh air is kept at the bottom part of the access tunnel.

Design verification: Numerical simulations have been adopted to verify that the designed TVS is able to meet the objectives specified.

Results from the emergency operation in a tunnel portion resulted in the following main findings:

- The critical velocity can always be achieved by operating the supply and exhaust fans as specified in table 3
- If the mechanical ventilation acts in the same direction as the natural draft effect (from portal Chile to portal Argentina), the critical velocity can always be achieved without closing the rail tunnel doors.
- If the mechanical ventilation acts in the opposite direction as the natural draft effect (from portal Argentina to portal Chile), rail tunnel doors must be appropriately closed in order to achieve the desired critical velocity.

Results from the emergency operation in an MFS indicated that velocities of 4.0-5.5m/s are achieved by setting 250m³/s for supply and 300m³/s for exhaust ventilation. Thus, the fulfilment of the ventilation criteria is guaranteed.

The proposed ventilation design allows handling freight train fires with maximum HRR of 250MW. In case of fire the safety of passengers will be increased and the damages on the civil structures will be limited.

Phase Two TVS

The final configuration of the MFS is illustrated in Figure 12 (page 44) showing different construction phases.

An additional extraction point is added in order to handle fire-related incidents in the northern tunnel. The main elements to be added to the MFS for Phase Two are described in Table 4 (far right).

Normal operation

Similarly to Phase One, the fans for the tunnel ventilation and the shaft tunnel ventilation are not used to supply fresh ambient air to the tunnel since the air exchange, as well as the temperature and humidity levels, are controlled by the piston effect. Mechanical ventilation shall be employed only if necessary.

For safety reasons and in order to preserve the construction, the North running tunnel and the South running tunnel shall be aerodynamically separated during normal operation. All the cross-passage and crossover doors shall be closed.

Design verification: Freight and passenger trains travel the tunnel during Phase Two with a maximum available speed of 100km/h for freight trains and 120km/h for passenger trains. The achievement of the tunnel ventilation objectives during the normal mode of operation has been verified for both summer and winter conditions. Only the results related to the summer are presented here but similar behaviours can be observed for winter.

Similarly to the South running tunnel analysed for Phase One, the natural draft effect will also generate a predominant air flow from Chile to Argentina in the North running tunnel. Thus a full air exchange can be guaranteed within 24h for typical meteorological situations in summer.

Due to the limited train velocities, the maximum positive and negative train-induced pressure fluctuations are small compared to high-speed rail tunnels. It has been verified that they range at 2-3kPa.

Examples of special equipment which might be designed for the tunnel are:

- *Doors in the rail tunnel and cross-passages:* The doors resist pressure differences of 30kPa working in both directions. During opening and closing, these elements resist corresponding air velocities, such as, they are permanently guided. They do not swing open or closed in an uncontrolled manner due to wind forces.
- *Signs:* Being exposed to the longitudinal air flow in a tunnel, these are designed solid enough to resist the wind forces.

Summer dry-bulb temperatures: Similarly to Phase One, a prognosis of the climate was undertaken for the North running tunnel. Simulation results indicated that the maximum dry-bulb temperature in summer does not reach 30°C and is consequently below the limit value of 35°C specified.

Congested operation

No specific ventilation requirements are specified for the congested mode of operation.

Maintenance operation

During Phase Two maintenance may be carried out in a stretch of the North or South tunnel, during which train traffic shall not be stopped. The position of the rail tunnel doors and the crossovers shall be planned in order to separate the maintenance zone from the rest of the tunnel and (at the same time) enable trains passage.

A set of 10 rail tunnel and crossover doors is foreseen in order to cover all the possible tunnel stretches that may be put under maintenance. The position of the rail tunnel doors in the northern and the southern tunnels, as well as the configuration of the crossovers, are planned in order to let the trains pass from one tunnel to the other. Thus, train traffic is not stopped during the maintenance of a particular tunnel stretch.

Selected rail tunnel and crossovers doors are appropriately closed in order to separate the tunnel stretch under maintenance and maintain the train traffic.

The amount of fresh air that has to be supplied in case of maintenance is smaller than that needed during emergency operation, so no specific ventilation requirements are specified for any maintenance operations.

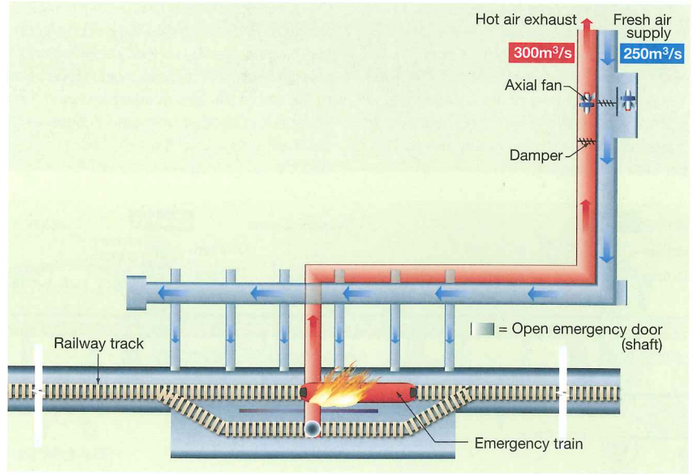
Table 4: Elements of the MFS to be considered for the construction of Phase 2

