

SEPTEMBER 2012

tunnels & tunnelling INTERNATIONAL



Western Europe

The 'Old World' of tunnelling still boasts mega projects and innovations

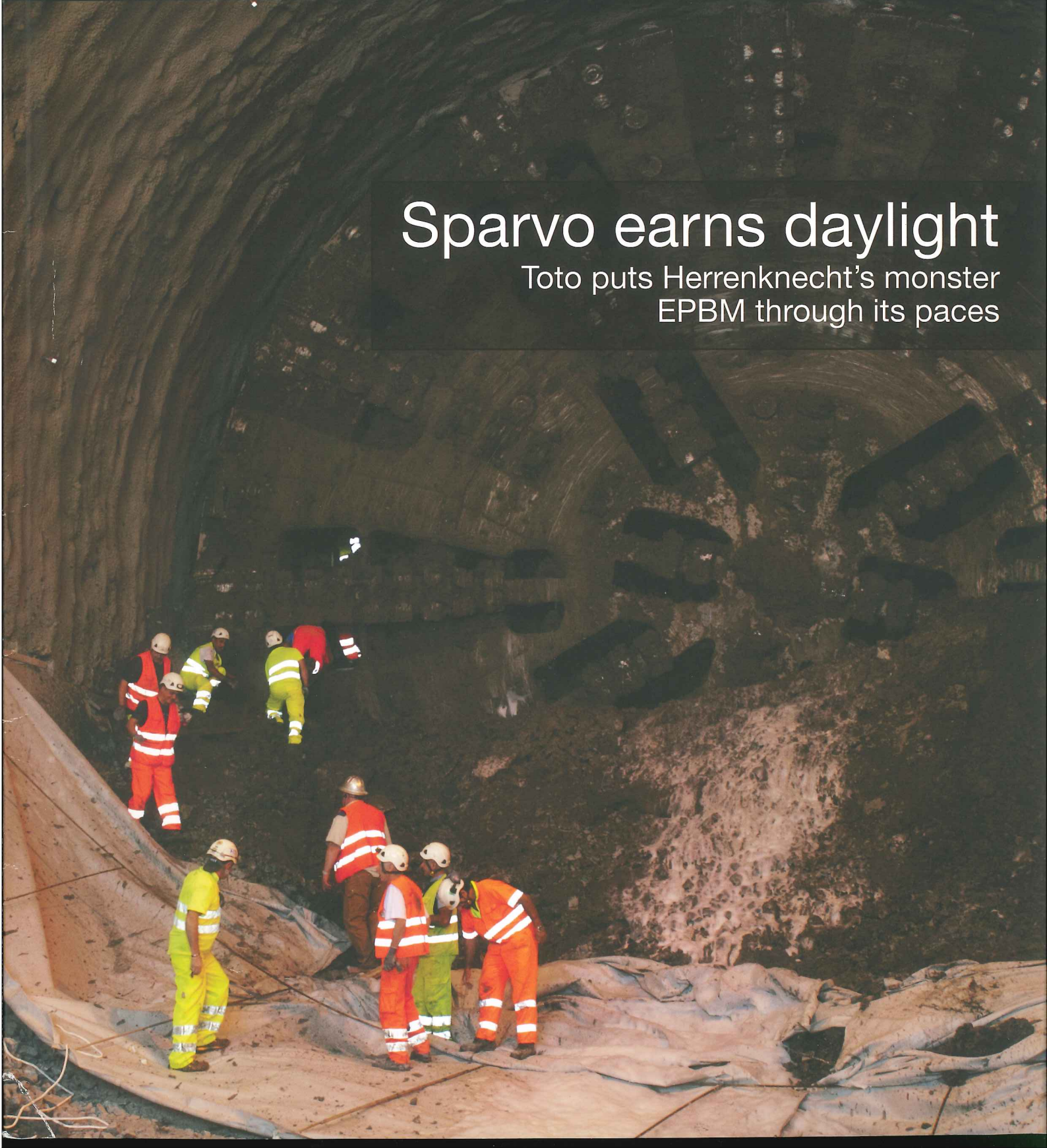
Drill and blast

A new move towards automation and a challenge to transmission convention

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Sparvo earns daylight

Toto puts Herrenknecht's monster EPBM through its paces



**BREAKTHROUGH
SOLUTIONS FOR
TOUGH JOBS
AROUND THE WORLD**

BEIJING METRO LINE 9 LOT 6

BEIJING, CHINA
RME246SE - Mixed Face 6.28 meter EPB TBM
Contractor: Beijing Urban Construction Group (BUCG)

- ✓ Completion of 2 parallel metro tunnels of 1.2 km each
- ✓ Lot 6: most challenging section in the 16.45 km Line 9 construction
- ✓ Tunnel drove under water table, river, lakes and a restricted zone
- ✓ Highly permeable gravel and cobble conglomerate geology
- ✓ High density of boulders encountered with average size >1m
- ✓ Equipped with unique heavy duty ripper teeth, 1200KW VFD main drive
- ✓ Successful completion demonstrates credibility and versatility of Caterpillar EPB technology in conquering complex geology



BUCG TBM project team celebrating with Caterpillar Tunneling representatives on the breakthrough of Lot 6 on April 10th, 2012 in the front of the "Diamond" TBM, as nicknamed by the contractor for its outstanding performance.

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comment

Understanding the odds

Hurricane season is well and truly upon us. Over the past couple of months the work of engineers on the US's southern coast has been put to the test. Every year the media homes in on the low lying city of New Orleans to see whether the flood defences put in place after the 2005 category five Hurricane Katrina will stand the test.

This year poses one of the biggest threats since Katrina as Hurricane Isaac passes – as I write – directly over New Orleans. The news is not good for the engineers. The USD 6bn levee system that was built following the overtopping in 2005 was designed for a one in 100 year storm. Early reports have shown the levees to be breached and some parishes flooded.

Hurricane Isaac is not a one in 100 year storm. According to the book Hurricane Watch by Jack Williams and Bob Sheets, the chance of a storm with Isaac's strength hitting New Orleans is 12.5 per cent a year, or one in eight years. There is a 3.2 per cent chance, or one in 30 years, of a major hurricane hitting the city.

This acid test for New Orleans should have been a category three or four hurricane. Not a category one.

When protecting cities the one in 100-year design criteria is unfortunately commonplace across North America. In Austin, Texas, for example, the new Waller Creek storm water relief tunnel is designed to cope with 85 per cent of the floodwaters from a one in 100-year down pour. The project is needed to protect downtown Austin from flash floods. It is important to understand a one in 100 year risk. There is a 63 per cent chance of a one in 100 year event occurring over that 100-year period. The formula for this calculation is:

$$Pe=1-[1-(1/T)]^n$$

Where:

Pe is probability

T is return period

n is number of years

The US is lagging behind other countries. Returning to the levees, the Netherlands famously has designed theirs for one in 10,000 year storm events. In Turkey, the new metro line crossing the Bosphorus is designed to withstand a one in 10,000 year flood.

The US does take a better stance when protecting the infrastructure itself over the cities it serves. The Alaskan Way Viaduct Replacement Tunnel in Seattle is designed to withstand a one in 2,500 year earthquake. It has a 100-year design life. This means there is a few per cent (3.9 per cent) chance that an earthquake will destroy the tunnel before it has fulfilled its intended life. Again, by comparison the US is lagging behind. In Australia, Brisbane's Airport Link Northern Busway project is projected against a one in 10,000-year flood. The UK is in a similar position to the US on London's Crossrail project, which has a one in 200 year flood protection on a 120-year design life. This gives a 45 per cent chance it will flood during its working life.

Jon Young

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On the cover: The Sparvo tunnel project used the world's largest EPBM to overcome the difficult local clays and deposits of firedamp



ITALY: THE WORLD'S LARGEST EPB SHIELD CELEBRATES ITS FIRST BREAKTHROUGH IN SPARVO.

"With the largest TBM in the world we are accustomed to records, two of the record-winning features are its size and its tunnelling speed", said Alfonso Toto, chairman of the management board and managing director of Toto Costruzioni Generali during the first breakthrough celebrations in the construction of the Sparvo Tunnel at the end of July. The Herrenknecht Earth Pressure Balance Shield with the world-record diameter (15.55m) did not even need 12 months for the construction of the 2,413 meter long tunnel. The tunnel provides space for two lanes in each tube with a hard shoulder each. With the TBM Martina, Herrenknecht set new standards for tunnel boring machines with respect to the equipment for specially gaseous soils.

SPARVO | ITALY

PROJECT DATA **CONTRACTOR**

S-574, EPB Shield
 Drilling diameter: 15,615mm
 Installed power: 12,000kW
 Tunnel length: 2,494m
 Geology: clay, argillaceous slate and sandstone

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Hundreds of workers trapped in flooded tunnel

CHINA

Rescue teams were last month trying to save some 450 tunnel workers trapped in a flooded tunnel under Northeast China's Liaoning province after Typhoon Damrey hit the province in the first weekend of August and brought torrential rains that left at least 10 people dead and 11 people missing.

National media in China and Australia reported that more than

300 workers from the construction team of a high-speed railway project and nearly 100 from a team working on a local water supply project have been trapped in a tunnel in the Qiaotou township of Benxi city on Monday 6 August.

About 20 of the trapped workers were rescued early on the Monday as firefighters set up a ropeway to pull people out of the under construction tunnel.

Water up to 2m deep had flooded into the tunnel from the

nearby Sandaohu and Xihe rivers after the torrential rain brought.

After Typhoons Damrey and Saola hit China, a third reached the south-eastern province of Zhejiang and was expected to bring more torrential rain to inland areas.

Torrential rain over the past month has caused floods and landslides that killed several hundred people, including at least 79 in Beijing, and forced the evacuation of more than one million across the country.

TBM delivered to London cable site

GREAT BRITAIN

The 56t TBM named 'Bernice' has been delivered to Brentfield Park in North West London and lowered into the Willesden reception shaft, it was announced last month.

Contractor J. Murphy & Sons received delivery of the Caterpillar TBM that will be used to bore a 1.3km long and 2.59m internal diameter cable tunnel for client, UK Power Networks.

Murphy is delivering a GBP 10M (USD 15.6M) contract from Brentfield Park to Taylor's Lane in Willesden, which also includes the construction of two vertical 28m deep, 7.5m internal diameter shafts at each end.

The tunnel will cut through London clay geology.

Secant piling was used for one of the shafts and a 143m of shallow tunnel for junction and reception chambers has also been constructed.

A 250t mobile crane was required to lower the machine into the reception shaft at Willesden. Tunnelling will follow testing.

Double shield TBM begins Kargi Kizilirmak hydropower expansion

TURKEY

A 10m diameter double shield TBM, launched in central Turkey in Spring 2012, has advanced over 400m despite difficult ground including unexpected fault zones and inflows of water and mud, US-based TBM manufacturer Robbins announced last month.

The excavation is part of the Kargi Kizilirmak Hydropower Project, what will become of Turkey's largest hydropower stations to date.

Crews for contractor Gulermak, project wonder Statkraft and Robbins are guiding the machine through changeable geology.

The project consists of an 11.8km long headrace tunnel through a mountainside near the town of Osmancik. Ground is expected to include volcanic-based rock with softer limestone for the first 3km, giving way to harder geology including marble for the rest of the route. Current advance rates of 20m a day are expected to continue.

Segmental lining of the tunnel will take place for the first 3km,

the remainder of the tunnel will be supported with ring beams and rock bolts, as well as final lining of shortcrete.

"We have had some very impressive efforts by the Gulermak and the Robbins teams," said Glen Maynard, Robbins Field Service Manager. "After the TBM has bored 175m with a temporary conveyor

system, tunnelling was interrupted to install the permanent conveyor system.

Gulermak completed this installation in six days; on day seven the Robbins continuous conveyor system was operational, and normal boring operation was then resumed."

Below: Machine assembly



Port Miami tunnel project reaches milestone

USA

A breakthrough on the Port Miami tunnel construction project was announced last month when crews reached the halfway point in the boring process. The TBM, known as Harriet, completed the first of two tunnel tubes under Biscayne Bay linking the port with the mainland.

The geology consists of mix of loose sand and limestone. The two

tunnel drives, each a little more than 1km in length, make a gradual 'S' shape as they connect Watson Island and the Port of Miami (on Dodge Island) beneath Government Cut. Each tunnel will have a 12.8m outside diameter and contain two traffic lanes, curbs, walkways, ventilation fans and safety features.

The tunnel is being lined with precast concrete segments each measuring 6.5m long, 2.1m wide

and 0.6m thick, and weighing 12t. One ring consists of eight segments and a keystone. For reinforcement, rebar cages are being made off site by a subcontractor and are trucked to the precast plant.

"The tunnel is critical to Port Miami's future growth because it will allow port traffic to move more expeditiously to and from the interstate system, and will help reduce traffic downtown," said mayor Carlos A Gimenez. "This project has been an engineering feat of note. But, even more significantly, the Port Miami tunnel is an example of what our port is all about – a public-private collaboration that will make our port even more dynamic tomorrow than it is today."

After tunnelling under the bay, Harriet will now be turned around and will start the dig back towards Watson Island. The project is a public-private partnership between Miami Access Tunnel, FDOT, Miami-Dade County and the City of Miami. Construction began May 2010, and the project is expected to complete in May 2014.

Left: Machine launch works



TBM arrives in Malta

MALTA

The TBM that will excavate a 6km cable tunnel to link Malta to the European grid has arrived on its assembly location, it was revealed last month.

The Robbins TBM will bore a 6km tunnel linking Maghtab substation to Pembroke Distribution Centre, close to Valetta, Malta's capital.

Malta based contracting company Polidano Group has been commissioned by the Government of Malta to excavate the tunnel for a total contract

value of approximately EUR 7M (USD 8.6M).

The 77m long TBM weighs 280t when fully assembled and is expected to have an average advance rate of 30m per day with peaks of up to 50m per day if ground conditions are favourable for tunnelling.

Charles Polidano, managing director of Polidano Group, said, "Our group boasts a portfolio of some of the largest completed projects on the island and this will continue to motivate us to look ahead of our competition, in whatever we do."

Global interest in Sydney

AUSTRALIA

There has been strong Australian and international interest in the AUD 7bn (USD 7.3bn) contract for Australia's longest and deepest tunnel, Sydney's North West Rail Link, the government in New South Wales claimed last month.

Six consortiums, made up of more than 60 companies, signalled their intention to bid for the contract to build the twin 15.5km tunnels between Bella Vista and Epping, following calls for expressions of interest.

News in brief

▼ New Crossrail lifts

A major contract for around 50 lifts for the new Crossrail stations, as well as five lifts for Bank, Greenford and Hammersmith tube station, has been awarded it was announced late last week. Kone was awarded the GBP 45M (USD 70M), which includes maintenance for 22 years. The incline lifts will allow Crossrail and TFL to provide full step-free access at the stations.

▼ Brunel's Box listed

Brunel's Box Tunnel is one of 35 buildings running along the Great Western main line to receive listed status thanks to a National Heritage programme. It is part of the route from London Paddington to Bristol Temple Meads and has been awarded grade II listed status. The tunnel, which opened in 1841, is 1.83 miles (2,937m) long and when opened it was the world's longest rail tunnel.

▼ Tianjin rail tunnel breakthrough

The tunnel connecting the main and western stations in Tianjin, China broke through. The 11.97m diameter slurry TBM was supplied to by NFM.

Chunnel mobile phone services launched

GREAT BRITAIN - FRANCE

A GSM-P optical fibre system for 2G and 3G telephone and internet services has been launched on the Channel Tunnel, it was announced last month.

The services will enable passengers of Le Shuttle and high speed trains to use their mobiles to make calls and access the internet

inside the tunnel itself.

The project, piloted by the equipment supplier Alcatel-Lucent, is the outcome of cooperation by the French telecoms operators Orange, SFR and Bouygues Telecom. The technology enables a wireless service 100m below sea level and throughout the tunnel.

The equipment was installed in 10 months.

"Eurotunnel is proud to be able to regularly improve the services we offer to our customers through major technological innovation, this time based on the expertise of Alcatel-Lucent," said Jacques Gounon, chairman and CEO of Groupe Eurotunnel.

Pascal Homby, chairman and CEO of Alcatel-Lucent France, added: "As a result of this

collaboration with Eurotunnel, and which has used many of the different technical skills we have at Alcatel-Lucent, we are very proud to have contributed to the provision of new communication services on board the trains in the Channel Tunnel."

The Channel Tunnel contains the longest underwater stretch of any tunnel in the world.

News in brief

▼ Coal miners rescued

Five coal miners have been rescued after being trapped on Wednesday 25 for more than 96 hours in a coal mine's tunnel collapse in southwest China's Guizhou province. Some 53 rescuers were sent underground to dig a tunnel to reach the miners; they were pulled out unscathed six hours later through a newly-dug tunnel. An investigation into the cause of the accidents is underway.

▼ Sri Lankan water tunnel construction begins

Construction of the main tunnel of the Uma Oya reservoir project in Sri Lanka started in the beginning of August. The Government of Sri Lanka is financing the USD 16bn project, aided by USD 450M from Iran. The 19km-long drill and blast tunnel, with a diameter of 3.5m, will divert water from the river to an underground hydro power plant. The Iranian Farab Company is the main contractor for the project.

▼ Stout joins MRS

Mine Radio Systems (MRS) announced the appointment of Jason Stout as VP of EMEA. Stout added that "since I joined MRS 18 months ago we have achieved substantial growth."

World's largest TBM completes first drive

ITALY

The TBM being used to build a twin-tube Sparvo road tunnel located between Bologna and Florence, broke through the northbound tunnel of on 25 July.

The colossal 15.615m machine was manufactured by Herrenknecht as an EPBM. It was

equipped with 76 disc cutters, 216 cutting knives, 24 buckets and one centre cutter.

The tunnel is 2,431m long with a 13.6m inside diameter. It will accommodate a triple-lane carriageway, including an emergency lane, 3.75m wide each. The tunnel will be equipped with 10 bypass - two of them for

vehicles - and 17 SOS posts for emergency calls.

Shortly after mid-August this year, the machine will be rotated 180 degrees by contractor Toto with assistance from Palmieri, and it will take three months to assemble the TBM again in the new cradle, ready to bore the southbound tunnel.

Below: The Herrenknecht EPBM newly assembled at the Toto worksite between Florence and Bologna



Breaking ground on Waterview Connection

NEW ZEALAND

Excavation work for the first of the Waterview Connection's two 2.4km-long motorway tunnels beneath Auckland is on-track to begin next year, with last month's ceremonial ground breaking for a 30m deep trench needed for the construction of the project's tunnels, the New Zealand Transport Agency (NZTA) revealed.

The trench will be used to assemble the 85m long TBM before beginning work excavation of the tunnels next year. Preparatory works and environmental controls have already been put in place to facilitate the start of construction including the provision of alternative open space, realignment and rehabilitation of

parts of Oakley Creek and the relocation of local wildlife and plant life to new habitats.

The TBM will drive to a depth 45m beneath the surface, passing below hard volcanic rock. "To create the launch pad for the machine, we first have to excavate through a significant chunk of this basalt to reach the softer soil conditions below," said Tommy Parker, state highways manager for Auckland and Northland, NZTA.

Excavation of the trench will involve a series of controlled explosions to fragment hard rock. "This not only allows the excavation to be carried out faster, it also significantly decreases the impact felt by local residents as it reduces the amount of traditional rock-breaking activity required," said Parker. "Basalt retrieved

through this process will be used throughout the project, and for landscaping."

"In addition to local landscaping initiatives around Owairaka and Waterview, the project will, in partnership with Auckland Council, also provide enhanced walking and cycle ways between the two communities. These elements are vital components of the overall project scope, as we work to deliver this key transport link."

The two 2.4km tunnels between Owairaka and Waterview, will provide a new six-lane motorway link between the Southwestern Motorway and SH20 the Northwestern Motorway. It is the country's largest road project to date. View a 3D animation of the project on the tunnelsonline channel on YouTube.

Plans for Washington station revealed

USA

A master plan to rebuild Washington Union Station, which includes improvements to a metro line and aims to increase capacity to accommodate future service expansion, was released last month.

America's government-owned passenger rail corporation Amtrak revealed the plan. Amtrak stated the improvements will accommodate three times as many passengers and twice as many trains.

The station serves the Metrorail's Red Line and phase four of the plan provides for further expanded tracks and platforms on a lower level, and the creation of a new Amtrak lower-level concourse. The works

involving the Red Line is planned to begin in 2028.

The approximate estimated cost for the plan is between USD 6.5bn and USD 7.5bn.

Phase one of the four stage plan, which involves improvements to existing concourse structures, will begin next year.

"Washington Union Station is an integral part of the Northeast transportation network, facing urgent capacity issues and a need to expand to support increasing ridership growth across all services," said Joe Boardman, Amtrak president and CEO. "This plan will transform the station into a world-class transportation hub to serve the region and the mobility needs of generations of passengers yet to come."

Lemay tunnel recovers from stall

USA

Work completed this summer on the stalled 16ft (4.88m) diameter tunnel feeding the Lemay Wastewater Treatment Plant, St Louis, Missouri. The 558ft (170m) long tunnel was halted in late 2010 when contractors encountered unexpected ground conditions, including tough rock.

A new contract was awarded to US-based trenchless specialist Sak Construction for USD 10.9M. Work began in December 2010 and completed 16 months later. The completed outfall sewer line is now in service, providing a new effluent discharge line from the

News in brief

Delhi Airport Metro delayed

The internal deadline for repairing the Express, which was shut down on 8 July 2012, has been pushed back from the end of August to mid-September. The reason for the rescheduling is the need for more rectification, sources told a local newspaper, along with the slow pace of work by Delhi Metro.

US museum gets TBM model

A model of the TBM for the Alaskan Way tunnel is now on display at the state's viaduct museum. At 10ft (3m) long, the replica is 1/35th the size of the machine that will arrive from Japan next year. The real machine will be 300ft (91.4m), 57ft (17.3m) in diameter and weigh 6,700t.

Venezuela metro planned

The Caracas metro extension scope will increase from 136km to 236km during the next seven years after boosting it from 45 to 136km since 1999.

Lemay Wastewater Treatment Plant to a structure on the west bank of the Mississippi.

A Sak Construction spokesman explained, "A tunnel boring machine excavated the tunnel to just over 11 feet (3.35m); crews then went in using non-explosive and explosive rock methods to further widen the tunnel to a 16-foot-diameter horseshoe shape to accommodate the installation of concrete pipe segments that were 12 feet (3.66m) long and 132in (3.35m) in diameter."

The project ran into an unknown and unmarked sanitary tunnel, which caused flooding during tunnel excavation and required the erection of a temporary bypass pumping operation. Black & Veatch designed the project.



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GRANDS PROJETS

European XFEL research project's tunnel system completes

GERMANY

Excavation has completed on a tunnel system that will house an X-ray research facility under Germany. Some 5.78km of tunnels were cut by two Herrenknecht TBMs. A 3.4km long tunnel, with an internal diameter of 5.3m, was cut at a depth of six to 38m. The overburden varies with the ground profile, as the tunnel remains horizontal.

At the eastern end of the tunnel a fan of smaller 4.6m diameter tunnels run to the main campus.

The European X-ray Free Electron Laser (XFEL) facility is

located near Hamburg in northern Germany. It will generate ultra-short X-ray flashes 27,000 times per second and with a brilliance that is a billion times higher than that of the best conventional X-ray radiation sources. Starting in 2015, it will open up completely new research opportunities for scientists and industrial users.

Using the X-ray flashes scientists will be able to map the atomic details of viruses, decipher the molecular composition of cells, take three dimensional images of the nanoworld, film chemical reactions and study processes such as those occurring deep

inside planets.

To generate the X-ray flashes, bunches of electrons will first be accelerated to high energies and then directed through special arrangements of magnets called undulators. In the process, the particles will emit radiation that is increasingly amplified until an extremely short and intense x-ray flash is finally created.

The small diameter tube system network at the end of the tunnel proved complex for engineers. The total of eight tunnel sections involved moving the TBM three times through a finished shaft and lifting it out of the shaft four times

for relocation. In order to keep the TBM directly on course over the route, Herrenknecht used a laser-guided navigation system from Vermessungstechnik.

"Tunnelling is one of the most difficult areas of the construction," said Dr Massimo Altarelli, CEO of European XFEL. He added, "We are delighted that this work is being completed on time."

The two 500t and 560t TBMs were used by Hochtief and Bilfinger Berger for excavating the tunnel system network. Operation of the two machines for the total distance of 5.78km took from July 2010 to the end of June 2012.

Abu Dhabi appoints pump station engineer

UAE

Abu Dhabi Sewerage Services Company (ADSSC) has appointed an engineering consultancy to provide contract administration and site overview

services for one of the world's largest underground pumping stations, located in the Emirate of Abu Dhabi, UAE.

Mott MacDonald won the project that is due to be completed towards the middle of 2015. The pumping station will be over 100m deep and approximately 40m in diameter and will have an ultimate peak pumping capacity of approximately 3.3M cu.m per day.

The cornerstone of this plan is the Strategic Tunnel Enhancement Programme (STEP). The focus of STEP is a deep 41km long tunnel sewer and several systems of link sewers that will collect and transport wastewater to a main



pumping station for onward treatment (see T&T February, page 37). At the downstream end of the deep tunnel an underground pumping station will be constructed to lift the sewage to the surface, and into newly constructed independent sewage treatment plants.

The pumping station will be housed in a large, deep structure at one end of the tunnel. The facility will also accommodate electrical and power generation facilities, operations and maintenance facilities, standby power fuel storage and pumping and a flow distribution facility.

Dry UAE is the third largest consumer of water in the world.

Marijuana metro tunnel shut down

ITALY

Police in Rome, Italy have closed down a cannabis factory in an abandoned metro tunnel. Built during the rule of dictator Benito-Mussolini in the 1930s, the tunnel is approximately 1km long and 7m below the surface level.

The factory was detected by the smell of its pungent crop wafting through an entrance near the Italian central bank. Some 900 plants were being cultivated and a total 340kg were seized with a street value of USD 3.7M.

The heat of the tunnel reportedly increased the potency of the fumes, and deployed sniffer dogs had to be pulled from the tunnel 'swooning'.

Local media reported the officer in charge of the raid said, "We wore masks when we entered to stop our heads spinning; I have

never seen anything like it."

The tunnel has not been in use since the end of WW2.

The factory was hidden behind a legitimate mushroom growing business at the entrance.

News in brief

Temporary lights in M4 tunnel to stay

Lighting installed in Newport's Brynglas Tunnels following a lorry fire in July 2011 will not be replaced until an extensive improvements programme begins, a freedom of information request revealed. The Welsh Government said that a contract has not yet been awarded for replacing the lighting in the westbound tunnel on the M4.

Amsterdam's oldest tunnel gets renovation

The IJtunnel is being renovated for USD 61.6M to meet with the new European tunnel safety criteria. The project is supervised by Ingenieursbureau Amsterdam.

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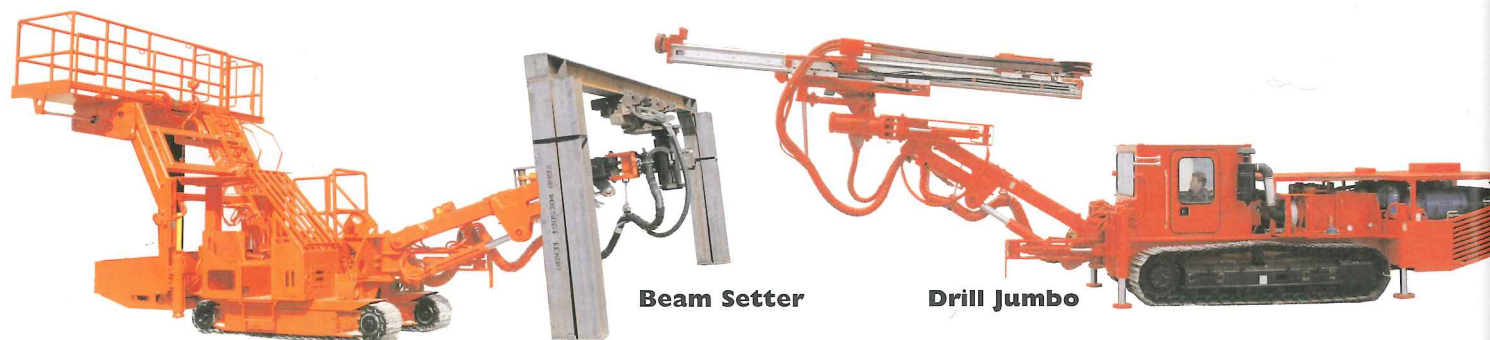
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SCL debate heats up

Dear Sirs,

"Traditional scientific method has always been at the very best, 20-20 hindsight. It is good for seeing where you've been. It is good for testing the truth of what you think you know, but it can't tell you where you ought to go, unless where you ought to go is a continuation of where you were going in the past," said R M Persig, in *Zen and the Art of Motorcycle Maintenance*.

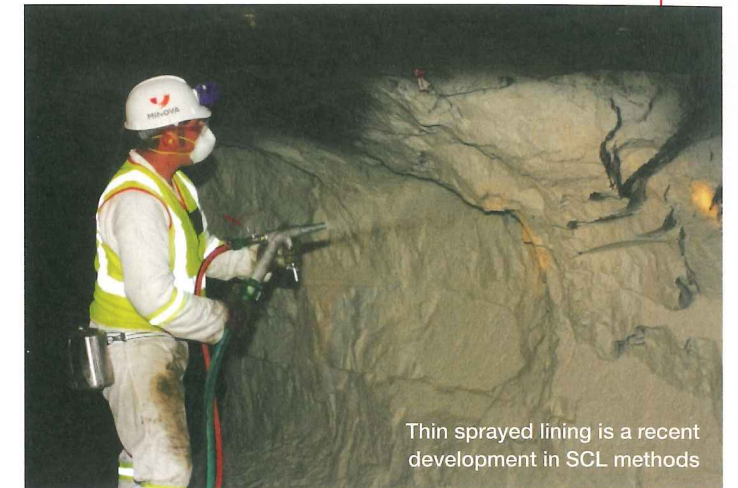
The article on sprayed concrete lining (SCL) by David Hindle (*T&T* August, p.46-47) reads as a cry from the heart over the development of the design and construction of soft ground tunnelling in UK in the past 20 years and calls for a debate on the way forward. To start the debate, I would ask whether our industry overdesigns as much as Hindle believes, or is current practice a successful local synthesis of the forces of globalisation? To answer, it is first worth trying to respond directly to Hindle's strap line question, i.e. what is the SCL? In my view, it is on one hand a subset of NATM that is applicable to urban soft ground regimes subjected to controlled safety requirements, and on the other hand it is a rebranding of NATM to allay public concerns following some notable failures. As to what NATM itself is, I would refer the reader to Part One of the UK Health and Safety Executive document on the Safety of New Austrian Tunnelling Method (NATM) tunnels, where a comprehensive attempt is made both to describe the meaning of the term and to outline the processes involved.

To provide a fuller response to the question there would need to be consideration as to how the simple, elegant, practical, adaptive, cost effective tunnelling method described by David ran up against a global environment that was looking for greater control over codification, contract, regulation, insurance, project management, societal risk, and

third party risk. Against this backdrop the method was producing major failure incidents worldwide that numbered 27 in the decade 1980/89, 31 in the decade 1990/99 and 23 in the decade 2000/2009. Urban tunnel failures in particular stood out, with spectacular surface cratering in Munich, Heathrow, Lausanne, Barcelona and Sao Paulo that led to demands that tunnelling engineers provide a greater emphasis on public safety and the reduction of construction risk.

Construction risk in soft ground tunnels therefore became an attempt by designers in UK to eliminate the variables that might result in failure mechanisms and this led to a bias in SCL towards high temporary loading conditions, near circular shapes and early closure of the ring. Reference to the article by Pickett and Stephenson also in August's *T&T* demonstrates the current position on temporary loading. Early closure of the ring should always be a priority, but results in an ambiguous approach to monitoring as, depending upon sequencing, the monitoring is more of a quality control (QC) function than for 'observational' requirements. QC of pre-designed in situ linings require checking for shape and thickness to confirm that they satisfy the specification, whilst the monitoring of the overall lining performance is required only to validate the pre-design and not to initiate design modifications. In other words the design is robust and is not a variable.

Clearly, the sequencing of SCL tunnelling is as important as the quantities and nature of the materials used, and this is a failure of marketing in the re-branding, and it will be interesting to see if the acronym has real durability. It is now 16-years-old! Hindle is correct to point to the adoption and development by UK contractors of new technology that has led to new sequencing arrangements for



Thin sprayed lining is a recent development in SCL methods

large diameter tunnels. One example would be the 'cods mouth' pilots and enlargements that were robotically driven at Kings Cross and which were straightforward and safe to construct. I have also seen, and can compare, a similar sized NATM drive using sidewall drifts that used lattice girder joints with extremely difficult connections and poor access for shotcreting. The removal of steel and girders from SCL can therefore lead to greater innovation in sequencing as well as the safety gain of removing miners from the build area. In addition, the substitution of fibres for strength and fire protection, used in conjunction with developments in composite linings and membrane performance (again see Pickett and Stephenson) should enable shell thicknesses to be reduced in future works. As for concrete supply and placement, it is self-evident that it will continue to be an issue for in situ work, but the risks are identified and understood and therefore their mitigation should be manageable.

I have some sympathy with Hindle's heretical view of the over-dependence on Finite Element Analysis in the clays of London, and would remind designers that they still need to have a separately derived set of likely outcomes before placing too much reliance on their FEA outputs. Having said that, there can be no doubt that the development of FEA to explore the behaviour of ground and linings, particularly in 3D, over the past decade has provided the designer with a powerful tool in his search for the optimum solution.

To sum up, it is my view that UK engineering has nurtured a method for soft ground tunnelling that is comfortable with its governance, but has room for on-going and future innovative developments to both plant and materials which should be regarded as a positive and balanced response to past problems. Whatever you want to call it.

Yours faithfully,

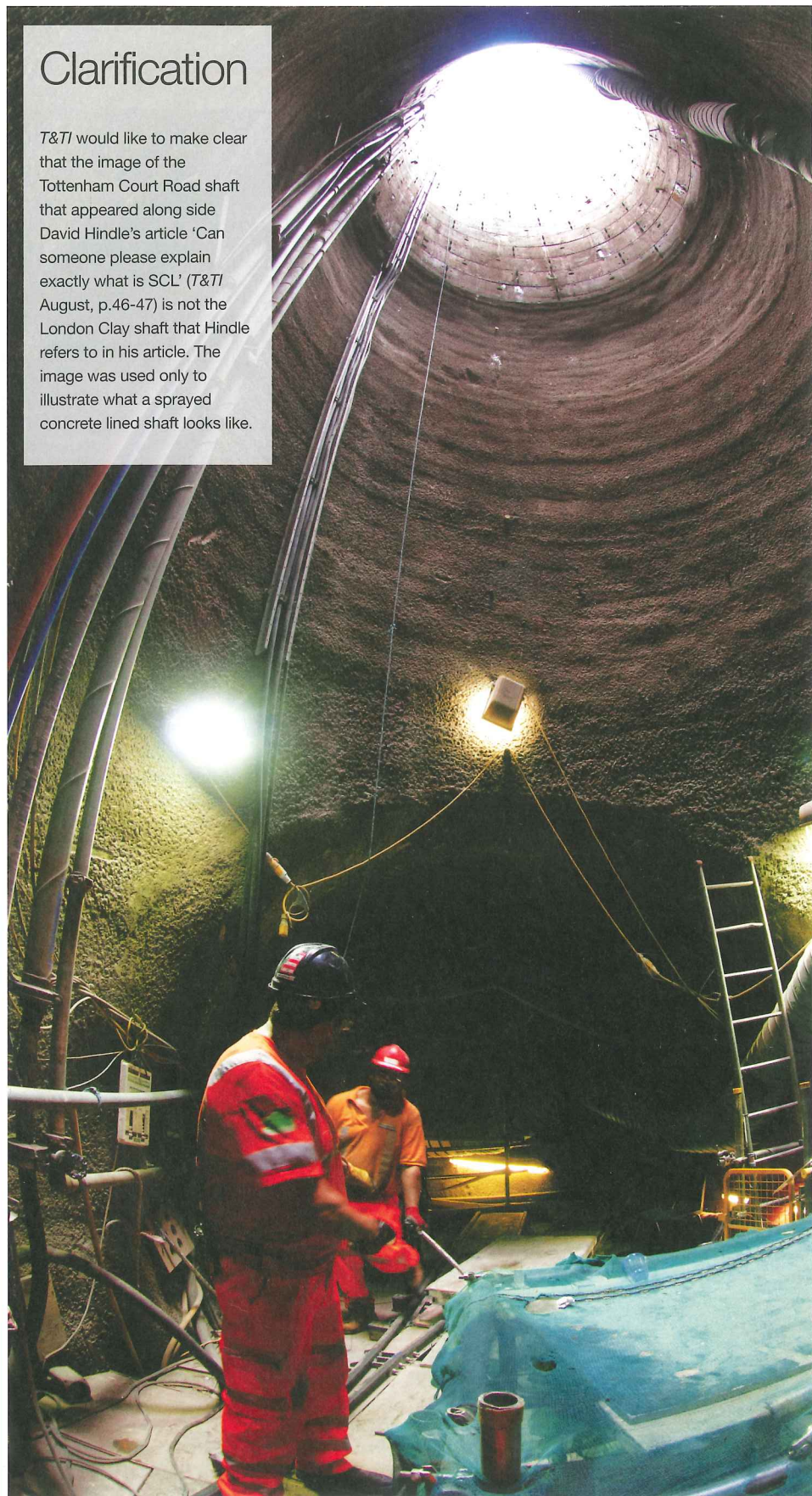
Guy Lance
BSc, CEng, MICE

References

Application of a database of unplanned tunnel construction incidents to promote safer construction and improve the perception of risk. G A Lance and J M Anderson. 4th International Conference on Forensic Engineering: From failure to understanding. ICE. December 2008.

Clarification

T&T would like to make clear that the image of the Tottenham Court Road shaft that appeared along side David Hindle's article 'Can someone please explain exactly what is SCL' (T&T August, p.46-47) is not the London Clay shaft that Hindle refers to in his article. The image was used only to illustrate what a sprayed concrete lined shaft looks like.



Hindle on firm ground

Dear Sirs,

Congratulations to David Hindle's paper (T&T August, p.46-47) which confirms my opinion that he is one of the rare (if not the only) British engineers who understands NATM and its principles - and maybe only British engineers are allowed to criticise sprayed concrete lining.

It may be a pretty cold comfort for British tunnellers that in Germany a similar tendency is evident, namely more and more high sophisticated structural analysis, resulting in thick shotcrete layers and heavy reinforcement, instead of understanding how to achieve a safe and economical structure.

Yours faithfully,

Wolfram Kagerer
Dipl-Ing, DGGT member, OGT member

SCL defined

Dear Sirs,

In response to David Hindle's article (T&T August, p.46-47), here is my definition:

An SCL tunnel is a tunnel with a sprayed concrete lining. The SCL interacts with the ground and, through the choice of excavation sequence, this interaction can be optimised to minimise the loads on the ground support. Monitoring is required for 'performance verification', to ensure that the tunnel is performing within the limits required by the design (given natural variations, for example, in advance rates and ground conditions), to determine when certain measures are needed (such as temporary inverts).