Element	Description
Access tunnel	A second branch of the access tunnel is required connecting the northern tunnel with the exterior. This is fundamental for separating the construction of Phase 2 from the tunnel elements of Phase 1. Thus, the train traffic of Phase 1 can be maintained during the construction of Phase 2.
Cross passages	The construction of the cross passages will be completed during Phase 2. They will connect the central safety tunnel to the northern tunnel every 100 m. As the first part of these cross passages (with the corresponding doors) was already constructed during Phase 1 (see figure 15), the train traffic of Phase 1 can be maintained without affecting the safety tunnel.
Cross-passage doors	Additional cross-passage doors are installed in order to separate the escape gallery from the tunnel. Generally, these doors should always be closed, but they might be opened in case of maintenance or emergency.
Central extraction point	Fire incidents in the northern tunnel will be treated similarly to the southern tunnel. For this purpose, another central extraction point will be constructed for Phase 2 and located above the tunnel North.

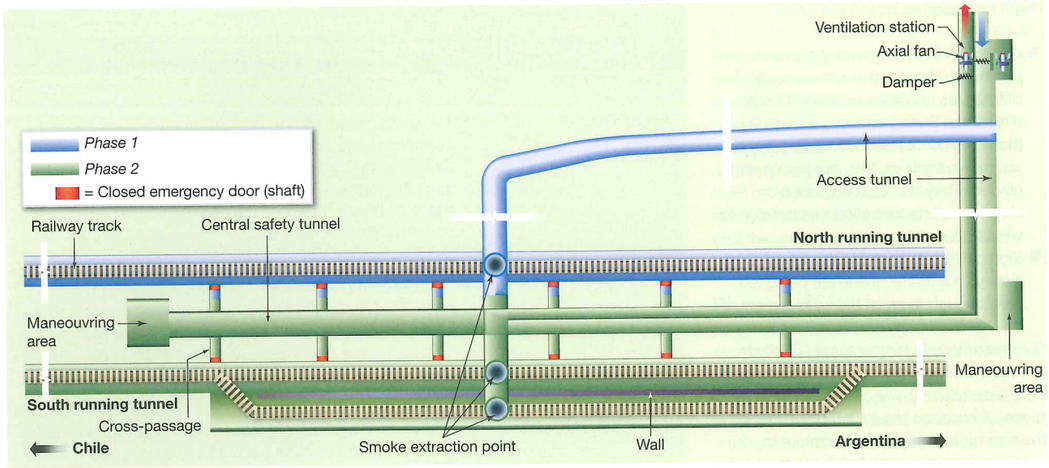
Emergency operation

TVS emergency operation is similar to that considered for Phase One. One extraction point is added above the North running tunnel in order to handle possible fires on trains. Similarly to the Phase One, in case of fire in an MFS, the smoke extraction points are used to control smoke propagation through the tunnel. At the same time fresh air is supplied to the cross passages to enable passenger evacuation.

During a fire incident in a stretch of tunnel, the TVS must provide a longitudinal air flow in the opposite tube. Selected cross passages shall be opened to enable passengers evacuation from the incident to the non-incident tube. In the non-incident tube a rescue train must be provided for the evacuation of passengers out of the tunnel. The other cross passages, as well as the crossover doors, remain closed. The figure



Left: Figure 11, ventilation procedure with the train on fire on the main track of the MFS. The supply fan is set to 250m³/s and the exhaust fan to 300m³/s.



Above: **Figure 12, MFS at Chile and Argentina during Phase Two**

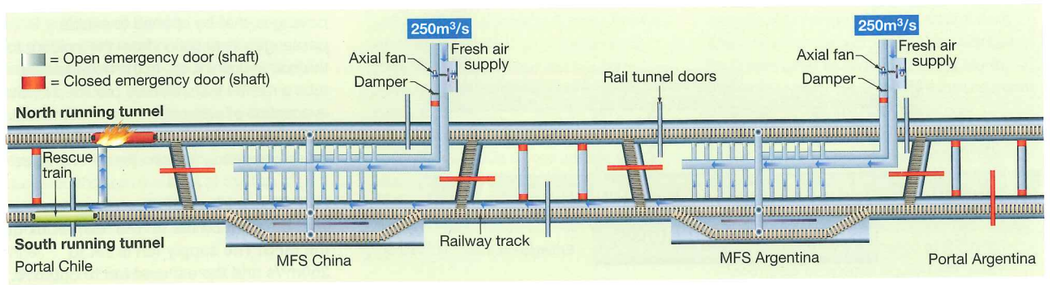
13 (below) illustrates the TVS in case of fire in the North running tunnel in the vicinity of the Chile portal.

Similar ventilation procedures are adopted with the train on fire located in the other stretches of tunnel segments, both in North and South running tunnels.

Design verification: The results for Phase One indicated that in the case of a fire incident in an MFS, the TVS provides air velocities in the escape galleries of 2-11m/s. Thus meeting the specifications.