Yours faithfully,

Alun Thomas
BA, PhD, CEng, MICE

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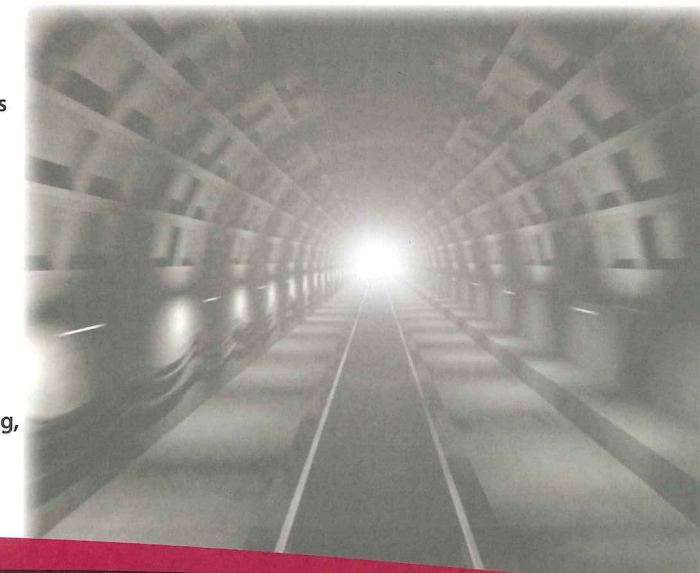
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Tunnelling in the Old World

Olivier Vion, executive director of the International Tunnelling Association (ITA) passionately defends tunnelling in an era of austerity as *T&T* looks into the market of Western Europe



Above: Olivier Vion of the ITA

Tunnelling in Western Europe is experiencing a slow down in 2011-2012. Over the last few decades, the tunnelling market has been globally constant with some better and some worse years, but with no real boom nor any real stop.

In fact this has been the case for the last 20 years since the construction of the Channel Tunnel. Since then, the tunnelling market has been growing steadily.

Of course, the first list of European Priority Projects (TEN-T) established in 1995 has been a starting point for many projects that include large tunnels all over Europe. Unfortunately some of the projects listed in 1995 are still in the design stage and their construction has been postponed many times.

Contributing factors

The main factors contributing positively to tunnelling projects in Europe are, on one hand, the move towards European integration, which can only be made through communication of people and goods and the awareness of climate change and the need of development of sustainable infrastructure.

This leads to new railway routes connecting European countries and the development of urban infrastructure such as metro systems, and also clean water, sewage and flood prevention infrastructure. All of which is mostly build underground. These structures are not only built in Asia but also in our 'Old Europe'.

In fact, the largest proportion of tunnels and underground space work in Europe is not for large projects that we hear about, but mainly for lengthening of metro networks, building sewage networks and constructing tunnels for all types of

commodities and utilities.

Of course the financial crisis has had some consequences on our market. But the 2008 and the 2011 crisis had opposite consequences. In 2008, in Spain for instance, the crisis affected private business, and mainly real estate so the government decided to emphasise public works construction in order to employ people previously working on building construction, so the tunnelling market was still very active between 2008 and the middle of 2010.

The 2011 crisis is affecting state finances, and one of the solutions to spend less is to halt projects. Tunnelling projects, which are often large, are the first to be stopped. Of course it is not always the end of the projects as for the moment the solution has generally been to just postpone parts of them.

Financial tightrope

Of course the financing structure chosen for these projects is one of the reasons they are targeted by the spending adjustments.

In Western Europe, except for the large NEAT projects in Switzerland, large projects need to be co-financed by the state, local regions, municipalities and eventually Europe. If one of these bodies is not able to finance its quota, the project is stopped.

It is what we are experiencing now in many countries.

The way chosen in Switzerland to finance NEAT (notably the Lotschberg and Gotthard tunnels) has been totally different, as they are financed from a separate budget with different sorts of incomes that have been secured from the beginning.

But the crisis doesn't mean that there are no works nor projects in Western Europe. The construction of the Sparvo tunnel (see

feature, page 20) in Italy is a good example as it is the largest EPBM (measuring at some 15.6m) in the world.

In Germany, the final decision and the beginning of the construction of the Stuttgart 21 project took place in the last month. This project is surely one of the most challenging in Europe. It combines a HSL and an urban project in order to allow downtown railway stations to cope with the arrival of HSL. Remodelling railway stations using the underground space is part of some of the most interesting projects across Europe.

Worth the wait?

Two of the most impressive TEN-T projects established in 1995 are still to be built. Both include large base tunnels: Brenner and Lyon-Turin. Why do these projects need such a long time before they reach the starting point? In my opinion, one of the main factors is that they are trans-national projects and as such are subject not only to one policy, but to two, both with different schedules and paces. Such projects are technically difficult, and are expensive, but the most difficult factor is that they need to be backed up by governments and local authorities. This is already difficult to achieve in one country, but even more so across two, as the priorities will not be the

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Above and left: Assembly of the Sparvo TBM by contractor Toto and manufacturer Herrenknecht at a section of the A1 Highway between Florence and Bologna, Italy

be more so in emerging countries, but also in western Europe, our challenge is sustainable development in urban areas. The global urban population will be multiply by two in the next 40 years. How we will be able to cope with this, and at the same time reduce global warming and cope with natural disasters is key.

It is clear to every one that one of the solutions is to make our cities denser. This can mean more skyscrapers, but maybe 'earth scrapers' using the underground space. One of the roles of the International Tunnelling Association (ITA) is to promote the use of it.

This means that we need to convince decision makers that the underground space exists, that it can be used and that in some cases it is the best choice.

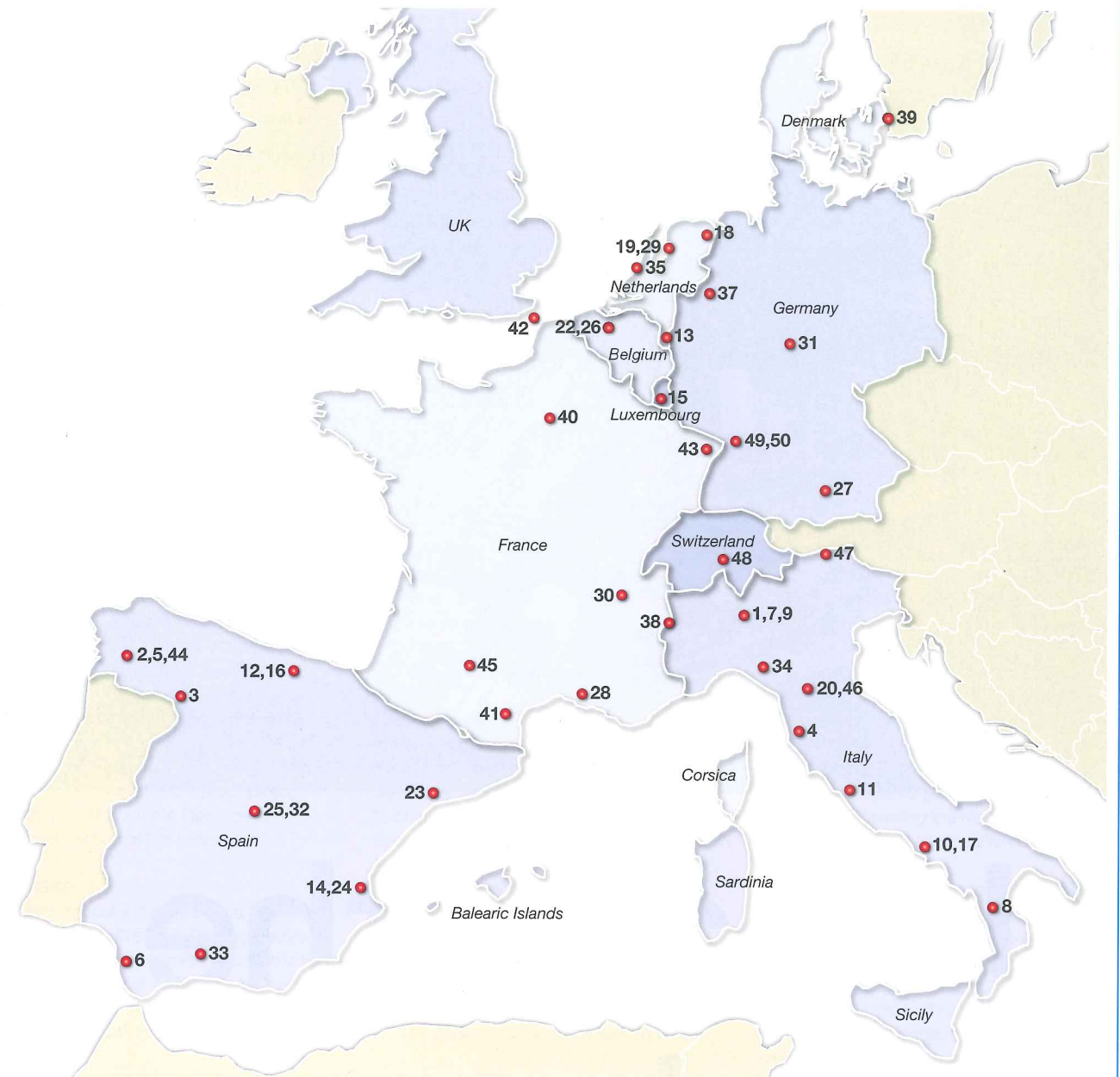
Of course, they will always reply that it is more costly, that could be the case or not, but it must not be studied separately. In

sustainable development, economics, social concerns and the environment cannot be studied separately. But of course the cost lead us back to the market.

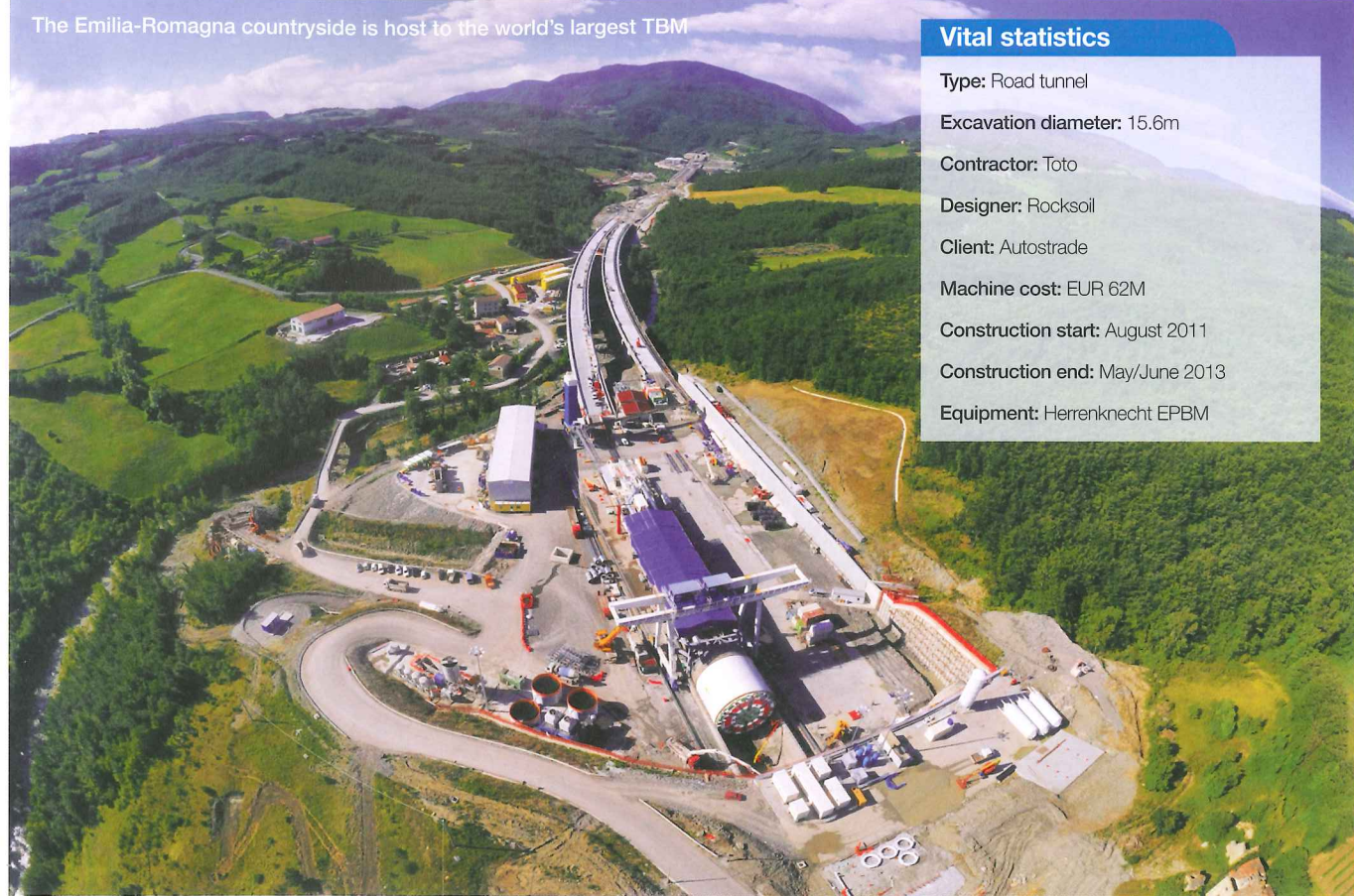
Big tunnelling projects are postponed because they are costly, and postponing one project saves quite a lot of money that can be spent in other projects that are in fact more costly, because they don't lead to a sustainable development.

We should think that in many European cities we are still building metro networks that began in the 19th century. The construction of the line four of the Budapest metro is a good example, as Budapest is the second oldest metro network in the world. How would we cope now, if people had not chosen to build a metro network in London, Paris, Berlin.

Building metro network, HSL, base tunnels, sewers; these are not costs, they are investments for the future. ▀



- | | | |
|--------------------------------------|--|---|
| 1) Rho to Linate airport road tunnel | 18) Delft rail tunnel | 35) Oude Maas road tunnel |
| 2) Tunnel de O Canizo, HSR | 19) Amsterdam Metro | 36) Das Maceiras-Vigo HSR tunnel |
| 3) Lubian HSR Tunel de la Canda | 20) Sparvo tunnel | 37) Lovenich glass road tunnel |
| 4) Grosseto-Siena road upgrade | 21) Perpignan to Figueras railway | 38) Mont d'Ambin base tunnel |
| 5) La Canda-Vilavella rail tunnel | 22) Brussels express network | 39) Copenhagen Metro |
| 6) Cadiz Port container terminal | 23) Barcelona Metro | 40) Paris Metro |
| 7) Milan Metro | 24) Lleida road development | 41) Perpignan to Figueras EHV line |
| 8) Cosenza highway | 25) Madrid Metro | 42) Channel Tunnel communications upgrade |
| 9) Brescia driverless metro | 26) Liefkenshoek rail development | 43) Saverre rail tunnel |
| 10) Naples Metro | 27) Garmisch street tunnel | 44) San Esteban II hydropower project |
| 11) Rome Metro | 28) Marseille Prado Sud road tunnel | 45) Toulouse Metro |
| 12) Bilbao Metro | 29) Zwolle rail station expansion | 46) Val di Sambro road tunnel |
| 13) A2 Maastricht tunnel | 30) Lyon Croix-Rousse road development | 47) Brenner base tunnel |
| 14) Mestalla stadium parking access | 31) Ebensfeld-Erfurt XRL | 48) Gotthard base tunnel |
| 15) Shafelter road tunnel | 32) Torrejon de Ardoz to Chamartin rail line | 49) Heslach road tunnel |
| 16) San Sebastian rail tunnel | 33) Quejigares rail tunnel | 50) Stuttgart 21 HSR |
| 17) A3 Salerno-Reggio motorway | 34) Marche-Umbria road | |



Vital statistics

Type: Road tunnel

Excavation diameter: 15.6m

Contractor: Toto

Designer: Rocksoil

Client: Autostrade

Machine cost: EUR 62M

Construction start: August 2011

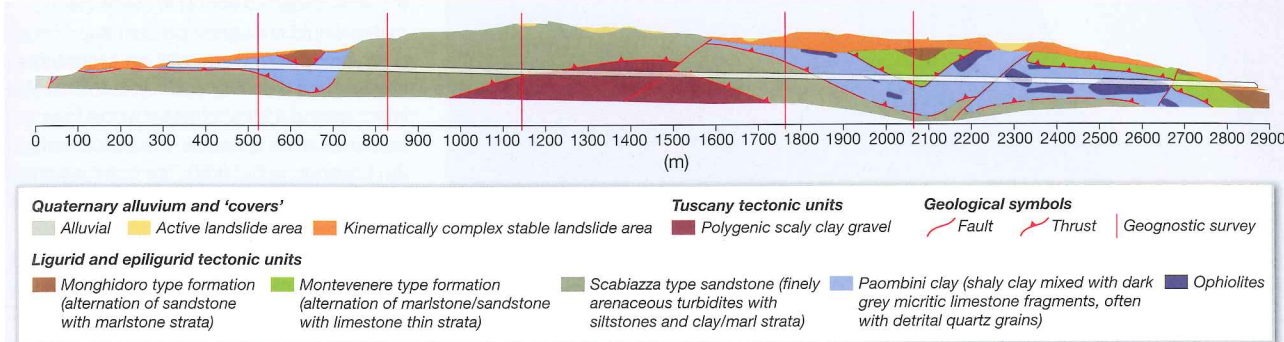
Construction end: May/June 2013

Equipment: Herrenknecht EPBM

The Emilia-Romagna countryside is host to the world's largest TBM

Unleash the beast

Italian contractor Toto Costruzioni Generali has had to overcome an excavation chamber clogged for months with clay, an inefficient approach specified in the tender, and the strain of leaving the site's gourmet canteen each day. Alex Conacher visits Bologna in the heat of early summer to meet Toto project manager Lorenzo Scolavino and his assistant engineers: Maurizio Pepino and Gianluca Comin, both environmental engineers specialising in mechanised shield excavation from Politecnico di Torino



Above: Figure 1, geological profile

Nestled in the Apennine Mountains, in the Emilia-Romagna region of northern Italy, the world's largest TBM is chewing through the local clays.

The area's smaller roads curve around medieval villages squatting on small but steep hills. The retired owner of a bell tower hurries out of his garden to show T&T the shell from an Allied tank that passed through during WW2.

Client Autostrada is responsible for Italy's motorway network, and is bankrolling a secondary route through the hills and mountains to relieve traffic pressure on the A1, known as the motorway of the sun.

Italian contractor Toto will execute the majority of tunnelling works on lots six and seven of this 'Variante di Valico' project, which is located on the Florence to Bologna section of the motorway.

The site

The site is located between two tunnels along the new diversion. Cutting away to the south, and towards Florence is the twin tube Sparvo tunnel, excavated by the 15.615m Herrenknecht EPBM, named Martina after Toto founder Carlo Toto's

granddaughter, who was born as the company completed TBM purchase.

Sparvo's north tube, almost completely excavated as T&T visits site in July, runs for 2,564m while the south tube will run for some 2,600m.

The neighbouring twin tunnel, 'Galleria Val di Sambro' heads northwards towards Bologna and is excavated by traditional methods; excavator with pneumatic hammers, and supported by steel ribs. The south bore of this tunnel runs for 2,995.5m while the north runs for 3,008m. Both twin tunnels will be linked by viaduct.

Out with the old

Sparvo tunnel was originally specified to be excavated by traditional methods, in the same way as Val di Sambro. The decision to change was an economical one, according to Toto assistant engineers Maurizio Pepino and Gianluca Comin. This is because progress on Val di Sambro has been incredibly slow.

Pepino adds, "It was especially bad in the beginning for Val di Sambro as we excavated the beginning inside a large landslide.

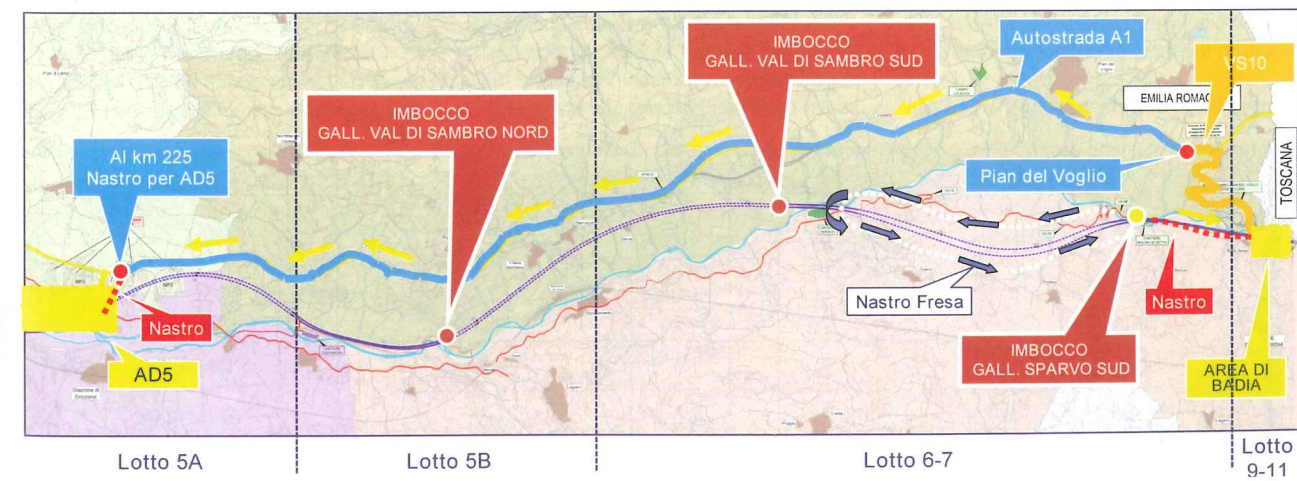
"The geology is very complex on Val di

Sambro, and although the tubes are only separated by 50-70m, the face is completely different. One is in limestone rock while the other is in poor soil and completely chaotic, we are facing different conditions metre by metre. The Sparvo geology is also complex and we have encountered highly variable face conditions: massive and stable claystone, swelling clay, medium and highly fractured sandstone, hard and abrasive ophiolites/serpentinites. However a clay matrix was always in place in each face as filler in discontinuities or among blocks."

The difficult conditions meant that client Autostrada was persuaded to allow Toto to excavate the Sparvo galleries with an EPBM. This, following the resolution of the clogging issues, will see Sparvo complete before Val di Sambro.

"This is probably the biggest concern for us," says Toto project manager Scolavino. "Excavation began on the Val di Sambro project in February 2010, and up to now [July] we are about 700m in. CMB is excavating from the other end of the tubes to meet us in the middle, they started some time earlier and are 1km in. We hope to finish by 2014.

Below: Figure 2, the tunnel locations relative to the work site





Above: Methane warning system at the lowest alert level, for normal running

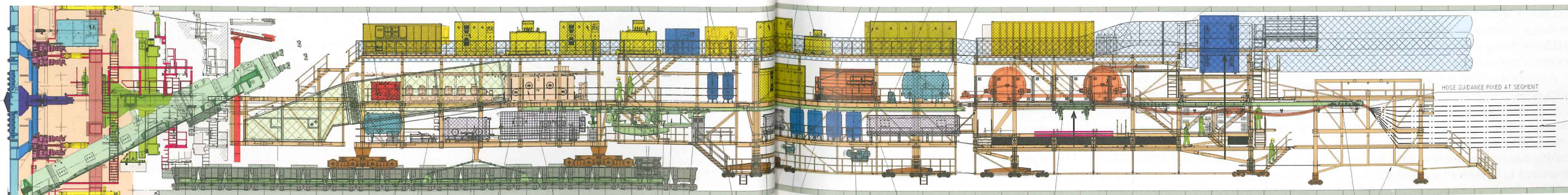
"Excavation on Sparvo began in August 2011 and will finish around May/June 2013. It's incredible because the ground is actually better for tunnelling in Val di Sambro. But it is this drive that will be the key to finishing close to schedule, Val di Sambro constrains completion and when finished will see the opening of the full Variante di Valico scheme."

Scolavino adds, "The price with which we won the tender was very low, and there is a lot of risk for us from this point of view. Although Sparvo will not finish quite on time - the north tunnel should have completed in June, and we are behind due to the clogging and an injury shutdown - Val di Sambro is the most likely to cause serious delays to the project."

The importance of conditioning

Tweaks to the conditioning system have solved early problems with machine clogging. "From the start of the Sparvo drive in August until October [2011] we had 20 lines of foam to condition the material," says Comin. "This consisted of 15 lines directly to the face, three lines into the

Below: Figure 3, Side view of the EPBM



centre of the excavation chamber and two lines into the screw conveyor.

"This resulted in the tragic clogging issues we experienced halfway through October. The absence of water in the central part of the excavation chamber caused a complete cementation of the clay, jamming the machine and causing a shutdown. The damage on the sealing system of the main bearing took two months to solve, resulting in around 60 days of jobsite standstill.

"Back in October we were also excavating a particularly adhesive clay. So through a collaboration between BASF Meyco (the foam agent supplier) and machine manufacturer Herrenknecht we added six lines of pure water, three into the centre of the chamber and three to the outer part. We also moved one of the foam lines from the screw conveyor to the centre of the excavation chamber.

"This lasted until January. By this time it had become apparent that the muck was too liquid for transportation and storage.

"For the final configuration the three water lines that were directed to the outer part of the excavation chamber were moved to the central part, supplementing

the lines already there. This made the material fluid enough to prevent any clogging problems and with an acceptable consistency to be transported in trucks. We inject around 120m³ of water to the face and excavation chamber in total for each 2m advance, split 50/50. The foam agent forms around 2.5 per cent of the total injected quantity on the face.

"In addition, the excavated material in this 2m advance is 390m³. Our specific volume weight is 2.2 or 2.3t/m³ so this is more or less 900t per advance/excavation.

"The muck was no longer too liquid. The pilot has been able to manage the conditions. Of course, this is after spending two months clogged. It was necessary to totally change the sealing system of the main drive. We also had to remove the material in the excavation chamber with a pneumatic hammer."

The team points out that conditions have varied and that these are only average values, at one point they injected 160m³.

Scolavino adds, "With this finalised system in place and increased experience with the machine, the south drive will surely be much quicker."

Gas provision

In addition to adhesive clay the Apennines are loaded with 'grissou', or firedamp in English - a mixture of flammable and explosive gases, particularly methane. "It is a big problem," says Scolavino, "but no secret, the TBM was designed to cope. The belt conveyor is sealed within its own tube to prevent the gas escaping, and there is an array of sensors and monitoring equipment to ensure the gas does not build up.

"The machine cost was very high, at EUR 62M (USD 77M) and the presence of gas was known, and this guided the design. For each shift there is a man to control and monitor the gas, this is subcontracted to Collins, a company that specialises in this. There are 10 monitors in each section with double redundancy, and the TBM's power is shut down if the methane ever exceeds a limit value."

Comin adds, "The limit varies in each section, with a strict value of 0.35 per cent in the shield, and three per cent in the tunnel. However if the gas gets above one per cent in the tunnel, the pilot has to decrease advance speed, and if this is not done the machine stops automatically. The explosive limit of methane is five per cent."

Scolavino continues, "There is a traffic light-style warning system of green, blue, yellow and then red. Red means evacuate. The belt conveyor tube itself has a double layer casing that is overpressurised so that if there is a hole, the pressure can stop the gas. There is also a special ventilation duct into the tube. The pilot can increase the airflow to about 25m³/s.

Martina the monster

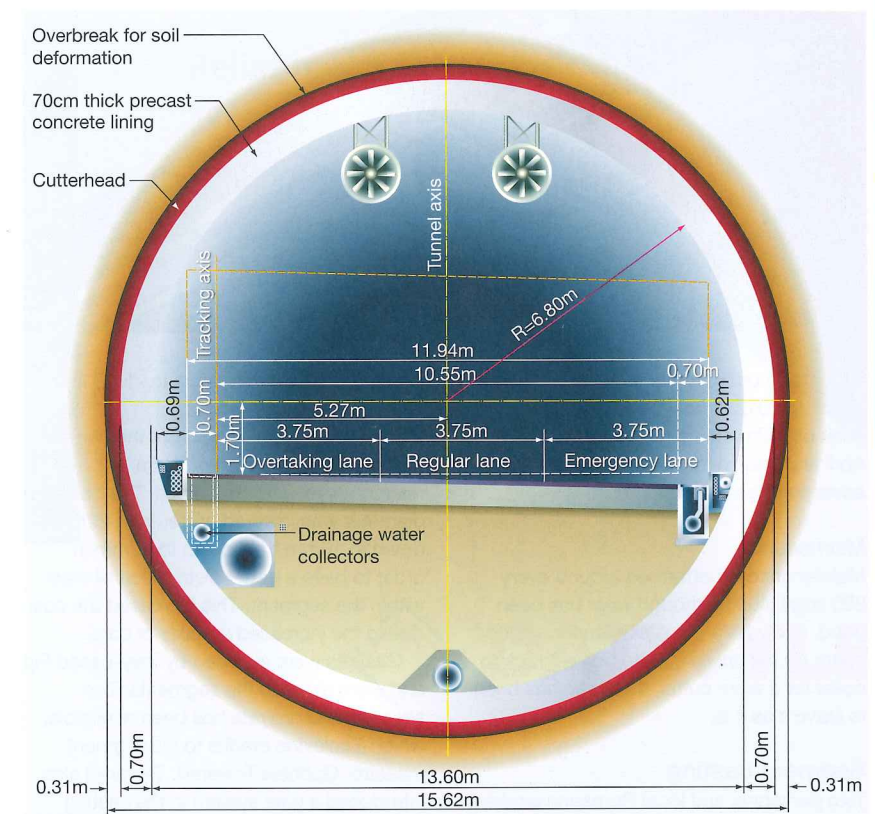
Besides a new belt conveyor tube style to deal with gas, the sheer scale of the project's TBM is not unknown to the industry. At 15.615m in diameter, it was the world's largest TBM at the time of manufacture and also one of the most powerful. Installed power is 12MW, maximum thrust force is 394,850kN at 500 bar, cutting wheel torque is 94,793kNm and total weight is 4,500t.

It is equipped with 76 disc cutters of 17-inch diameter, 216 cutting knives, 24 buckets and one centre knife, a setup to deal with the expected geology of clay with argillite and sandstone.

Pepino adds, "The size of the machine has made working in the tunnel totally different. It is much more comfortable. In most TBMs space is very limited but not here, each workman can fulfill his task in a perfect environment."

The site runs eight-hour shifts, with fifteen workers per shift.

The shield was also designed with a conical shape - with the excavation diameter larger than the rear shield diameter. This was due to fears of squeezing ground according to Comin. "It is 15.615m at the cutting wheel but the rear shield is approximately 15.3m. There is a 300mm annular void, so it is necessary to



inject 30m³ of grout to fill the gap. The project value for injected grout is 29.5m³ in a 2m advance."

The Rheosil 143 foam agent was provided by BASF, Mapei supplied the component grout and Condat the tailskin grease. "In clays where we encountered swelling, we had to talk with the designer, Rocksoil to accept less grout injection. In places it has been reduced to 22m³, so there has been a convergence of the tunnel around the shield and final lining of 50 or 60mm at the maximum."

The TBM is linked to a transforming plant near the Florence portal that is itself connected directly to the Italian high-speed rail network. Some 18MW are available, total installed power is 16.8MW, and as of July, 11MW was the maximum power used for excavation, ring build and all normal

Above: Figure 4, tunnel cross section

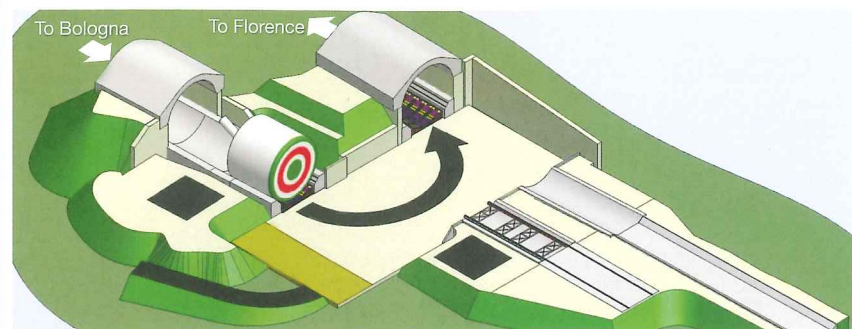
TBM operations. There are 38 hydraulic motors to rotate the cutting wheel, but the machine can fit up to 50.

Scolavino adds, "Although there is no way to run the TBM if this link is interrupted, it is a national line so we have never had this problem. The connecting line is 132kV and was realised especially for our work. The line has to run approximately 10km across mountains and through forests. We actually had to lay foundations for the transformer plant by helicopter."

Annual power use is 62,000,000kWh, equivalent to a town with a population of 20,000 people.

Performance

In terms of advance rates, Toto managed to



hit a maximum monthly production of 406m in March 2012. It has also seen a week peak of 122m during the week ending 22 April and has on three occasions hit 22m advance rates in a day.

Maintenance

Maintenance is performed around every 200 rings (400m), though wear has been good, and where there is at least one good cutter on the specific cutter wheel track to cover for a worn cutter, the tactic has been to leave it as it is.

Segment casting

Toto personnel and local Romagna workers cast the segments on site. With the largest machine in the world, comes the largest precast lining.

The universal ring is a nine plus key arrangement with a total ring weight of 160t. The segment length in the direction of the machine advance is 2m and the thickness is 0.7m. Scolavino adds, "Perfect workmanship along the production chain is needed for this; at the point of casting, transportation, stacking and placement.

"The thickness has been connected to a series of difficulties, for example the curing process. The tolerance is also very strict, we check this manually by micrometer, and every two to three months, our guidance company VMT also comes to check the Aeroform moulds by laser. The Aeroform moulds are the most expensive, but they have the highest performance."

Bar reinforcement is used, with 110kg used per m³ of concrete. According to Scolavino, special studies were conducted to design the steel reinforcement to avoid fractures during positioning, due to the weight of the concrete.

A carousel system is in use in the casting yard with four series of 10 moulds (10 moulds to a ring). The design production is 80 segments per day, and the factory works 24 hours a day, six days a week. A baking oven/curing chamber allows segments to be demoulded after 80 minutes. The system has been effective

even in temperatures down to -14°C in the winter, with 2.5m of snow.

There are no polyfibres, but the corners of the segments are given extra reinforcement with wire mesh. The bar diameter was lowered twice, from 22mm down to 16mm then down to 12mm in order to have a better distribution of steel within the segment. This increased the cost due to the increased number of bars.

Gaskets were supplied by Italy-based Fip and were glued to the segments. The segment discard rate has been negligible, which Scolavino credits to his segment maestro, Gabriele Trovarelli. Trovarelli also introduced a gate system in the casting yard, where the carousel will only move if all of the gates are closed between the workers and the moulds, greatly reducing the risk of injury.

Turning the TBM

The north and south drives are excavated by the same machine. But with such an enormous TBM, and a small area to turn, an experimental manoeuvre is needed to 'rototranslate' Martina to face the southern drive. The first 20m have already been excavated and lined with steel ribs and sprayed concrete. Design was by Toto and Rocksoil, the sprayed concrete machine is CIFA-manufactured and was also used on the Val di Sambro part of the project.

The process is much like the Tower of Hanoi puzzle. The portions must be shifted through the prepared bays opposite the portals and rejoined in the correct order ready for the southern bore. First the shield will be moved, then the first gantry, then the second, which will need to be moved behind the first and then the two moved behind the shield.

The machine sections will be positioned on special Palmieri metallic cradles, and raised by 80 'Aero-Caster' air pillows manufactured by Aerogo Systems. Toto, working with Palmieri, the company also supplying TBM cutters, will do the move.

A test to carry half the required load was carried out at the Palmieri factory relatively

Left: Figure 5, TBM rototranslation

close to the site, which was successful and it was decided to use five cradles to move the TBM. The test area was not ideal however, as there was a joint in the floor which allowed the air to escape and the pressure to disappear. As T&T visited site, Toto was busy casting an incredibly flat concrete floor for the operation, which has a tolerance of a 1mm variation over a metre. This will ensure there is no loss of air pressure during the transition of the EUR 62M (USD 77M) piece of kit. The move will take three months to fully rotate and set up the TBM following the breakthrough at the end of the northern drive on 25 July. The cutterhead was due to be in position for the south drive in August.

Comin adds, "We will commence the south drive around the beginning of November. We also have to assemble the steel launch portal, then disassemble and remount the vertical conveyors, move the ventilation system, install another series of conveyors and two new hoppers."

Conveyors and muck

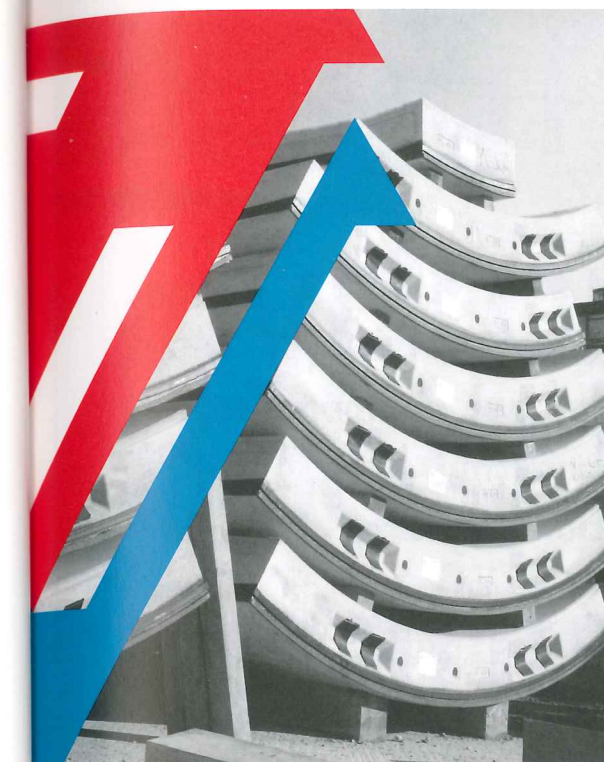
Marti supplied the project's conveyor system, with vertical storage by H+E Logistik. Once on the south bore, the conveyor system will feed back through the north tunnel to the original system.

The conveyor distributes muck between five storage areas of 5,000m² ground space each and 20,000 to 40,000m³ of total storage, depending on the height of the heap. The divisions are for chemical tests for oil, grease and so on. Once the muck is definitely clean, it can be moved on. A hopper moved between the storage areas.

The muck is combined with lime to eliminate excess water in the material and give a good consistency. Early on in the excavation, the initially selected SLF 41 foaming agent was not working and when the conditioning system was being fine-tuned the material was too wet. This meant it was difficult to store and impossible to transport. The team adds that there was a risk of days of standstill due to the liquidity.

The material will be used for environmental improvements, creating gardens and so on. But the storage on site faces restrictions also. A nearby river is incredibly pure and feeds Bologna's aqueducts. There are 10 enormous water treatment plants to avoid dust contamination in the summer.

Scolavino finishes, "Special mention should go to TBM chief Ulisse Beozzo. Apart from that, there is a prize to finish this job on time, and we will still try to get it." ■



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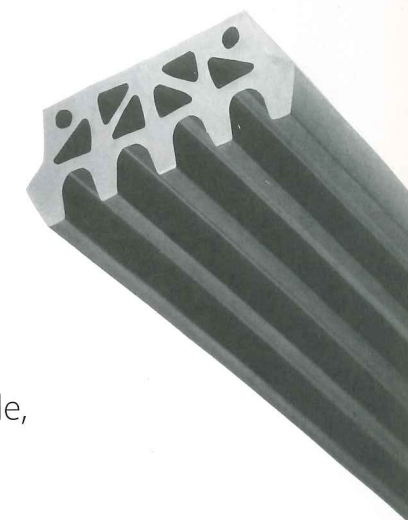
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N.T.A. – Metropolitan Mass Transit System Ltd.
Tender No. 017/2012 – Pre-Qualification

For the Design-Build of NATM Tunnels for the Tel-Aviv LRT Red Line Project (the "Tender")

Following the Invitation for Pre-Qualification in relation to the design and construction of NATM Tunnels for the Red Line Project published by N.T.A. – Metropolitan Mass Transit System Ltd. ("NTA") on June 21st, 2012, NTA amended several Pre-Qualification Requirements. For further information please refer to Addendum no. 2 published on NTA's website at: <http://www.nta.co.il/site/en/neta.asp?pi=464>.