As indicated in Figure 13 (below), in case of fire in a stretch of running tunnel, selected cross passages shall be opened and maintained with an overpressure in order to allow evacuation of passengers. Similarly to a fire in the MFS the air velocity along the opened cross passages must range between 2-11m/s. Following the values specified during Phase One, this ventilation objective has been verified by considering a supply ventilation of 250m³/s (see figure 13, below) at the MFSs of both Chile and Argentina. It has been verified that, due to the natural draft effect, the ventilation objectives cannot be achieved without closing the rail tunnel doors. In addition, the desired air velocity along the cross passages cannot be obtained by considering only one MFS supplying 250 m³/s. The two axial fans for the supply of fresh air must be operating at once.

Below: **Fig 13: Phase 2 emergency mode with train on fire in running tunnel North near Portal Chile**



Civils design

The supply capacity of the TVS shall be set to 250m³/s and the exhaust capacity to 300m³/s. In order to limit pressure losses at tunnel walls, air velocity in the ventilation shafts should range at 10-15m/s. The ventilation ducts for the extraction of hot air shall have a cross-sectional area in the range 20-30m².

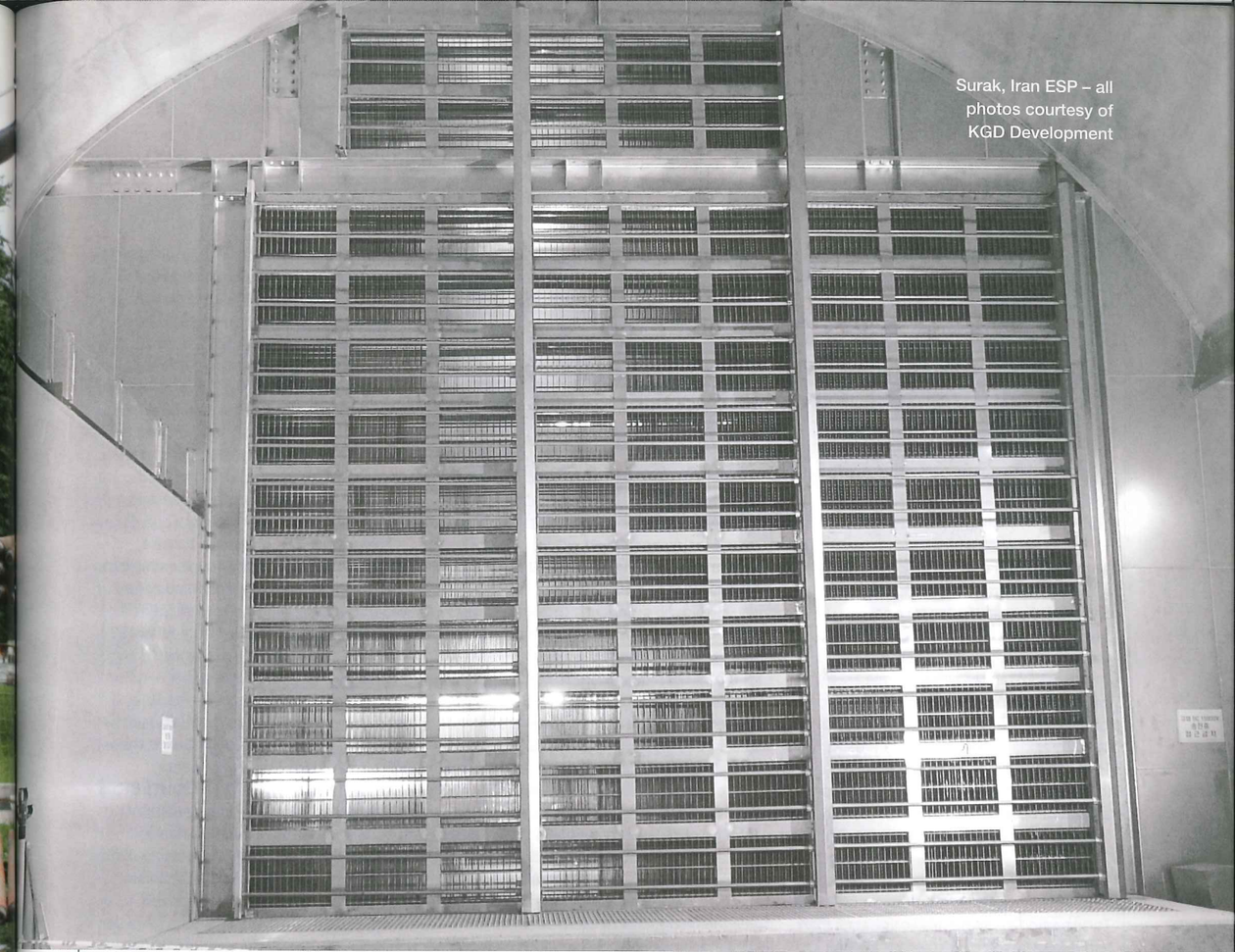
Due to the important length of the access tunnels (about 4km), the axial ventilators have to overcome a high pressure loss, estimated at about 7500Pa. The necessary power of the ventilators is 3.5MW each with the first in operation while the second is in standby guaranteeing 100 per cent redundancy.

The area of each extraction point shall be of about 20m². Four dampers having an area of 5m² each shall be considered, installed at a distance of approximately one metre from each other.