Itzhak Zuchman
CEO
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Hydropower boost for sleepy Spanish region

The San Esteban II hydropower project nears completion in northwest Spain. Contractor Ossa gives this snapshot report of tunnelling conditions on site



Inland Galicia, an autonomous 'nationality' in northwest Spain is dependent on the agricultural industry for its economy. In Ourense, one of more densely populated provinces in the sleepily growing nationality, work has begun to upgrade the 57 year old San Esteban Hydropower Plant.

A new 176MW Francis turbine generator will supplement the four 66MW Francis turbines that have been installed on site since 1955 and generating power since 1956. Works are nearly complete, with a 8,754mm Voith-Siemens rotor installed in the turbine shaft on 2 May.

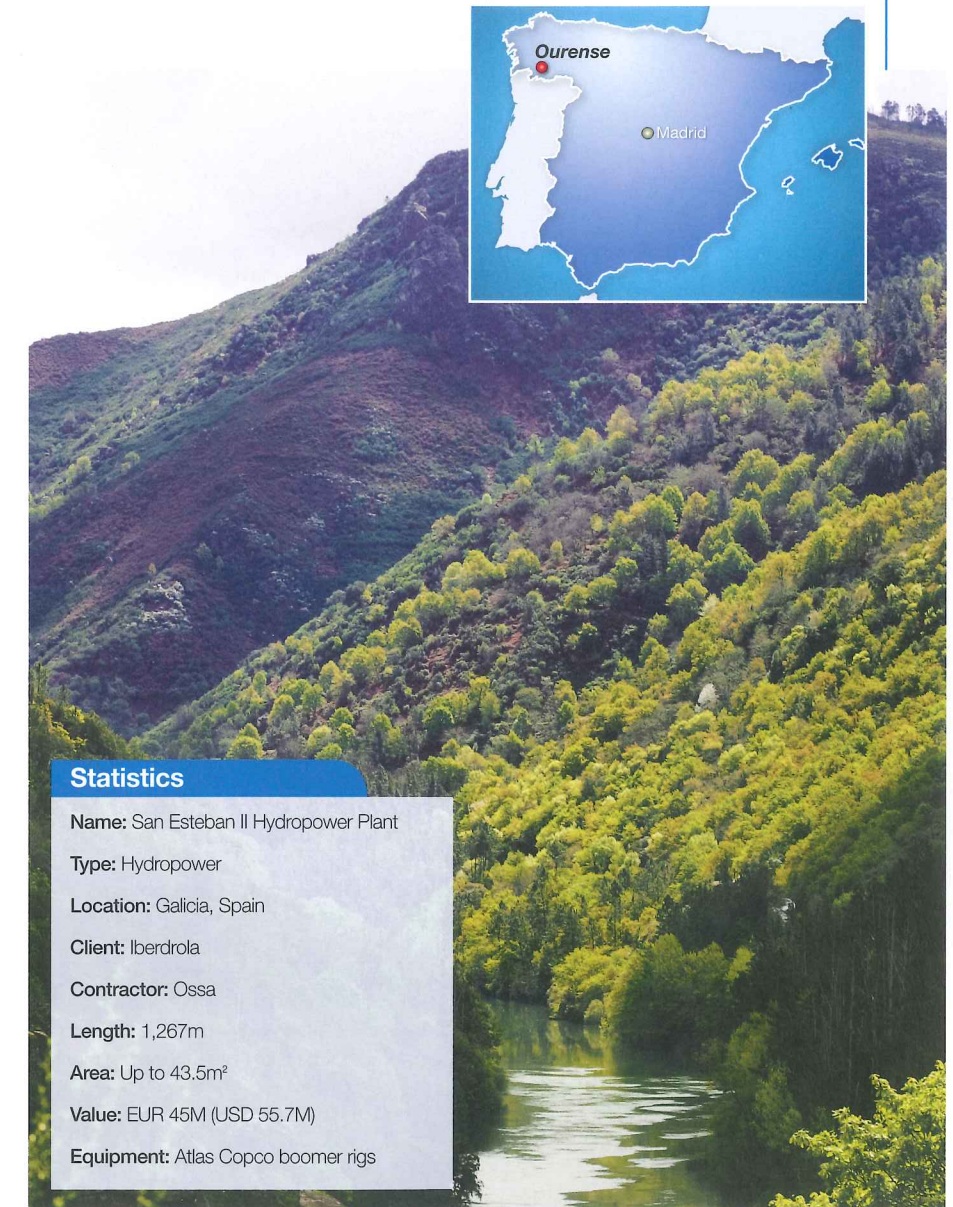
The plant is scheduled to be operational from the end of November.

The plan

The San Esteban II Hydropower Project aims to increase the power capacity of this head by constructing a new underground plant, located within the rock mass supporting the left side of the dam.

The plant operator, Spain-based privately owned multinational electric utility company, Iberdrola, contracted Ossa, a sixty year old Spanish contractor that originally focused on mine construction, to undertake tunnelling works.

The value of the works is approximately EUR 45M and the starting date for



Statistics

Name: San Esteban II Hydropower Plant

Type: Hydropower

Location: Galicia, Spain

Client: Iberdrola

Contractor: Ossa

Length: 1,267m

Area: Up to 43.5m²

Value: EUR 45M (USD 55.7M)

Equipment: Atlas Copco boomer rigs

WIDEN TUNNELS WITHOUT INTERRUPTING TRAFFIC !

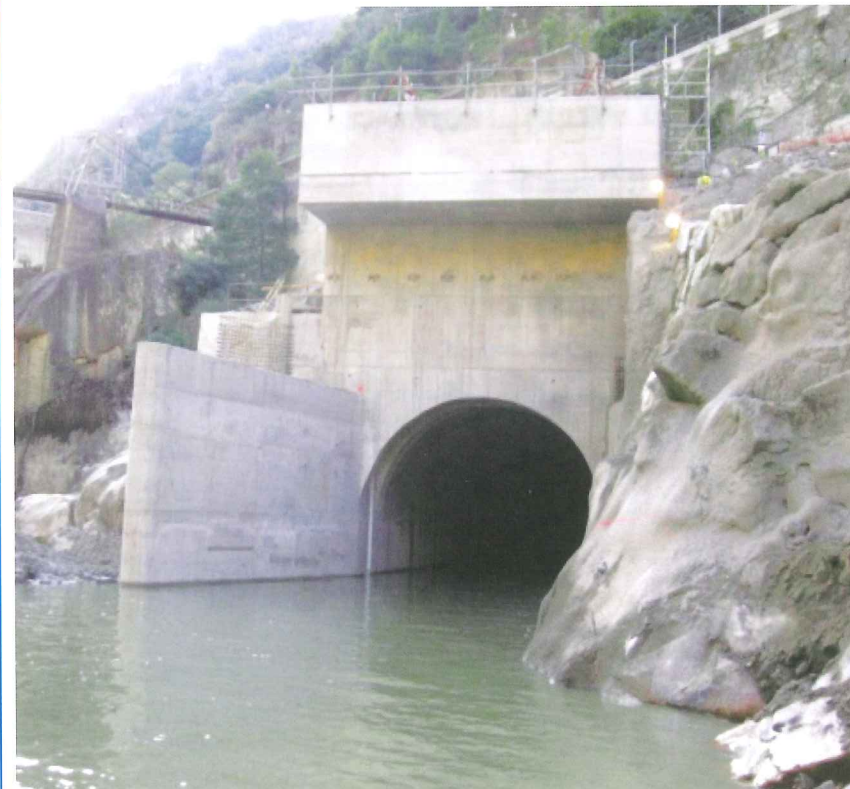
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Above: Protective concrete cofferdam on San Esteban II project

construction was August 2008.

Works required

The main work required for the project is the excavation of the power and transformer caverns as well as the cavern and shaft for the intake gates. The works also call for the construction of the whole hydrological circuit for the power plant expansion, including both the intake and outlet structures.

Dimensions and bearing

Some 12 galleries, allowing for all access, auxiliary works, communication and exploratory/reconnaissance testing are being excavated, amounting to a total of 1,267m of tunnelling, with section areas ranging from 8.4 to 43.5m².

The value of all civil and associated civils work is approximately EUR 45M (USD 55.7M) and work began in August 2008 following the contract award and are due to complete imminently as T&T goes to press.

Equipment used

For the majority of the civil engineering work, the construction plant used was an Atlas Copco Rocket and Atlas Copco Boomer two-boom jumbos with and without basket as well as a Putzmeister concrete spraying Robojet; pilot drill; 2.4m-

diameter reamer; raise borer and a Brokk 400 drilling excavator.

Thinking geologically

Excavation methods and materials

The excavations have been carried out in terrain consisting of granite with varying degrees of weathering and fracturing. For the majority, drill and blasting has been employed, using different types of supports, sprayed concrete, rock bolts of various lengths and diameters, and in places the occasional use of metal trusses.

The use of explosives, given the proximity to a dam, a hydropower plant and also an external transformer yard, has faced keeping a strict check on the vibrations produced by the blasting, and adapting the firing plans to the nature of the rock, so as to minimise the effects on the existing facilities.

Quality and investigation results

Regarding the quality of the rock mass, the excavations that were carried out during the construction of the hydropower plant have been conducted in two quite distinct lithotypes: two-mica granite, and dykes of a diabasic nature.

In general, the quality of the granite rock mass has varied widely. The RMR index

values range from 40 to 70, while the Q quality index gives values of between 0.5 and 20. The bedrock compression resistance tests show variable results from 35 to 105MPa.

During the construction of the San Esteban project, four dykes and one sill of diabasic rock have been intercepted. The RMR of the dykes varied between 30 and 40 (poor to fair quality), while Barton's Q index gave values ranging from 0.2 to 1.5 (very poor to poor quality).

In view of these geomechanical classifications it proved necessary to apply special treatments in the sections of galleries and/or waterways excavated in this lithotype.

According to simple compression tests, carried out during the geotechnical investigation stage in November 2007, the simple compression resistance of the intact rock ranges from five to 53MPa.

The level of seepage recorded in the underground circuit at San Esteban II is low but very sensitive to precipitation. The thaw and the torrential rain during February and March 2010 increased the number and quantity of such upwellings.

Nature's own cofferdam

One of the challenges was the construction of the discharge structure. The San Pedro and San Esteban reservoirs are respectively downstream and upstream of the structure. Construction works necessarily affected the normal use of both reservoirs, as it was necessary to maintain maximum reserves in San Esteban and keep the level low in San Pedro. Moreover, the level of the river between the two reservoirs had to be kept to a minimum, with the resulting negative environmental impact of low water levels.

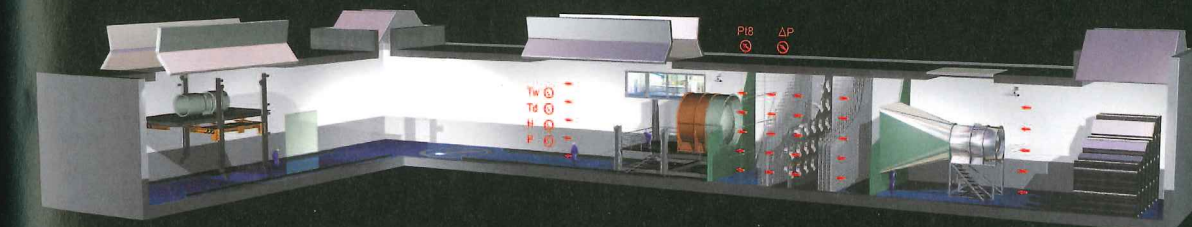
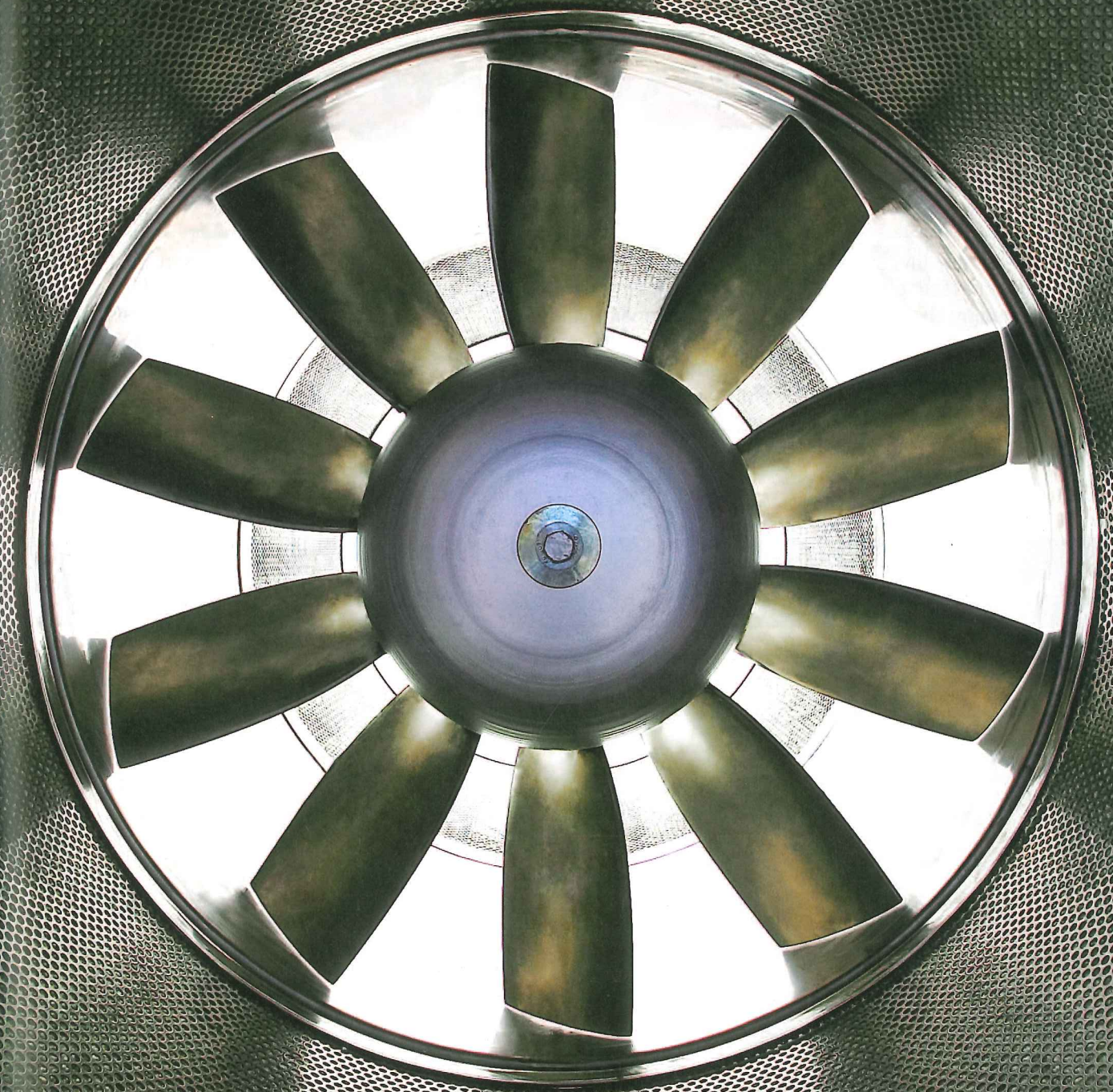
In order to minimise the duration of this disruption, the construction methodology planned for the project was substantially modified. This made it necessary to lower the river level in two stages, since the works were to last longer than the maximum permitted period for a 'watercourse at environmental flow' (minimum approved flow).

The solution involved carrying out the excavation for the site by the open cut method, keeping some of the terrain initially unexcavated as a barrier against possible water inflow.

This made it possible for civil engineering work to proceed, benefiting from the protection of this natural cofferdam, without affecting the river, and to complete the remaining excavation and the discharge channel in a one-stage operation with the watercourse at environmental flow. ▀



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NTA - Israel Metropolitan Mass Transit System Ltd
Tender No. 060/2011 – Pre-Qualification Requirements

For the design, supply, construction, installation, integration, testing and commissioning of Systems – Depot – At Grade (SDAG) for the Red Line Project

Following the Invitation for Pre-Qualification in relation to the design, supply, construction, installation, integration, testing and commissioning of the Systems – Depot – At Grade (SDAG) for the Red Line Project published by N.T.A. – Metropolitan Mass Transit System Ltd. ("NTA") on June 28th, 2012, NTA amended the Pre-Qualification Requirements so that one of the requirements regarding the Civil Engineering Experience was cancelled and the Financial Pre-Qualification Requirements regarding the Integrator were amended. For further information please refer to Addendum 3 published on NTA's website at: <http://www.nta.co.il/site/en/neta.asp?pi=464>.

Itzhak Zuchman
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N.T.A. – Metropolitan Mass Transit System Ltd.

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ASHKENAZY ZALSMAN / BSB



Bilbao metro line two gets support

An in depth look at the varying support systems used on the Ariz Basauri section of Bilbao metro line two and how the methods reacted to the changing ground conditions. Spanish contractor for the project Ossa gives this report

The Ariz-Basauri stretch of Bilbao's metro forms the end of Line Two, and was constructed as part of project's fourth phase.

There are two stations constructed in this section, Ariz and Basauri, located at the focal points of the population centres in the municipality of Basauri.

Each of them has two entrances, as is standard in Bilbao metro stations.

The substantial differences between the entrances in terms of length and vertical level are due to the orography of the municipality, the urban spread of which extends up the slope mountain on its southern side.

The longitudinal profile, in turn, is designed to bring the stations closer to the surface, bearing in mind geological constraints, so as to reduce the length and difference in level of the entrances and avoid giving the public the feeling of being stifled underground.

Scope

The EUR 66.86M (USD 82.7M) section of line in Ariz-Basauri is 2,372m long, with the tightest curve having a radius of 250m. The maximum gradient is 5.5 per cent to span paleo-thalweg and pass below an existing rail trench. The cross sections of the tunnels are 57m² for straight running

tunnels and 62m² on a curve. Station caverns are 188m². Work began in December 2006 and was completed in November 2011.

Parties

The Department of Transport and Public Works of the Basque Regional Government is the client, and awarded the project to contractor Ossa. Euroconsult is the



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The San Anton Bridge in Bilbao



Vital statistics

Name: Bilbao Metro Line Two Ariz-Basauri
Type: Metro
Length: 2,372m
Section: 57 or 62m²
Value: EUR 66.86M (USD 82.7M)



Roadheader excavation

contractor's consultant, with Boma as architect and In Situ handling electrical tomography.

Excavation

The excavation and support works were carried out using NATM, with a heavy roadheader and an Atlas Copco two boom jumbo with baskets.

All this was divided into two phases, top heading (2/3 of the total surface) and bench excavation (bottom 1/3 of the surface). In this respect special treatment was applied in specific areas described in the course of this report: paleo-thalweg and the underpass below the Adif rail trench.

Geology and investigations

As a general guide, it is a karst area with filled-in paleo-thalweg. The Ariz-Basauri section is the eastern end of Line Two. Apart from a short initial at grade stretch, its entire route runs underground beneath the

built-up area of Basauri.

During execution, three Cretaceous sedimentary formations each with different geotechnical behaviours have been excavated: marls and marly limestones (known locally as cayuelas); bioclastic limestones of the Arraiz Formation and calcareous sandstones with calcareous siltstones of the Ereza Formation. Of these three lithotypes, the last two have not been commonly found during the execution of either Line One and Two of the metro.

In the round of investigations carried out for the 1989 Civil Engineering Plan, an area of paleo-thalweg was detected roughly in the middle of this section. In subsequent rounds of investigations, the characteristics of this area were gradually defined; the tunnel would be excavated in soil-type clayey fills of alluvial origin, deposited on the limestones of the Arraiz Formation.

As soon as the works began, a round of geotechnical investigations were carried

out, enabling the nature and configuration of the materials in this area to be more precisely defined.

It was determined that the limestones were intensely karstified and the presence of a regional fault at the point of contact between the Arraiz limestones and the Ereza sandstones was also confirmed.

This information made it possible to adjust the tunnel excavation process. Systematic forepoling with micropiles in the 120m stretch in karstified limestone, and forepoling with jet-grouting from inside the tunnel in the 30m that were affected by the fault was adopted.

In those stretches where the karstification of the limestone was most intense, the micropile umbrella was reinforced with repeated selective injections (reinforced grouting). To protect the buildings situated on the crossing of the fault, two shafts were sunk in order to carry out compensation grouting.

Right: Figure 1, Bilbao metro map

During the excavation of the tunnel in this area, horizontal boreholes for core sampling were systematically drilled from the face of the tunnel, exploratory drillings were made with logging of drilling parameters, by france-based Jean Lutz, and the drilling of the micropiles was geologically recorded.

During the actual works, the analysis of all this new information enabled the need for reinforcement of supports to be more precisely determined before beginning to excavate each stretch of forepoling.

Monitoring

In the jet-grouting area a specific auscultation (listening) system was installed in order to monitor the movement and angular distortions suffered by the buildings. This information served as the basis for regulating the compensation grouting carried out from the shafts.

Ground treatment and grouting

Treatment in the karstic area

The geotechnical exploratory operations performed during the execution of the works indicated the presence of areas of karstified limestones with low rock cover. This was in the section of the tunnel starting from the end of Ariz station on the Basauri side. A new geographical profile was in this way obtained for the course of the route and a new study of support requirements was produced.

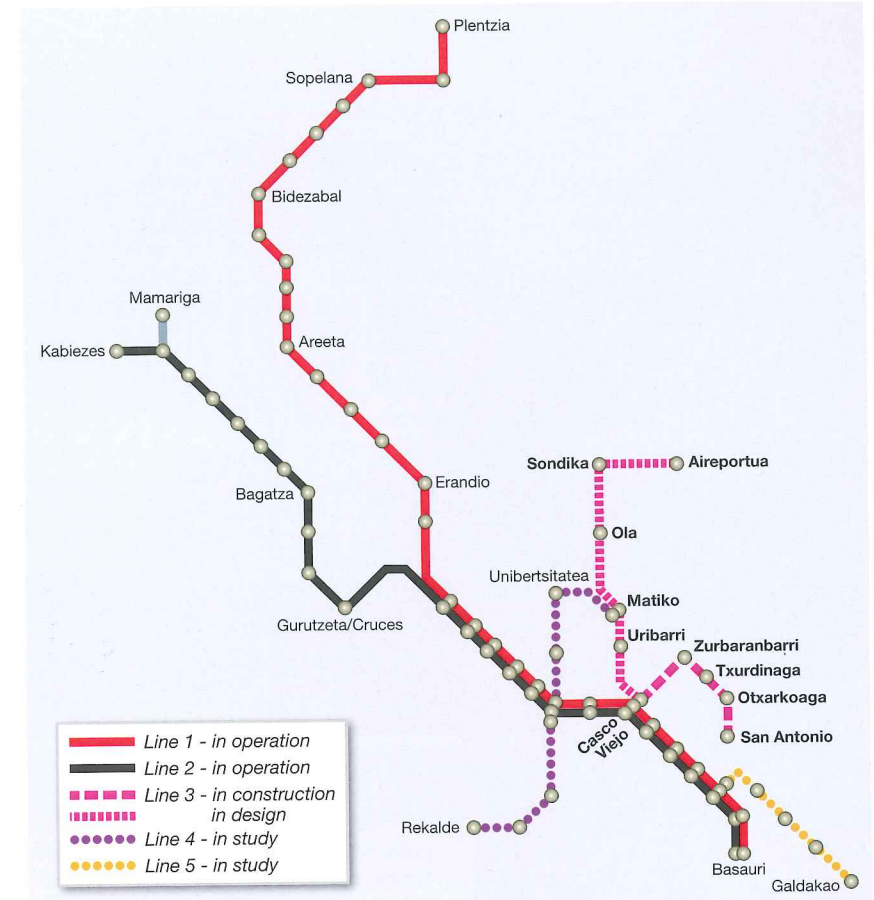
The nature of these sections called for a new type of heavy support to ensure the stability of the excavation, protected by forepoling with micropiles.

It was necessary to implement a support called ST-V, consisting of 88.9mm diameter micropiles at 12m long and with 3m overlaps, with sleeve valves every 1m for injecting grout – producing reinforced grouting – TH-29 trusses every 1m, double mesh and sprayed concrete.

It was also proposed that the extent of the karstic area to be excavated should be explored by means of exploratory drilling prior to executing the crown of micropiles. This was executed in a truncated cone arrangement, relative to the tunnel itself, with angles of the order of 40°, which made it possible to acquire more precise knowledge of the material.

Reinforced grouting consisted of:

- Micropiles Ø 90mm e = 7.2mm
- Injection valves at every 0.5m without seals
- Length: 12m
- Overlap: 3m



Treatment in areas of fills

In areas of fills, the objective when passing through is both to avoid the excavation face collapsing and to reduce inflow of water and reduce surface disruption.

To achieve this, the aim is to replace the fill material with another more solid material, so as to enable it to be excavated while maintaining sufficient resistance to avoid it falling in on itself. In short, the idea is to 'create' the rock as one passes through, so as to be able to excavate it safely afterwards. The treatment in turn also aims to make the terrain under the tunnel secure, so as to minimise any possible settlement once the tunnel is in operation, providing firm support for the counter-vault down to bedrock level.

The description of the treatment parameters is as follows:

- Perimeter and central jet-grouting in the top-heading and vertical jet-grouting to the supporting rock in the bench area as well as Type One subhorizontal jet-grouting with a 'preventer' device.

Perimeter treatment involved:

- Columns 9m long
- Reinforced drying jet crown: 38 units of 0.5m diameter

- Drying jet crown: 39 units of 0.5m diameter

- Drying jet counter-vault: 16 units measuring 0.8m in diameter.

Face treatment called for:

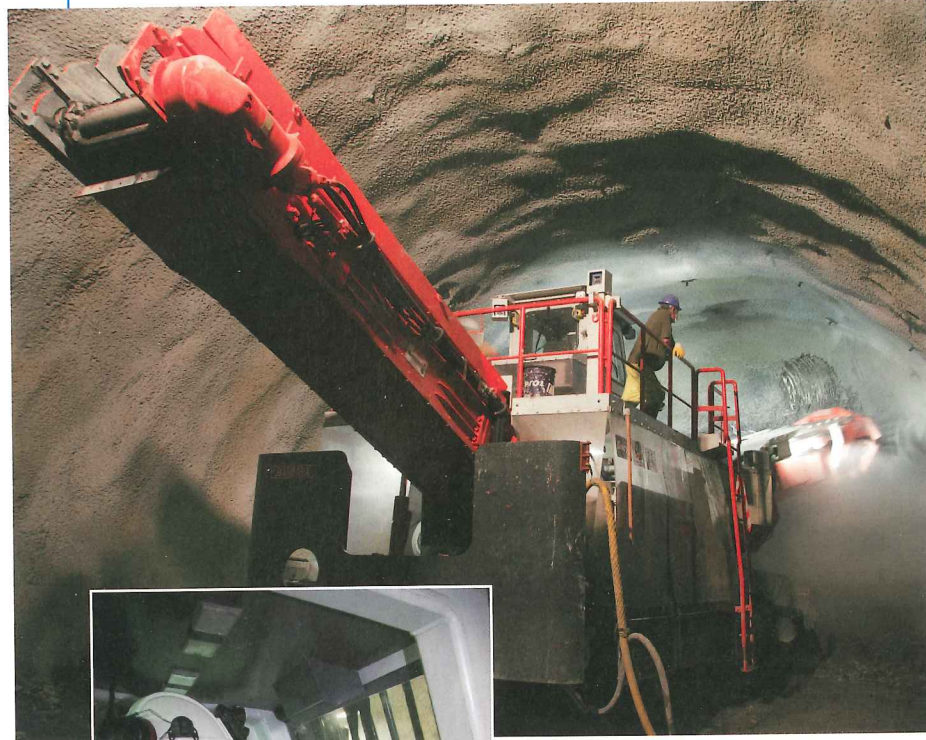
- 'Stabilisation' jet: 49 units of 0.8m diameter
- Cut-off 'plug' jet: 40 units of 0.8m diameter, 2m long and 7m from the face

Passing below

The underpass below the trench of the Bidebieta-Basauri railway station, with a 4m covering of rock above the crown of the tunnel, also involved the need for reinforcement of the support. This involved heavy support: HEB-200 trusses supported by forepoling with micropiles.

For the underpass below the trench, in a rock mass with RMR in excess of 60, the loads acting on the support were due to the formation of blocks across the joints in the rock mass, rather than those due to the strain deformation effect produced by the excavation of the tunnel.

The section below the rail lines, due to its possible repercussions on rail traffic, called for a new type of support to ensure the stability of the excavation. And it is



Above: Rig in use on the Bilbao Metro



therefore necessary to specify a heavier support called ST-VI, consisting of a first umbrella of 88.9mm diameter micropiles 18m long with 4m overlaps and a second 12m umbrella with sleeve valves every 1m for injecting grout, HEB-200 trusses every 1m, double mesh, elephant's foot, a protective crown of Swellex type rock bolts and sprayed concrete. The definition of this type of support is set out below.

To perform the calculation, it has been assumed that the umbrella rests at one end on the last truss executed and is embedded in the face at the other end, the span being the distance between the support and the effective embedding. The support on the last truss is regarded as secure given the rigidity of the overall structure comprising the HEB truss and the sprayed concrete.

Strictly speaking, the length of the unsupported span should be the distance between trusses, 1m. However, a certain additional margin is needed so as to be able to place the truss in position. This additional distance is between 200 and 500mm. The length of an unsupported span has therefore been taken as 1.5m, to be on the safe side.

It has been assumed that the effective embedding of the micropile is half a metre into the rock, again to be on the safe side.

Therefore the span length taken into consideration in the calculation is 2m.

Loading actions considered

To estimate the loads on the micropile umbrella, the Code for Actions on Railway Bridges (IAPF) was used.

The Type B Train scenario has been adopted. This consists of a uniformly distributed overload of 12t/m, extending over a distance of 15 or 30m, immediately followed by other uniformly distributed overloads of 10t and 1t/m.

The combination of these last two overloads (of 10t or 1t/m) will be of indefinite extent in terms of length and the values will be such as to produce the most unfavourable effects.

However, when traversing the tunnel orthogonally with respect to the tracks, the most unfavourable scenario for this configuration has been considered,

adopting a uniform longitudinal load of 12 tonnes per linear metre.

This hypothesis is very much on the safe side. Since the calculation is performed for a longitudinal section of the tunnel, to obtain the load acting on each of the micropiles in the umbrella this load is divided by the distance separating adjacent micropiles.

The micropiles are of N-80 quality steel, with a resistance of 550MPa. The external diameter of the micropiles is 88.9mm and their walls are 7.2mm thick.

Elaboration on the calculation

The proposed support for the underpass below the trench is designed so that the heavy forepoling is capable of absorbing the transmitted loads on its own.

The trusses and the sprayed concrete are only considered as providing support for the forepoling.

To ensure that this support is as rigid as possible, HEB-200 trusses and HP-30 sprayed concrete with a minimum thickness of 400mm has been used.

The calculation is performed assuming a continuous beam resting on rigid supports spaced the same distance apart as the trusses and embedded in the face. In this case the beam will correspond to the heavy umbrella located at the top of the crown of the tunnel, which is assumed to be subjected to the greatest load.

An analytical calculation will confirm that the maximum stress in the most heavily laden fibre of the steel section of the umbrella does not exceed the resistance of the steel.

Project restrictions

As a preparatory step for surface monitoring and to assist in defining it, a prior inspection plan was established for buildings in the areas that were most liable to be affected by the excavation. This plan determined that the inspection zone should focus on the inter-station tunnel near Ariz station and also on the area surrounding Basauri station.

The geological study determined that the works on the tunnel could give rise to significant surface deflections.

In order to have a mechanism for responding to ground movement resulting both from the excavation of the tunnel and from the treatment of the terrain itself, a plan was prepared for compensation grouting. This was executed from two shafts that were excavated at the surface, with three injection levels and a swept area covered by means of cement grout injection sleeves. ■



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Intelligence in modern drill and blast

The shift towards safety and sustainable solutions in tunnelling takes place on two tiers. Firstly, tunnels offer a way to protect sensitive landscapes and to reduce disruption, noise and vibration caused by motorways and other infrastructure on the surface. Hence, despite the relatively high cost of underground excavation compared to surface construction, more and more underground parking caverns and road and railway tunnels are being demanded in urban areas. Secondly, there is a need to make the actual tunnel building safer and more environmentally friendly.

With drill and blast, you cannot avoid having some negative side effects on the

In all projects, the target is to stay ahead of the schedule and below budget. To this end, computer assistance is increasingly employed in tunnelling. Sandvik applications manager for tunnelling Juha Kukkonen explores recent developments and future ideas for drill and blast rigs as the technology moves ever closer to automation

surrounding environment. Most of these effects are actually caused by waste energy, which also means a waste of money, and one of them is definitely vibration. Blasting creates a stress wave into the rock, causing not only loosening and fracturing of the rock but also transference in the particles of the intermediate, i.e. vibration. This vibration may damage nearby structures or sensitive instruments, and also create a danger for people. However, vibration can be minimised if the correct tools, techniques and methods are chosen.

Tender data logging

In the future we will see further development not only towards increased performance of the equipment—recyclability of components, accuracy, multi-functionality—but also towards stricter demands on the total quality of tunnels, care of the environment and decreased vibration and noise levels from excavation. Constant measurement, control and documentation of the project will be required from the contractor. Hence, in contract negotiations, for example, the way the risk is shared between the project owner and the contractor may be determined by the data logged. As a natural consequence, any responsible contractor strives to minimise the side effects and maximise the documentation of the excavation process.

This is where the needs for economical, safe and environmentally-friendly tunnelling come together, and where modern technologies and practices step into the picture.

With their help, the whole drill and blast cycle can be optimised, and blasting design made so cautiously that no damage to the surrounding structures is caused.

Proper planning is a key function

Careful planning is an essential function for effective drill and blast operations. However, planning must be flexible as well in order to be able to react to the rapid changes of the process. To be able to get the best possible tunnel quality, the profile of each round should be measured and the results immediately utilised for the next

round. Vibration can also be best limited and minimised with a careful analysis of the drilling pattern, charging, and the ignition plan—combined with measurements—to locate the points where maximum charge weight per delay or excessive burden could be reduced. Drilling plan and accuracy, choice of explosives and detonators, and quality of charging work all have a great effect on resulting vibrations.

The blast plane

As blasting initiates from the bottom of the blast hole, it is vital that the burden and spacing between the holes in the blast plane is as planned. If drilling is not accurate, there is no possibility to correct the blast by charging.

Therefore, to meet the challenge, the optimal and logical place to begin design of the drilling pattern is from the end of the round, i.e. in the blast plane. This approach, combined with a modern accurate drilling rig, guarantees optimised excavation result.

The importance of drilling accuracy

Drill plan design and the accuracy of the drilling equipment have a significant role in the overall control and productivity of a tunnel construction site. As a matter of fact, economical excavation is based on the ability of drilling equipment to drill the hole into a planned location. The profile of the excavated tunnel can also be controlled by blast management and correct placing of drill holes.

The accuracy of drilling is essential also from the point of view of excavation advance. In particular, the accuracy of the cut holes, and even more importantly the accuracy of the hole end locations, is fundamental. As blasting initiates from the bottom of the hole, it is vital that the burden and spacing between the holes in the blast plane is as planned.

Drilling accuracy, accurate hole placement and correct blasting methods are the most important factors affecting the pull-out. In the drilling pattern layout, the choice of cut and cut hole placement also affects the final advance.

As the blasting sequence in a tunnel blast always starts from the cut holes, the



Operator's console with Sandvik iSure software

placement, arrangement and drilling accuracy of the cut is crucial for successful blasting in tunnelling.

Simply put, only drilling errors limit the received advance per hole length.

When designing the cut, the following parameters are important for a good result: diameter of the reamed holes, burden, and charge conditions. In addition, drilling precision is of utmost importance, especially for the charged cut holes closest to the reamed cut holes. Even the slightest deviation here may cause the charged cut hole to meet the reamed hole, or make the burden too big. An exceedingly large burden causes breakage or plastic deformation in the parallel cut, resulting in a shorter advance.

The diameter of the reamed cut hole is a good parameter for better advance of the blasted round. The larger the diameter, the deeper the round can be drilled and the greater advance expected. One of the most common reasons for a short advance is an overly small size, and even more so, the inaccuracy of the reamed cut in relation to the hole depth.

Drill plan design starting from the end of the round

Combining a drilling pattern designed from the blast plane with an accurate drilling rig guarantees optimised excavation result. Also, when the burden and spacing between the holes are according to plan, the energy of the explosives is used correctly for breaking the rock between the holes and for moving the rock mass to create an open space for the next row of holes. This enables initiating instead of uncharging the energy incorrectly and causing extra vibrations.

Sandvik's foray into intelligent jumbo software

iSURE (intelligent Sandvik Underground Rock Excavation) software is a new tool for managing tunnel or underground excavation projects. With it, the drilling and blasting design takes place in the blast plane. This way parameterisation of the drill holes and burden calculation can be used for optimising the locations of the holes. The explosives used in different parts of the pattern are also specified, as the degree of charge and the relative strength of the explosive are used for calculation purposes during the design process. Based on this information, the total consumption of the explosives per round, and for example charge detonating at specific time (per specific delay), can be illustrated.

Another of the features being introduced

with modern drill rig software is the ability to include detonators and group or surface delay detonators in the design process. The software enables real time monitoring of momentary situation as the design advances. If selected, information is available on the real delay times with or without extra surface delay, the number of detonators initiating at the specified delay time, and the amount of explosives initiating simultaneously.

As the excavation advances, the designer can easily revise the vibration measurement results and go back to the drilling and blasting pattern design to trace the cause of increased vibrations and make modifications as required.

In addition to the real time momentary illustration, the design process is made easier for the user by blast simulation. Simultaneous detonators on a specified delay time can be highlighted, while the already initiated delays are displayed faintly.

Equipment: instrumentation, remote access and multi-usability

The total economy of tunnelling operations can be improved by putting more emphasis on the accuracy of the drilling. Reductions in overbreak and underbreak in turn lead to reductions in haulage and scaling time as well as in volume of shotcrete.

Better drilling accuracy can be achieved through instrumented and automated equipment. The development of instrumentation and automation in face drilling rigs started in the 1980's. However, wide acceptance of the new systems had to wait until early 2000.

Drilling with highly instrumented and automated machines is effective and fast, since the machines can repeat the designed drill plan round after round. In grouting and probing, additional solutions for mechanised long-hole drilling improve the efficiency by reducing the drilling and auxiliary times. This also improves safety, since there is no need for the assistant driller to stay at the face, in the front of the machine.

Today, there are several different instrumentation levels available and in use. The most sophisticated systems, fully computerised drilling jumbos, can be operated manually, in semi automatic, or fully automatic modes.

In fully automatic mode the jumbo performs drilling according to the pre-programmed drilling pattern, whilst the operator concentrates on supervising the system. Also the tunnel geometry can be controlled as the input data includes the curvature and inclination of the tunnel.