Conclusions

A ventilation concept has been developed for the CBA-BT. Both, Phase One and Phase Two have been analysed and specific ventilation objectives established according to the normal, emergency, maintenance and congested operational modes referencing other major tunnel projects. The ventilation system has been designed for handling a fire on a freight train, which represents the major traffic of the CBA-BT. In addition, passenger traffic has also been considered.

The maintenance and congested mode of operations are not relevant for defining the dimensions of the TVS. Train passage during the maintenance mode of operation can be managed by properly opening and closing the tunnel and crossover doors. Rail tunnel doors are also necessary during the emergency mode of operation in order to reduce the impact of the natural draft in direction of the Argentina portal.



Surak, Iran ESP – all photos courtesy of KGD Development

ESP filtration use and developments

Mountainous Japan was the first country to use electrostatic precipitators to filter tunnel air. Arnold Dix of the University of Western Sydney and Atsushi Katatani of Panasonic Ecology Systems give a history of the improvements and use of ESPs in Japanese tunnels

Following the destruction of Japan's road network during World War II, expressway companies were established to construct and maintain roads independently of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

The main priorities for these companies included construction of two long expressways as main arteries for the national road network run by Nippon Expressway Company (Nexco). The first expressway, the Meishin Expressway between Nagoya and Kobe, was fully completed in 1965. The second was the Tomei Expressway between Tokyo and Nagoya, fully completed in 1969.

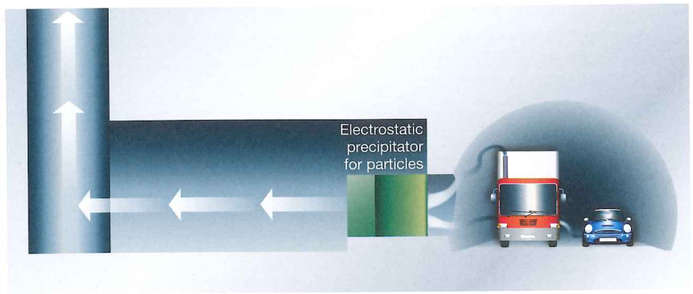
After completion of the two basic expressways, Nexco began to extend their road expressway network throughout Japan, creating expressways such as the Hokuriku Expressway, the Sanyo Expressway and the Kyushu Expressway.

In 1959 the MEC (Metropolitan Expressway Company) was established for the Tokyo region. In 1962 the HEC (Hanshin Expressway Company) was established in Osaka to develop the expressway network. The purpose of both the MEC and HEC was to relieve congestion and to increase transportation capacity on the road network.

Nexco's expressway tunnels

Japan is very mountainous. All Nexco Expressways required the construction of long mountain tunnels.

In the 1960s, Nexco's expressway



Above: Shaft electrostatic precipitator

tunnels were constructed with limited budgets through difficult geological conditions.

In most instances either simple longitudinal ventilation or simple longitudinal ventilation with intermediate fresh air and exhaust shafts were used. These designs were chosen because they required the minimum cross sectional area of tunnels and were able to meet Nexco's in-tunnel air specifications (T. Baba et al, 1979)

During the 1960s in Japan there was rapid and unexpected economic growth. This resulted in greater traffic volumes than had been expected. By the late 1960s residents near the Tennozan tunnel in the Meishin Expressway and the Nihonsaka Tunnel in the Tomei Expressway were sensitive to air quality.

Community concern in the late 1960s focused on the impact of human health at the Tennozan Tunnel while the concern at the Nihonsaka Tunnel focused on crop damages caused by black soot (especially oranges and/or green tea trees). In 1994 Panasonic installed the world's first electrostatic precipitator (ESP) for purifying tunnel air in the Tennozan Tunnel (PIARC, 2008). And in 2000, Fuji Electric Company installed ESPs for removing soot at the Nihonsaka Tunnel.

Japanese tunnel ventilation expressway standards

In 1964 Nexco produced 'The Manual for Designing Car Road Tunnel Ventilation'. This document is possibly the first standard for tunnel ventilation in Japan. Although this document was large (around 400 pages) it is clear that the main concerns were sufficient volume of ventilation air, the visibility index (VI) and carbon monoxide (CO) concentrations in the tunnels.

In 1975 the Japan Road Association (an extra governmental organisation of MLIT) published 'The Road Tunnel Manual' which included the tunnel ventilation standards for all roads including non-expressways. This was the first official publication on tunnel ventilation in Japan.

The 1975 manual focused upon several aspects of tunnel design: geometry, design, construction, ventilation, lighting, emergency facilities and maintenance/repair.

A number of parameters were considered with the 1975 standard: a CO concentration of 100ppM or less; VI of 50 per cent or more for the first and second-class roads and 40 per cent or more for the third and fourth-class roads; how to calculate ventilation air volume; how to model the dispersion on tunnel exhaust including calculation of effective heights of stacks, exit velocities, stack optimisation and ground level calculation.

It is not surprising that in 1975 there was no mention of ESPs in the manual as the technology had not yet been proven.

ESP trials

In 1975 Nexco and its associated companies began field-testing and development of ESPs at the Tsuburano Tunnel (T. Baba, 1991).

Early ESP trials focused upon improving VI values. In long tunnels this meant the construction of short bypass tunnels in which ESPs could be installed.

The use of ESPs in bypass tunnels allowed visibility to be improved without the need for an external ventilation point part way through the tunnel. The first ESP plant was installed at the Tsuruga Tunnel in 1980. At that time there was no Japanese standard for ESPs. Designs were determined on the basis of the specific needs of a project. Approval was based upon the successful liaison between the client and the ESP manufacturers.

In 1987 Nexco specified a tunnel ESP standard in Japan. This 'standard specification for tunnel ESP systems' formed part of the official documents of the 'Common Specifications of Mechanical, Electrical and Communication', (1987 version) by Nexco.

Under the Nexco standard, the required performance of ESP systems was specified as 80 per cent soot collection at 7m/sec.

The 1987 Nexco specification was designed to ensure sight improvement distances (VI) within tunnels but not for purifying tunnel air to be vented.

In 1994 the world's first ESP system for purifying tunnel air exhausts was installed in the Tennozan Tunnel. There was no specification for the environmental performance of ESPs in the Tennozan tunnel and accordingly the same specifications for achieving visibility improvement were used.

The 1987 Nexco standard was revised in 1996 and 2006. A summary of these revisions appears in Table 1 (below, left).

Table 1: Specification revisions of tunnel ESP systems

Specification	First edition (1987)	Revision one (1996)	Revision two (2006)
Processing velocity (m/s)	7	9	9
Polarity	Positive	Negative	Positive or negative
Discharge pole	Wire	Wire	Spike
Soot Collection (per cent)	80	80	90
Power consumption per unit flow (W/m³/s)	Approximately 35	55	110
Method of cleaning ESP	Air blow	Water spray	Water spray

Following the introduction of ESPs for environmental improvement in the Tennozan tunnel in 1994 there was a series of projects in Japan where ESPs were installed in the exhaust sections of tunnel ventilation systems (R. brandt, 2009). Examples include the 1997 Shimoneseki ventilation station in Kanman tunnel, the 1998 Tennozan west ventilation station, the 1999 Moji ventilation station in Kanmon tunnel and the 2000 Nihonsaka ventilation station.

Installation of the ESPs for suspended particle matter (SPM) removal for the above tunnels was in accordance with the Nexco specifications. In no instance was the effect on ground level concentrations used as the basis of the specifications for the ESPs. The basis for using the technologies is that the SPM removal occurred, not that SPM removal resulted in a change to ground level concentrations.

Construction of metropolitan expressways

The first metropolitan expressway was partially opened in Tokyo in 1962. There was, and remains, an emphasis on creating radial ring roads. Even today, road networks are still under construction to create further outer ring roads.

The use of expressway tunnels became more common in the 1990s. Typically major urban road tunnels used transverse or semi transverse ventilation systems. Generally such systems do not require air to be purified because of the continual fresh air being supplied by a transverse or semi transverse ventilation system. However, in areas outside the tunnel ventilation stacks, community concerns about the effects of exhausted air were being raised.

These concerns were also applied to both longitudinally ventilated tunnels and those with ventilation stations.

In 2002 the MEC constructed its first urban tunnel with ESP systems for purifying tunnel exhaust to the atmosphere. A selection of projects used ESPs for external air quality management (R. Brandt, 2009): the 2002 Asukayama Ventilation Station (MEC) the 2003 Midoribashi Ventilation Station (Nagoya Expressway), the 2006 Kitamachi Ventilation Station (Tokyo Metropolis), the 2008 Jujo & Yamashina Ventilation Station (HEC) and the 2009 Yumeshima Ventilation Station (MLIT).

The performance of each of these installations was assessed on a project by project basis. The impact of installation and use of the ESP technology on ground level concentrations was not calculated. It is not expected that this will occur in the future because studies and calculations demonstrate the technology has no measurable effect.

It is expected that increased concerns about the effects of NO_2 by the community will promote the further development and use of NO_2 removal technologies this century.

Denitrification systems

In recent years there has been increased concern about the health effects of NO_2 from tunnel exhaust.

1970s to 1980s

In the 1970s and 1980s Japan experienced significant issues with photochemical smog. Concern was widespread and there were issues with acid rain. There was a demand that NOx (nitrogen oxides) should be removed from tunnel exhausts as part of a campaign to manage photochemical smog and acid rain in urban areas.

1990 – Denitrification Committee

In 1990 MLIT convened a committee, 'The Committee for Surveying NOx Decrease in Metropolitan Area', to develop denitrification systems capable of removing 80 per cent or more of NOx from tunnel air.

1991 to 1992

The MLIT entered into arrangements with six private companies to develop NOx removal technologies. These companies tested their equipment at the Ohi ventilation sites in MEC. The six Japanese companies were: Panasonic, Kawasaki Heavy Industries (KHI), Mitsubishi Heavy Industries (MHI), Ebara, Hitachi Zosen and Kobelco. Each company used a different technique to remove the NOx. Each company achieved 80 per cent efficiency or better NOx removal.