The automatic drilling cycle consists of the following automated main process elements:

- Positioning of drilling boom and alignment of drilling feed to correct position (look-out angle specified in pre-programmed drill plan)
- Forward movement of drilling feed—the feed is supported and aligned against the rock surface
- Forward movement of rock drill—the drilling bit is supported against the rock surface
- Collaring of the hole to specified depth using adjustable collaring power
- Collaring of the drill hole to the specified depth using adjustable collaring power
- Drilling of the hole to specified depth using adaptive drilling features
- Hole cleaning with compressed air
- Return of rock drill to back end stop and retraction of drilling feed from the rock surface

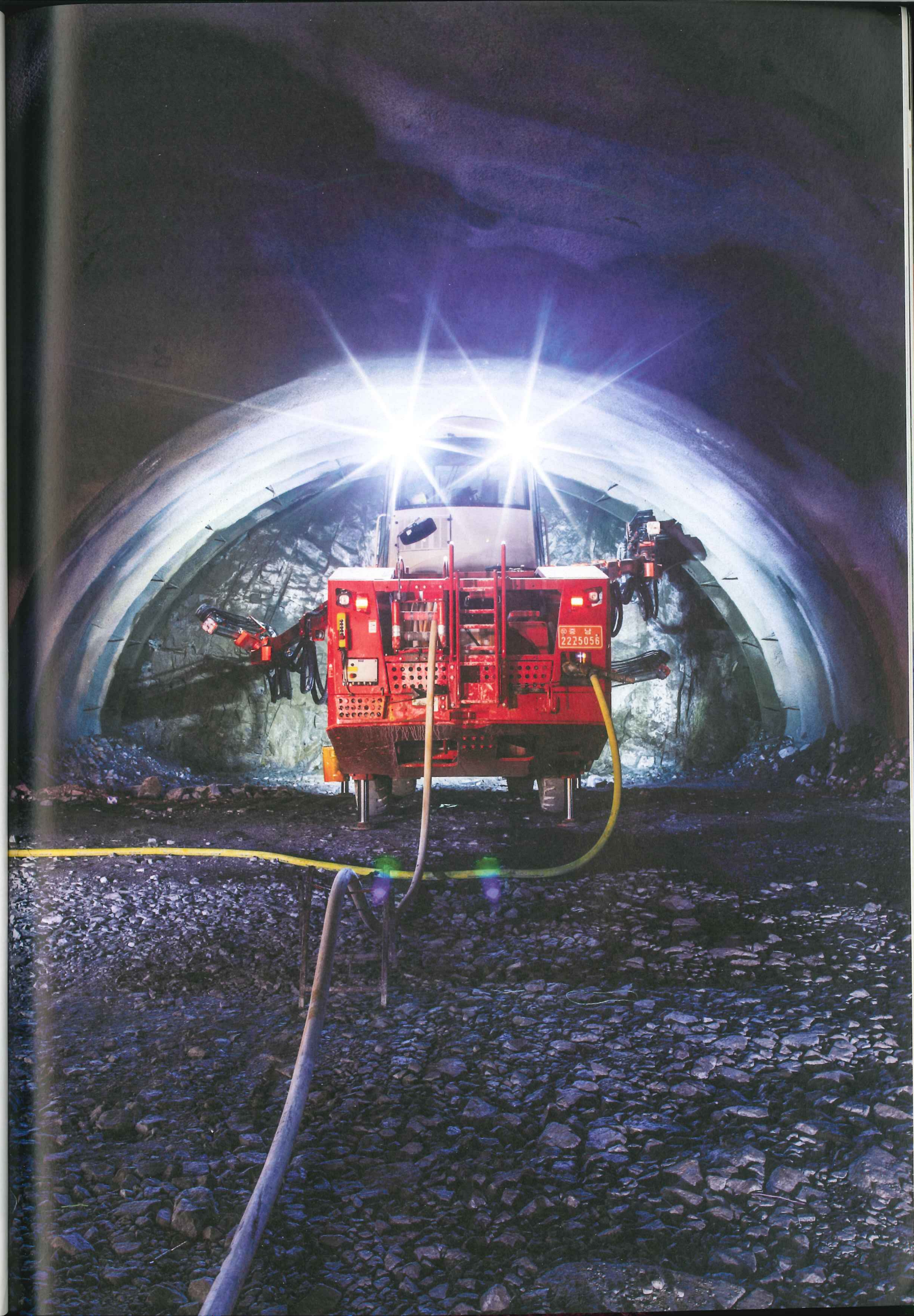
Advanced instrumentation provides many advantages. The drill pattern can be optimised with respect to the number of drill holes in the round, blastability, haulage and pull-out. Good repeatability ensures that the desired quality is achieved by all operators on the rig.

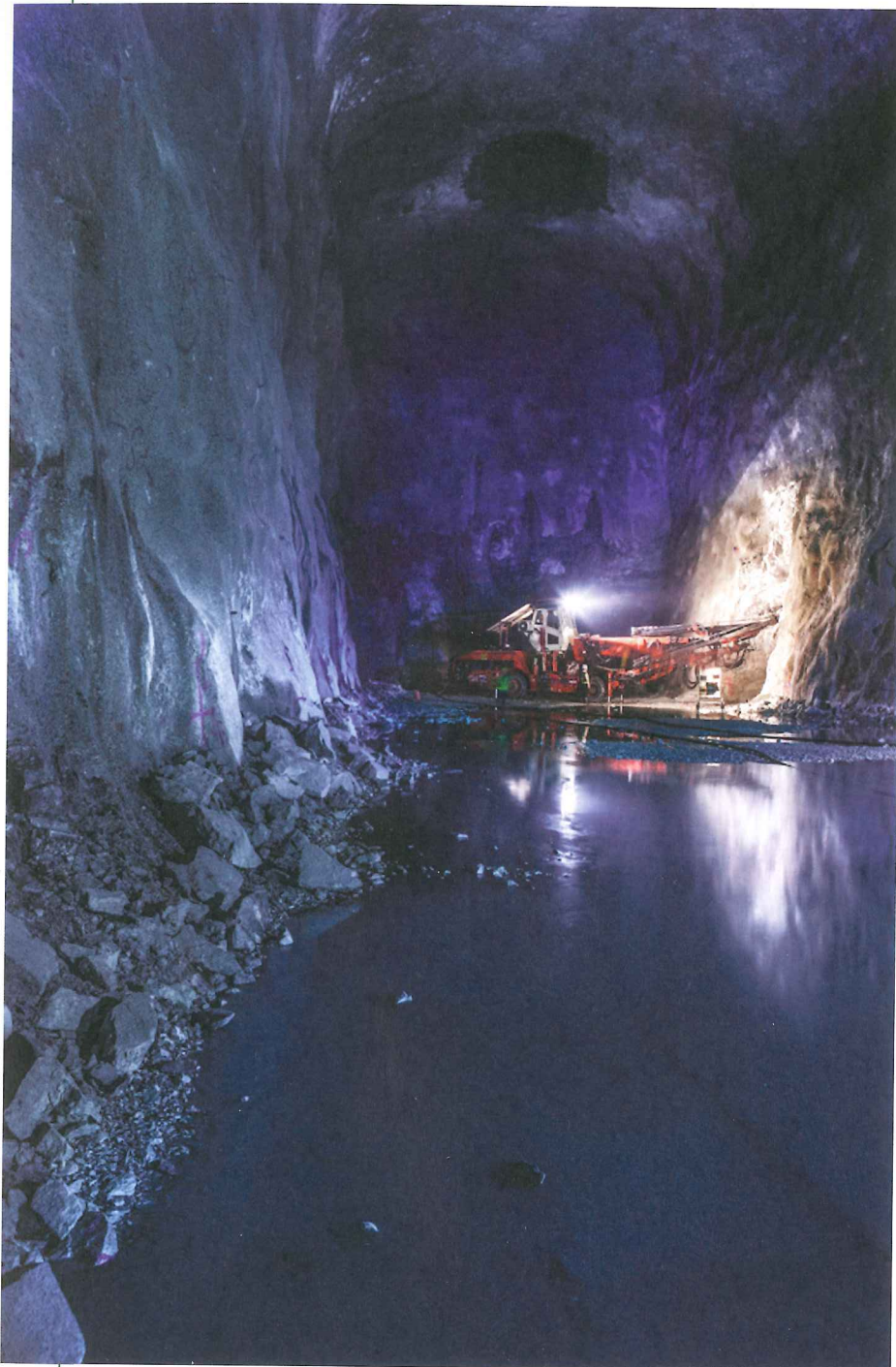
In the Sandvik DTI-series of tunnelling jumbos, the most advanced systems are the full data. It is also possible to extend the full data controls with additional features such as optimised drilling, by adjusting the parameters per hole type and allowing the drill cycle to be adjusted according to rock conditions. Both of these features make better use of the expertise of experienced operators.

Accuracy of the drilling process is also improved by advanced navigation systems such as 'total station navigation' in the Sandvik DTI series. These offer an automated way of navigating the rig to the correct position in the tunnel, and minimises the risk of human errors and significantly improves accuracy—tests show even 50 per cent better accuracy compared to traditional laser navigation. Thanks to increased accuracy in measuring tunnel depth, drilling round accuracy through curves is also improved. With total station navigation, reporting is possible in both, plan and project coordinates.

Remote access will save time

Remote access minimises the amount of time wasted going back and forth in the tunnel. It offers access to the jumbo's user





Above: Drilling work by contractor TaeAh on the Jurong Oil Caverns project in Singapore, the largest caverns under construction in South East Asia

interface on any computer connected to the same network as the rig, independent of their location.

However, for safety reasons remote rig operation has so far not been possible.

Remote access offers web-based data transfer: drill plans, bolt plans, tunnel lines and data collection files can be shifted to and from the rig over a web browser.

Each rig with the remote access function will have a dedicated website for information transfer, and on the same page rig status and estimated time remaining are also shown.

The remote access feature can be further enhanced with a separate online measurement while drilling (MWD) data module. With it, comprehensive MWD data

can be viewed as a colour-coded freely rotatable and zoomable 3D model on any computer connected to the same network as the rig.

One rig for multiple uses

The possibility of using a drilling jumbo for other tasks besides just drilling is in ever greater demand.

Sandvik DTI jumbos, for example, can be used not only for face, injection or probe hole drilling but also for bolting. The systematic bolting instrument called iBOLT offers computer-assisted navigation for the best accuracy and an easy working process. With the computer assisted bolting, simultaneous drilling of face holes and bolt holes is possible.

This considerably speeds up the tunnelling process, as you can drill face holes with two booms, for example, while one of the booms is used for bolting. Furthermore, such a system supplies not only bolt hole position and length logging in plan coordinates, but also in project coordinates. MWD data collection for bolt holes is available, too.

All reports can be transferred to common land surveying software.

Accuracy is also key in bolting. A good system offers assisted boom control so that the booms need not be operated by one articulation at a time, but instead, after drilling the first hole, the control keeps the boom on the fan automatically.

Trends in equipment hardware

Another strong trend is the requirement for equipment to be built from recyclable components and materials, which applies to drilling tools as well. In addition to this, manufacturers are trying to develop oil spillage protection and the machines' use of biodegradable oils only, which most of them can do these days.

Low emission TIER4i engines are also now required by law in Europe, the USA and Japan.

In recent times manufacturers have put a strong focus on operator environment and their working conditions.

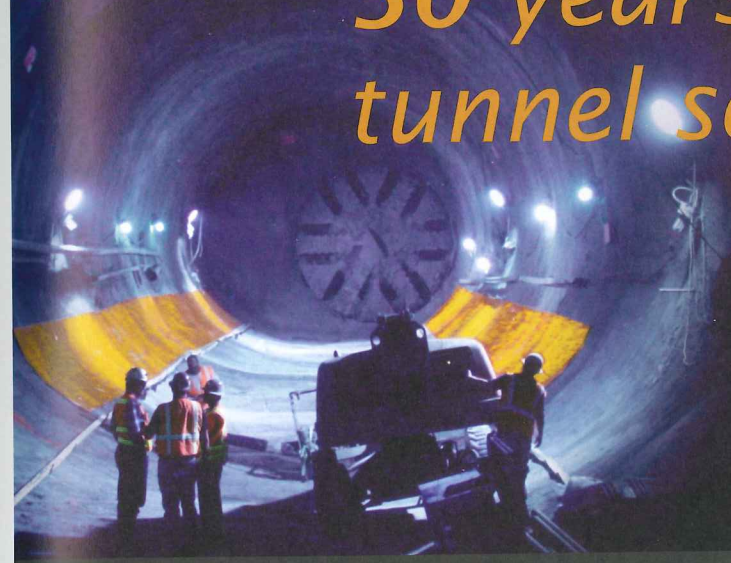
The amount of noise, dust and vibration in operator compartments is minimised, and new ways of decreasing those even more are being constantly developed.

In general, new drilling rigs are designed for safe operation and service to start with. One example is a manipulator for long hole drilling that ensures safe operation, as it eliminates personnel from the utility boom. Work safety has also recently raised fully mechanised bolters to a place among popular investments. ▀

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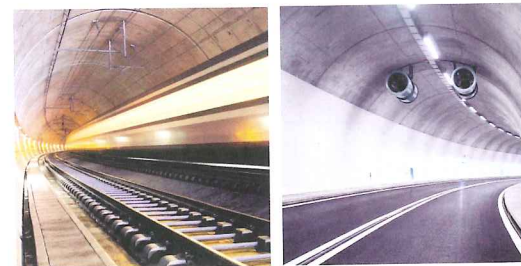
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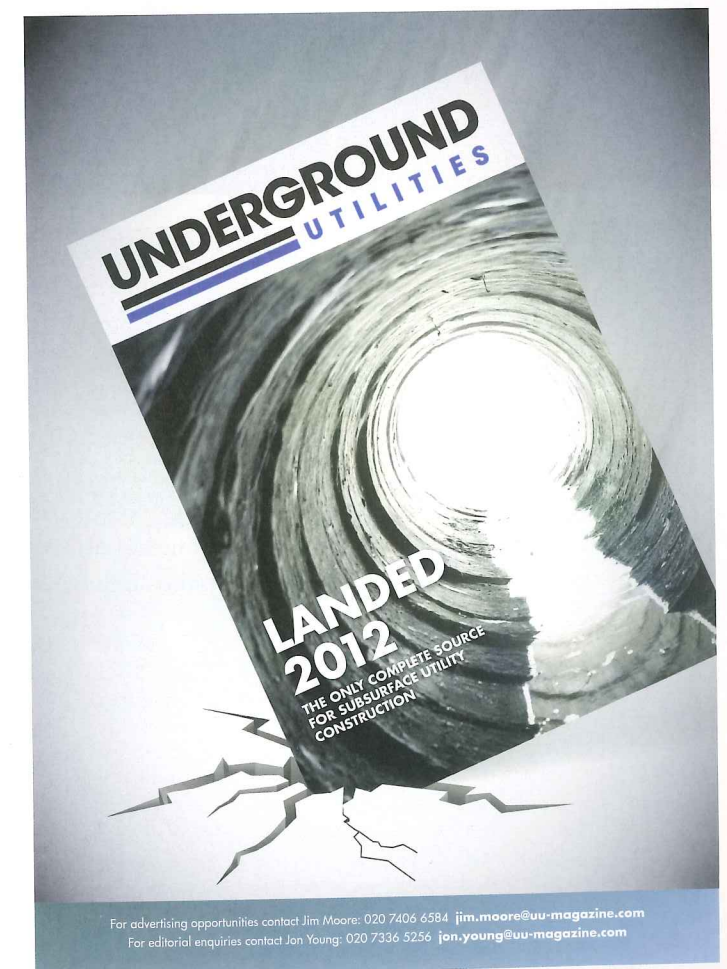
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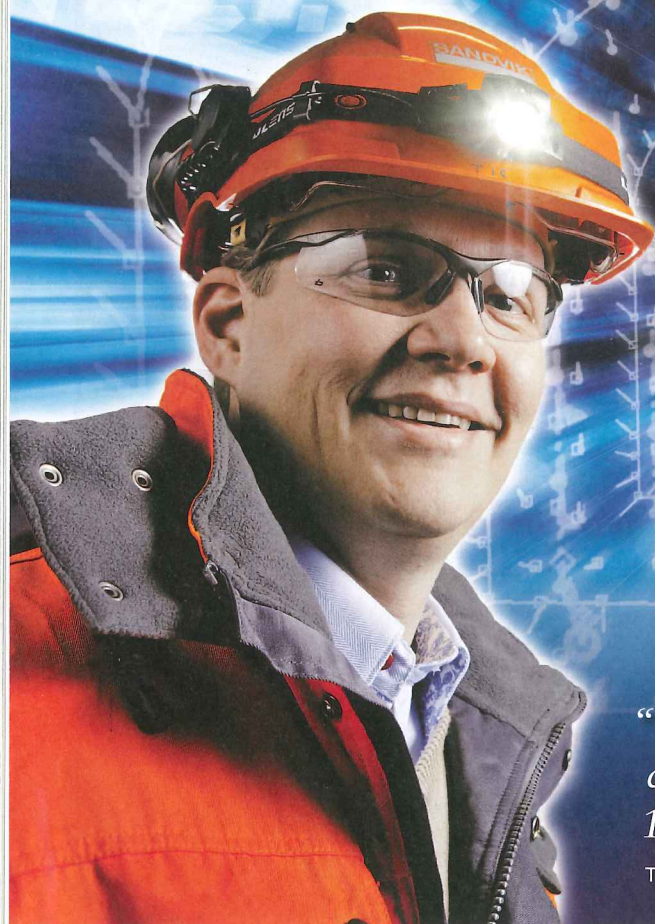
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East Side Access blasts

Typically in New York the ground transmission constant used for determining blast vibrations (the K value) is 300. As East Side Access progressed and blasting data analysed it was recognised that there was significant local variation in the K Value. This paper by Andrew Rhodes and Mark Thompson of Hatch Mott MacDonald and Lawrence Weller of URS examines the various factors influencing decisions made to optimise blasting, and the theory behind predictions

The USD 8.3bn East Side Access Project (ESA) being constructed by Metropolitan Transportation Authority Capital Construction (MTACC) will provide a new commuter rail link from Long Island to a new terminal located directly beneath the existing, historic Grand Central Terminal on the east side of Manhattan. Construction of the Manhattan Segment of the ESA Project requires the excavation of twin station caverns in rock, beneath the existing operating Grand Central Terminal. The approach to the new ESA station caverns includes eight bored tunnels that split from

two through a series of Wye caverns. The work described in this paper is contractually split into two separate contracts, CM009 Manhattan Tunnels awarded in 2006, and CM019 – Manhattan Structures I awarded in 2008, both to the Dragados USA/Judlau contracting joint venture. The design was performed by the general engineering consultant, a joint venture of Parsons Brinckerhoff, STV Incorporated, and Parsons Transportation Group. Construction management was provided through the program management consultant (PMC) headed by URS with Hatch Mott MacDonald as a subconsultant

and the consultant construction manager (CCM) headed by Jacobs Engineering.

Expectations

Rock excavation has been performed by a combination of TBM, roadheader and over 450,000 cubic yards (344,049 cu.m) of drill and blast excavation. Managing the engineering and 'psychological' expectations of the third parties associated with the overlying structures and the impact of vibrations experienced from the blasting is a challenge. The distinction between the engineering expectations and psychological expectations can be



TBM work on ESA



David Sailors

described as follows: engineering expectations are the requirements to prevent physical damage to any overlying structure or facility, including railroad signal systems and traction power.

Meeting the psychological expectations of third parties requires providing an accurate depiction of what would happen with each blast in advance, so that no one would be startled or surprised by the vibration from blasting.

Blasting background

Rock excavation by drill and blast has been performed regularly in the New York City area for more than 150 years. Over time and as New York became more intensely developed, sensitivity to blasting operations and the impact on structures increased. The recent 50 years have seen the engineering criteria of 2in/sec (50.8mm/sec) as the allowable vibration level become the norm for safe blasting. Numerous papers

and subsequent studies have addressed whether or not this 2in/sec guideline is unnecessarily conservative including crucial and cogent arguments about the importance of additional factors such as the frequency of the vibrations. Decades of excavation projects have proceeded using the simple 2in/sec guideline and this long period of use has increased the stature of this initial limit without taking into account that this criteria was established for wood

frame and sheetrock construction affected by surface blasting, not modern steel and concrete structures.

The ESA project has evaluated the use of alternative vibration limits and means of monitoring at several locations over the last four years of drill and blast activity. Data has been obtained from dynamic strain gauges on existing structural columns and structural concrete for correlation with peak particle velocity (PPV) measurements. Test

blasts have also been performed, intentionally designed to exceed 2in/sec to evaluate the engineering implications for the specific adjacent structures. These studies have confirmed that 2in/sec is most assuredly a conservative engineering criterion for vibration monitoring.

This paper will not delve into the comparison of engineering criteria and its relations to the potential for genuine physical damage, as this has been examined in other published papers.