1995

In 1995 MLIT announced a tender for a low concentration denitrification test plant that attained an 80 per cent of NOx removal at 44m³/s of gas flow (S. Yoshida et al, 2007) The successful bidder was Kobelco.

NOx Removal – 1997 to 1999

Following the successful operatons of the Kobelco test plant with 80 per cent NOx removal efficiency, MLIT announced that the field trial was a success.

NOx Removal 1997

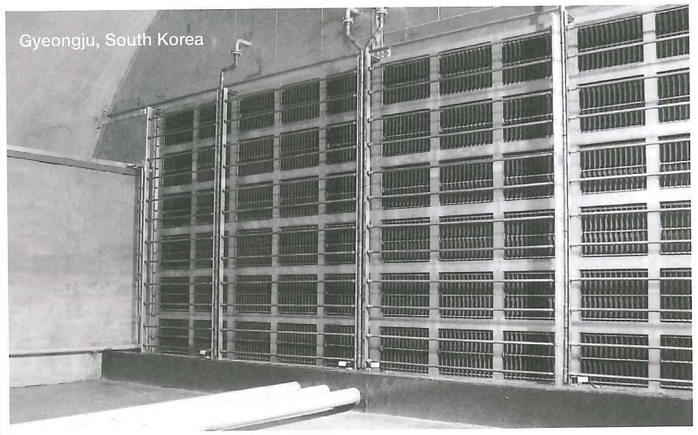
In 1997 the committee investigating how to decrease the NOx levels in the metropolitan area confronted a series of issues.

- The committee concluded that it was technically possible to construct full scale plants for NOx removal.
- The cost for constructing these full scale plants in both initial capital cost and ongoing expenses was grossly disproportionate to the environmental benefit achieved.
- The environmental standards of Japan did not (and do not) specify NOx limits. NO_2 limits are set in a zone between 0.04ppM and 0.06ppM. The committee decided that NO_2 is more harmful to the human body than NO as the ACGIH regulation value in the USA for NO was 25ppM or less.
- It was considered that if the committee concentrated only on the NO_2 removal the cost might be more realistic, however it was unclear what the removal specification should be.

Technically this issue is complex because of factors including oxidation rates of NO within the tunnel, the effect of ozone on oxidation rates produced by the EPs and the external oxidation of NO.

The committee undertook a technical comparison comparing NO_2 removal with NOx removal. The analysis included:

- Modelling of diffusion from a hypothetical exhaust stack at a hypothetical tunnel ventilation station.
- Modelling of the impact on inhabitants in an area around a hypothetical ventilation station in order to evaluate the effect of NOx concentrations with the use of such technologies.
- The ratio of NO to NO_2 used at the inlet of the air purification system was 90 per cent NO and 10 per cent NO_2.
- For NOx removal the purification ratios were 80 per cent of NOx and 80 per cent of NO_2. The impact of these purification ratios was modelled for both NOx and NO_2 concentrations at ground level.
- For NO_2 removal, a range of removal values were applied as part of a simulation for likely ground level concentrations.
- As a result of the simulations it was established that the performance of a 90 per cent removal of NO_2 was comparable with an 80 per cent removal of NOx (NO and NO_2) (S. Yoshida et al, 2007). The results of the simulation case study concluded that less emphasis should be placed on NO removal.



It was determined that the most efficient method of ensuring the protection of health was to focus on NO_2 removal. NO_2 removal required approximately half the size plant to a NOx removal plant, the energy consumption was approximately one fifth and the cost was approximately half. Importantly, the ongoing operational cost with a focus on NO_2 removal were one fifth the cost of the projected NOx removal alternative.

As a result of these investigations MLIT concluded that NOx denitrification for tunnels in Japan should be abandoned. It said that the purpose of tunnel denitrification is limited to the impact upon the area proximate to the tunnel ventilation stacks and should not be calculated in terms of its effect on the total urban area. It was decided that the most prudent form of denitrification was NO_2 denitrification.

2000
In 2000 MLIT announced two tenders for the tunnel denitrification test plants. The new specifications were 90 per cent removal of NO_2 at 22m³/s of gas flow. These were known as 'Tokyo Pilot Plants'.

2001 to 2003
In 2001 two successful bidders were announced being Panasonic and KHI, both with NO_2 adsorption technology (S. Yoshida et al, 2007). The two types of NO_2 denitrification were then evaluated. In 2002 to 2003, testing of both the NO_2 absorption and NO_2 adsorption plants was performed.

March 2004
MLIT announced that the Tokyo Pilot Plants had been successfully finished with preferable results.

2004
MEC announced two tenders for the NO_2 denitrification plants of the Shinjuku Line tunnel in the Central Circular Route. The first tender was with a gas flow of 1,672m³/s and the second with 1,837m³/s (PIARC, 2008 and S. Yoshida et al, 2007). The NO_2 removal ratio of 90 per cent was the same on both tenders. The successful bidders were Panasonic in the first work section and Nishimatsu with absorption in the second work section.

December 2007
The first work section with four ventilation stations was constructed by Panasonic and was in daily operation of between three and 17 hours per day depending upon the operational hours of the ventilation ducts. Five Nishimatsu ventilation stations opened in March 2010.

2009
In 2009 Nexco announced a tender for a NO_2 denitrification plant in the Shintomei expressway. The specifications to be achieved are 180m³/s gas flow with 90 per cent NO_2 removal. In July 2009 Panasonic was successful in that bid.

Conclusions

Originally electrostatic precipitators were used to ensure in-tunnel visibility. Subsequently they have been used in conjunction with NO_2 denitrification equipment in urban road tunnels where local NO_2 levels are an issue, to remove particles to assist with meeting external air quality objectives. The electrostatic precipitators also protect the NO_2 removal process from particles.

Currently the performance of ESPs and NO_2 removal equipment is described by the efficiency of the removal of suspended particles and NO_2 for a given volume of air. There has been no project in Japan where the effect on ground level concentrations of either NO_2 removal or soot removal has been used to develop the specifications of the air cleaning technology.

The availability of denitrification technology in Japan does not of itself mean that it is used on every project. For example the Jujo and Yamashina ventilation stations of 2008 in HEC do not require denitrification despite the fact that they postdate the plants on the Central Circular Route (2007).

The use of ESPs and/or denitrification equipment is not mandated in Japan and decisions to use ESPs or ESPs with denitrification appear to be made on the basis of local factors. Where air purification is specified under new tunnel construction plans, such technology is usually adopted.

Typically a decision about air purification and the type of technology used is political and involves dialogue between citizens, politicians, and clients. There is no official standard on emissions from exhaust stacks. A policy on emissions from ventilation stacks is not expected.

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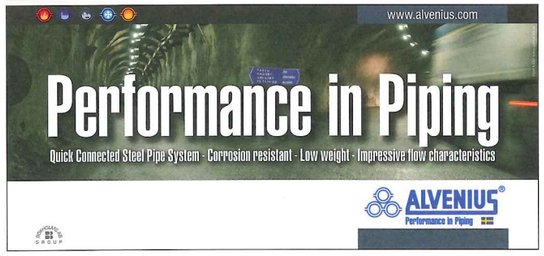

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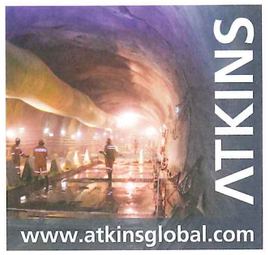

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27 - 29 MARCH 2012
INTERtunnel 2012, Turin, Italy
The tenth edition will be staged at the Lingotto Exhibition. Italy's only regular exhibition on tunnelling technology but also with great international input. Italy claims the greatest number of tunnels in Europe and also has cross-border projects between Turin and Lyon, France, and also the Brenner Base Tunnel to Austria. Alongside Expo Ferroviaria rail exhibition. For more information email: intertunnel@mackbrooks.com or tel. Arianna Rosini on telephone +44 (0)1727 814 400

12-14 APRIL 2012
UnderCity 2012, Dubrovnik, Croatia
Colloquim on using underground space in urban areas in south-east Europe. Contact Tanja Rabar on tel.: +385-51-410-447, email tanja.rabar@hubtig.com or see www.undercity2012.com.

16-21 APRIL 2012
Intermat, Paris-Nord Villepinte, France
International exhibition of equipment, machinery and techniques for the construction and building materials industry. Companies registered so far include Casagrande, Cifa, Herrenknecht, Jean Lutz, Montabert, Peri, Robit and Sandvik. Enquiries to Maryvonne Lanoe or Maud Carcy on maud.carcy@comexposium.com, tel.: + 33 (0)1 76 77 11 93 or see www.intermat.fr

24 - 26 APRIL 2012
3rd Int Conf on Shaft Design & Construction, London, UK
Organised by the Mining Technology Division of the IMMM and the BTS at 1 Carlton House Terrace. The scope includes all areas of design and construction of both civil engineering project and mine shafts. Contact Paul Harris at IOM Communications by email paul.harris@iom3.org, tel. +44 (0)20 7451 7302 or see www.iom3.org/events/sdc2012.

18 - 23 MAY 2012
World Tunnel Congress WTC 2012 & 38th General Assembly of the ITA, Bangkok, Thailand
Organised by the Thailand Underground & Tunnelling Group (TUTG) of the Engineering Institute of Thailand with the ITA, the theme is 'Tunnelling & Underground Space for a Global Society.' For more information email: secretariat@wtc2012.com or visit www.wtc2012.com

29 MAY - 01 JUNE 2012
SSCS - Numerical Modelling, Strategies for Sustainable Concrete Structures, Aix-en-Provence, France
Organised by the Association Francaise de Genie Civil (AFGC). Contact Nadget Berrahou-Daoud on tel.: +33 1 44 58 24 29, email afgc@enpc.fr or see www.afgc.asso.fr

24 - 27 JUNE 2012
North American Tunneling Conference (NAT), Indianapolis, Indiana, USA
UCA's biannual conference, which has continued to grow each year with more exhibits, technical sessions & attendees. More information regarding housing and registration will be available at http://uca.smenet.org/ in spring 2012

18 - 21 SEPTEMBER 2012
Eastern European Tunnelling Congress, Budapest, Hungary
The Hungarian Tunnelling Association is organizing the 1st Eastern European Tunnelling Congress to share experiences and exchange knowledge of design, construction management, research results and technical developments of tunnels completed by the regional associations and experts. The planned regional sub European conference is open to all other co-organizers and participants as well as to those who having ongoing or completed projects, research works in this area.
More information at http://www.eetc2012budapest.com/

7 - 9 NOVEMBER 2012
13th World Conference of ACUUS, Singapore
The Associated research Centers for Urban Underground Space (ACUUS) is presenting 'Underground Space Development – Opportunities and Challenges.' The intent is to focus on new opportunities in a re-focus on developing the urban underground space as part of sustainable development, and the many challenges and issues that planners, developers, and engineers face. More information at http://www.acuus2012.com

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition, which is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site:
Editor, 'Tunnels & Tunnelling International', Boundary House, 91-93 Charterhouse Street, London, EC1M 6HR, United Kingdom.
Fax: +44 20 7936 6826
Email: editor@tunnelsandtunnelling.com
Web: www.tunnelsandtunnelling.com

BRITISH TUNNELLING SOCIETY

ALL BTS MEETINGS ARE AT THE INSTITUTION OF CIVIL ENGINEERS, LONDON, UNLESS OTHERWISE STATED, AT 17:30 FOR 18:00 UNTIL APPROX. 19:30. TRADITIONAL BAR AND SNACKS WILL BE AVAILABLE AFTERWARDS.

19 JANUARY 2012
Tunnelling Induced Settlements in London Clay - Effects on Buildings
Of particular interest in view of the Crossrail and other major London tunnelling projects now in progress, and following publication of the BTS Monitoring Guide in Autumn 20111, this presentation will be made by Prof Robert Mair, Head of Civil & Environmental Engineering at Cambridge University and Chair of the Geotechnical Consulting Group, Dr Jamie Standing of Imperial College, London, and Dr Keith Bowers of London Underground Tunnels, Transport for London

16 FEBRUARY 2012
Chile Mine Rescue
A joint meeting with the MinSouth local society of the Institute of Materials, Minerals and Mining. Brian Robinson of Mine Rescue will describe the famous rescue of the 33 Chilean Miners in 2010 and ask whether we are prepared for a similar event in the UK.

15 MARCH 2012
Report from the BTS Compressed Air Working Group
Presentation by Dr Donald Lamont, Hyperbaric & Tunnel Safety and Roy Slocombe, Director of Herrenknecht International to link with the joint BTS/ITA international seminar on high-pressure compressed air work.

19 APRIL 2012
Harding Memorial Lecture
Speaker to be confirmed.

24-26 APRIL 2012
Shaft Design & Construction Conf
See main listings.

contacts

Jon Young

EDITORIAL

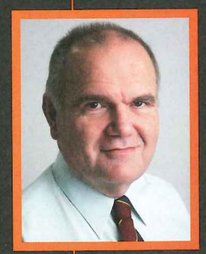
EDITOR
Jon Young
Tel: +44 20 7336 5256
Email: jon.young@tunnelsandtunnelling.com

TECHNICAL EDITOR
Maurice Jones
Tel: +44 1296 397 353
Email: maurice.jones@tunnelsandtunnelling.com

AMERICAS EDITOR
Nicole Robinson
Tel: +1 612 9402 780
Email: nicole.robinson@tunnelsandtunnelling.com

NEWS EDITOR
Alex Conacher
Tel: +44 20 7336 5257
Email: alex.conacher@tunnelsandtunnelling.com

REGULAR CONTRIBUTORS
Adrian Greeman, Bernadette Ballantyne, Patrick Reynolds, John McKenna



Maurice Jones

PRODUCTION & DESIGN

DESIGNER
Dan Becker

TECHNICAL ILLUSTRATOR
Nick Stenning

PRODUCTION CONTROLLER
Loraine Lee
Tel: +44 20 8269 7799 Fax: +44 20 8269 7840
Email: llee@progressivemediagroup.com

Nicole Robinson

ADVERTISING

HEAD OF SALES
Jim Moore
Tel: +44 20 7406 6584
Email: jim.moore@tunnelsandtunnelling.com

EUROPEAN SALES
Randolf Krings
Tel: +49 611 5324 416 Fax: +49 611 5324 519
Email: t&t@emcmedia.de

CLASSIFIED AND RECRUITMENT
Tom Willard
Tel: +44 20 7406 6599
Email: tom.willard@tunnelsandtunnelling.com

ITALIAN SALES
Ediconsult
Tel: +39 02 477 10036 Fax: +39 02 477 11360
Email: milano@ediconsult.com

Alex Conacher

MARKETING

MARKETING MANAGER
Shelly Wills
Tel: +44 207 936 6671
Email: shelly.wills@progressivemediagroup.com

MARKETING EXECUTIVE
Jeanette Pletten
Tel: +44 207 936 6694
Email: Jeanette.pletten@progressivedigitalmedia.com

Jim Moore

HEAD OFFICE: **World Market Intelligence**
John Carpenter House, 7 Carmelite Street,
London EC4Y 0BS, UK
WEB: www.tunnelsandtunnelling.com
EMAIL: editor@tunnelsandtunnelling.com
TEL: +44 20 7336 5256
FAX: +44 20 7936 6813

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