Modern day requirements for drill and blast management have increased as the awareness of the general public and other stakeholders to environment impacts and life quality has grown. Thus, the criteria for blasting on the ESA project were not limited to genuine physical potential for damage. Rather the performance criteria became evaluated on the basis of the ability to predict a specific outcome associated with each planned blast event.

It was not sufficient simply to remain below a threshold vibration limit. It was necessary to come within 20 per cent of a predicted anticipated vibration level.

Ultimately, the ESA project has proceeded with two sets of vibration monitoring criteria: engineering criteria to ensure the physical safety of adjacent structures, and public perception criteria to ensure that no one from the public is adversely impacted.

This paper does not deal with the evolution of the public perception criteria as that is entirely subjective and simply the preferred choice of the primary third party but it must be noted that a thorough public relations advisory was implemented to notify the neighbours and get feedback from the community.

In addition to these engineering and psychological criteria, the ESA project also had to comply with criteria associated with landmarks and historic structures as well as utilities. The NYC landmarks laws limit the vibration level at landmark structures to 0.5in/sec (12.7mm/sec). Third party utility companies specified their own levels of criteria, for example Con Edison required that a level of 1in/sec (25.4mm/sec) be maintained at their steam lines. This paper does not address the additional measures needed to comply with these further constraining criteria.

This paper deals with the challenge of predicting the level of vibration within 20 per cent for each blast and each location for each type of blast.

Initial predictions

Anticipated levels of vibration from blasting

were predicted using the relatively standard formula in which predicted PPV in inches per second is equal to the Scaled Distance (SD) factor (to the exponent minus 1.6) multiplied by the Ground Transmission Constant K.

$$\text{Predicted PPV} = K * (\text{SD})^{\text{exp} -1.6}$$

Where Scaled Distance is the factor equal to the distance from the blast to the sensor divided by the square root of the maximum pounds per delay.

Data from previous excavation projects in New York City has indicated that for a 95 per cent confidence level, K equal to 300 is generally acceptable. Consequently, the contract specifications for the ESA project required initial test blasts in each area of the contract to commence with initial predicted PPV obtained using K = 300. Based on the results from the test blasts and subsequent production blasts, the contractor would update the project specific regression data, and would be permitted to propose revised K values to enable improved efficiency of blasting operations.

In New York City, it is typically not possible to place geophones on existing ground adjacent to existing structures. Therefore, the placement of geophones is generally within existing structures on concrete footings, slabs, grade beams or similar structural elements. Thus, the actual levels of vibration recorded will typically include effects from both the attenuation through the natural ground between the blast location and the sensor as well as a component of ground to structure transmission. Therefore, in practice, the K transmission constant now incorporates not only the ground transmission, but also a component of structural response that also varies from location to location. A significant number of blast records are required to identify trends that can be justifiably defended as sufficiently reliable to permit adjustments while retaining the required 95 per cent level of confidence.

In addition to the natural transmission within the ground, and the additional effect of the ground to building response, the actual vibration obtained also varies significantly as a function of the type and execution of the blast itself. Blasts that are geometrically more confined behave differently from those with ample relief. Thus, additional variation with respect to blast type also requires evaluation.

For some reason, any mention of the specified requirement for the contractor to perform a 'regression analysis' of the blast vibration results was always met with a



David Sailors

Above: Workers inspect segmentally lined running tunnels

great deal of dismay and rolling of eyeballs by the contractor. There is nothing super technical or razzle-dazzle about a regression analysis. It simply consists of determining the equation of a line that provides the best fit for the actual data. The younger generation of course does this on the computer. But an adequate estimate can also be obtained from old-fashioned eyeballing of the plot of the data.

Distinction by blast type

As mentioned previously, the ESA project has included excavation by TBM bores as well as drill and blast. Many of the drill and blast regions have involved enlargements of TBM bores while other headings have been conventional full-face blasting.

And as the East Side Acces project includes multiple levels, there has also been routine bench blasting.

The different geometry of each typical blast type generated fundamental differences in the relief of the shot that affected the vibration level. Slash shots into

the TBM bore, and bench blasts both experienced the benefit of blasting towards an open face. Conventional full-face blasts required burn holes and initial burn cuts, and generated a higher level of vibration when all other factors were equal. Thus, distinction based on type of blast was an element of obtaining more consistent predictions of the anticipated vibration.

Specifically, a portion of the ESA project known as the GCT1&2 Wye cavern was located directly beneath the historic portion of the Grand Central Terminal, and included segments with one TBM bore, portions with two TBM bores, and portions without a TBM bore all in the same general plan area of about 200 by 200 ft (61 by 61m). In the segment with two TBM bores, the additional relief associated with the combined bores enabled K values of 210 to be used.

This in turn allowed the contractor to maintain 10ft (3.05m) round lengths throughout this segment with zero exceedances of predicted levels or criteria.

In the portion without any TBM bore, higher levels of vibration were experienced resulting in exceedances. The K value was raised to 240, and ultimately the contractor needed to cut back to a 9ft (2.74m) round length to comply with the criteria.

Distinction by ground conditions

With respect to the geology, the project is entirely underlain by Mica Schist bedrock of the Manhattan formation comprising good to very good quality sound rock. This generally good quality was beneficial both for the consistency of the blasting with respect to fragmentation and perimeter control and also the consistency of the transmission of blast energy. This effectively reduced the number of variables that needed to be adjusted during the course of blasting a typical heading. On average, K = 210 was validated for the majority of the site, which permitted substantial improvements in the efficiency of planning and executing the blasting program.

In localised areas, this formation included layers of extremely hard amphibolite that acted to attenuate blast energy. Thus, in the area of the amphibolite, K values as low as 150 were utilised effectively to advance.

Conversely, there were also areas of slightly greater than average natural fracturing of the rock which resulted in higher than expected levels of vibration. In these areas, K = 300 was required to be retained to ensure compliance with agreed upon vibration criteria.

Conclusion

Evaluation of the vibration monitoring results of more than 1,000 blasts for the ESA project provided sufficient data to determine locations where a lower value of K could be successfully utilised to improve the efficiency of blasts, and also where high levels of caution were required. This enabled the contractor to plan larger blasts with confidence in pre-determined areas.

It must be noted that these results and findings are distinctly site specific, and cannot be automatically extrapolated to different locations regardless of general similarities in circumstances.

A test blast program is always recommended practice for new locations or proposed changes in methodology. The authors recommend that more research needs to be completed on modern structures to allow for vibration criteria to be raised where construction requires close proximity blasting to newer buildings. ■

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Chemical control

Chemical grouting has been successfully used for over forty years to control the movement of groundwater in a wide variety of applications including tunnels, subway systems, sanitary sewers, mines and construction projects. This paper illustrates the versatility of chemical grouts by reviewing three projects where chemical grout was utilised to address some very difficult water control challenges.

The featured product is acrylamide, which can be used alone or in conjunction with other types of grout such as cementitious products. Acrylamide grout is injected as a two component product that

will react and form an impermeable gel when the components combine. There are notable differences between the acrylamide based products and cementitious products. The most notable and significant difference is that acrylamide is a true solution grout that contains no particulates and has a viscosity of one to two centipoise (cps) MPas. This feature enables the acrylamide grout to penetrate very small geological features that other grouts could not penetrate and to seal small cracks and

Jim Gentry of chemicals firm Avanti International presents this paper on the use of chemical grout to control groundwater infiltration

fissures where groundwater seepage is occurring. The product also has an adjustable gel set time from a few seconds to several hours which enables the operator to determine the product travel before it forms a gel.

When properly applied the product has a half-life in the soil of 362 years (per testing by the US Department of Energy).

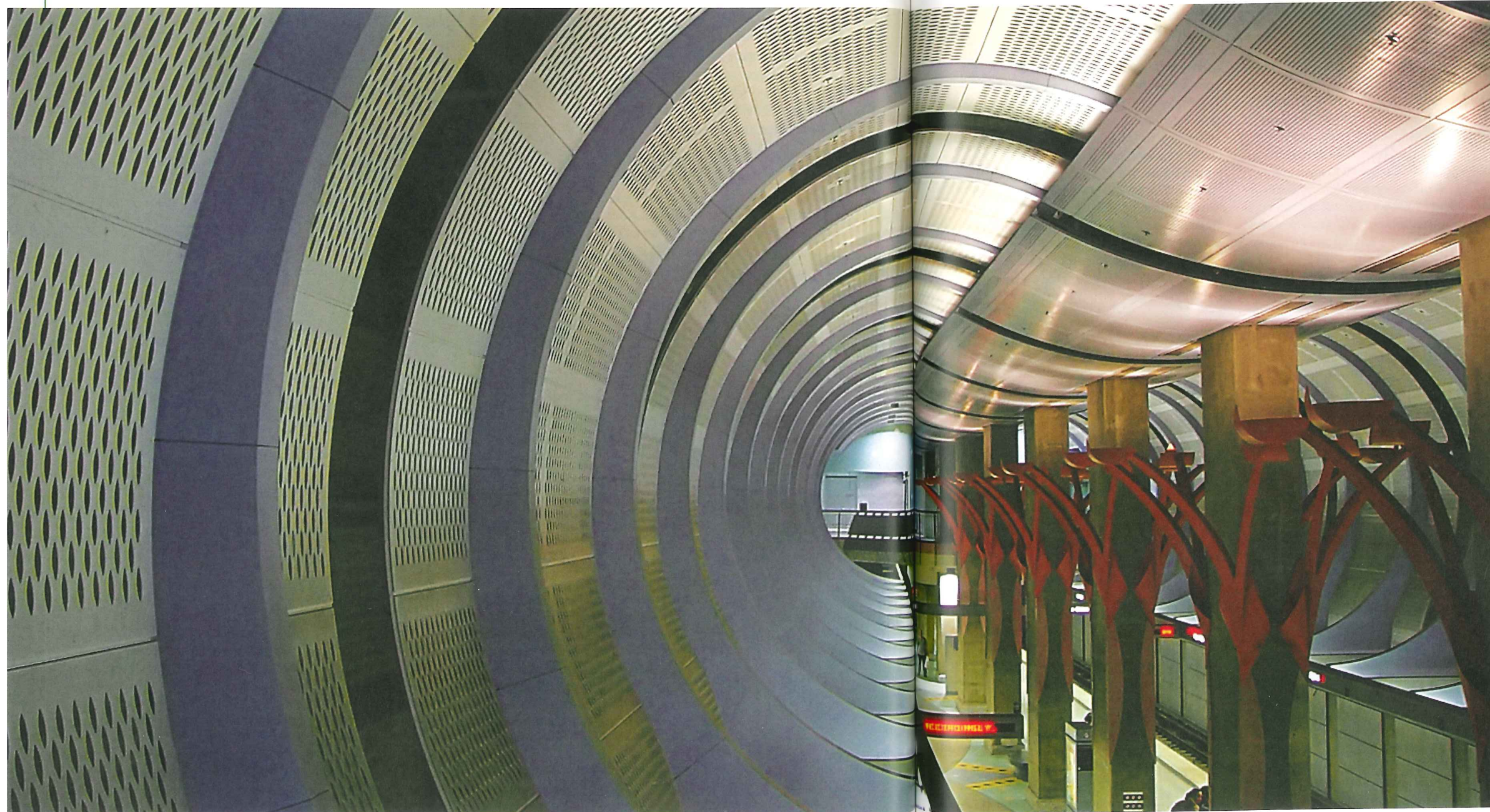
Sewer overflows

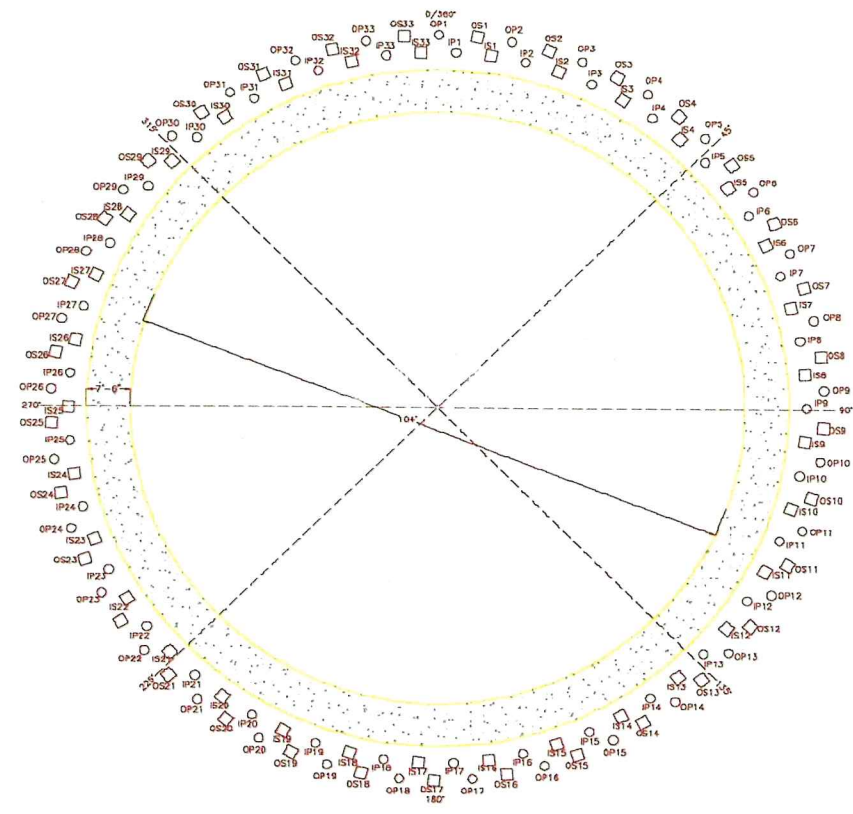
The US Environmental Protection Agency cited the City of Dearborn, MI, for combined sewer overflow violations. The City elected to address these violations by constructing two 120ft (37m) diameter, by 150ft (46m) deep shafts to collect and treat the sewer overflows that occurred during storm events. A plan view of the shaft is shown in Figure 1 on page 50.

These shafts are positioned adjacent to outfalls along the Rouge River. The initial site investigations revealed that several types of very porous geology were located in the 150ft shaft depth and that artesian conditions were also present. In addition, methane and hydrogen sulfide were detected in the groundwater.

Engineers and consultants elected to perform a pre-excitation grouting program around the perimeter of the two shafts prior to construction to prevent problems with water and gas entering the shafts during excavation and construction. The very large volumes of water made pumping to remove the water impractical and the pre-excitation grouting program was completed prior to the excavation of the shaft. The grout selected was required to meet the following performance criteria: (1) very low viscosity in the range of 1-2cps MPas capable of penetrating all of the site geology which included silt, clay, glacial hardpan, gravel and rock, (2) adjustable set times from a few seconds to several hours, (3) chemically resistant to gases present which included methane and hydrogen sulfide, (4) strong enough to withstand the artesian pressures of up to 100psi (6.9 bar), (5) compatible with the caisson sinking construction techniques being utilized and (6) cost effective when compared with other options. Acrylamide grout was the only product that met the above stated criteria.

Left: The Hollywood Metro Tunnel contractor selected U.S. Grout's Ultrafine to seal the tunnel against water inflow and to prevent settlement





Above: Figure 1, Grout holes on the perimeter of the shaft

An infiltration rating of two lugeons in the soil around the two shafts was established by engineers as the maximum water infiltration that could be accepted and still maintain the construction schedule. Two grout curtains were established around the shaft perimeters, the outer curtain was formed using cementitious grout and the inner and less permeable curtain was formed using acrylamide grout.

No additional grouting was required after the initial grouting process was completed.

Testing revealed that the grouting program achieved a final permeability of 0.2 lugeons, which is ten times better than the specified objective.

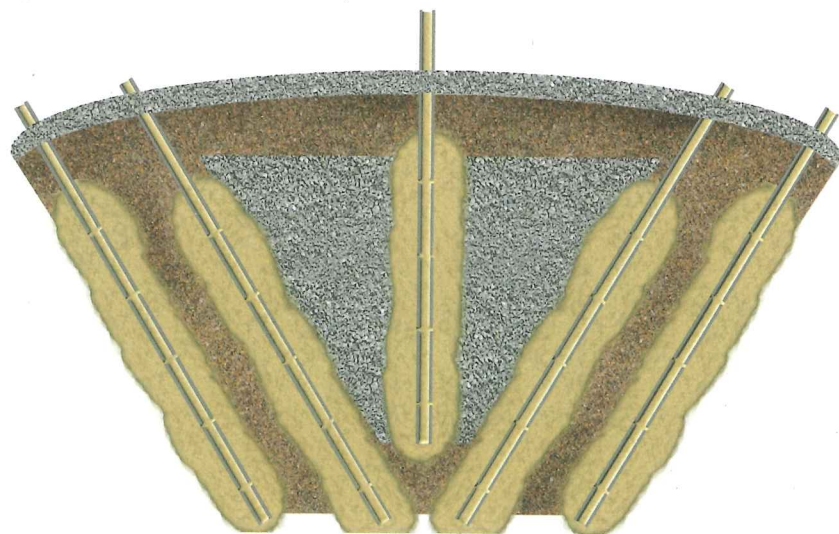
Pre-excavation grouting for the City of Dearborn utilised over 145,000 gallons of acrylamide grout, making this one of the largest acrylamide grouting projects ever performed in North America and the final results far exceeded the original project requirements. The project was completed during some very challenging weather conditions including snow and freezing rain and was completed without any safety or environmental issues.

Nuclear waste

Acrylamide grout was also utilised to complete a hazardous waste containment

project at the Oak Ridge National Laboratory (ORNL) facility. In 1985 federal and state regulatory agencies began close monitoring of the waste management operations at the US ORNL and other US Department of Energy (DoE) sites. At Oak Ridge, they discovered that remote monitoring wells were indicating radioactive

Below: Figure 2, Acrylamide chemical grout injected via probes to encapsulate hazardous waste, cementitious grout in the trench and acrylamide grout in the soil adjacent to the trench



waste leaks from several burial trenches containing mixed (radioactive and hazardous) waste. They concluded that the DoE did not have adequate solutions for long-term containment of the waste materials and a comprehensive study was undertaken to identify an acceptable containment method. Acrylamide grout was selected as part of the program because there is a long history of test work at ORNL, which demonstrates that of the available grouting materials, acrylamide is the only material with a history of withstanding radiation exposure satisfactorily over time.

US DoE testing also demonstrated that if acrylamide is properly injected into the soil where it remains in a moist environment it has a half-life of 362 years. This longevity and stability was required to avoid the necessity for subsequent additional containment measures.

The project entailed encapsulating a large volume of mixed liquid and solid waste from the Manhattan project that was stored in several trenches at the facility. A typical trench side view is illustrated in Figure 2. The largest of the trenches, trench five, is 300ft long and 10ft wide (91m by 3m) at the surface and 15ft deep and 4ft wide (4.6m by 1.2m) at the bottom of the trench. Polyethylene sheeting was originally used to contain the waste in the trenches. The trenches were filled with gravel and 9.5M gallons of liquid radioactive waste was poured over the gravel into the each of two trenches. Fractures subsequently developed in the geology surrounding the trenches providing pathways for the contaminated liquid to seep into the soil

and also into the groundwater which was located about 25ft (7.6m) below the bottom of the trenches.

To contain the waste material in the trenches, cementitious grout was injected into the trenches using a single row of injection locations down the middle of each trench that were 6ft (1.8m) apart.

Cementitious grout was injected into two-thirds of these injection locations with acrylamide being injected in every third location. Acrylamide grout was injected into the surrounding soil using two rows of six foot spacing placed one and 2ft (0.3m and 0.6m) from the sides of the trench to encapsulate the entire trench. Injection of the grout was accomplished using sleeve pipes with rubber sleeves that function as valves to allow the grout to exit but prevent any contaminated material from exiting the trench. After completion of the project no further contamination has been noted in any of the monitoring wells around site.

Subway tunnels

The Toronto Transit Commission (TTC) subway system is one of the largest in the world with over 27 miles (43km) of underground tunnels and numerous below grade structures in varying geological zones and hydrological conditions. The

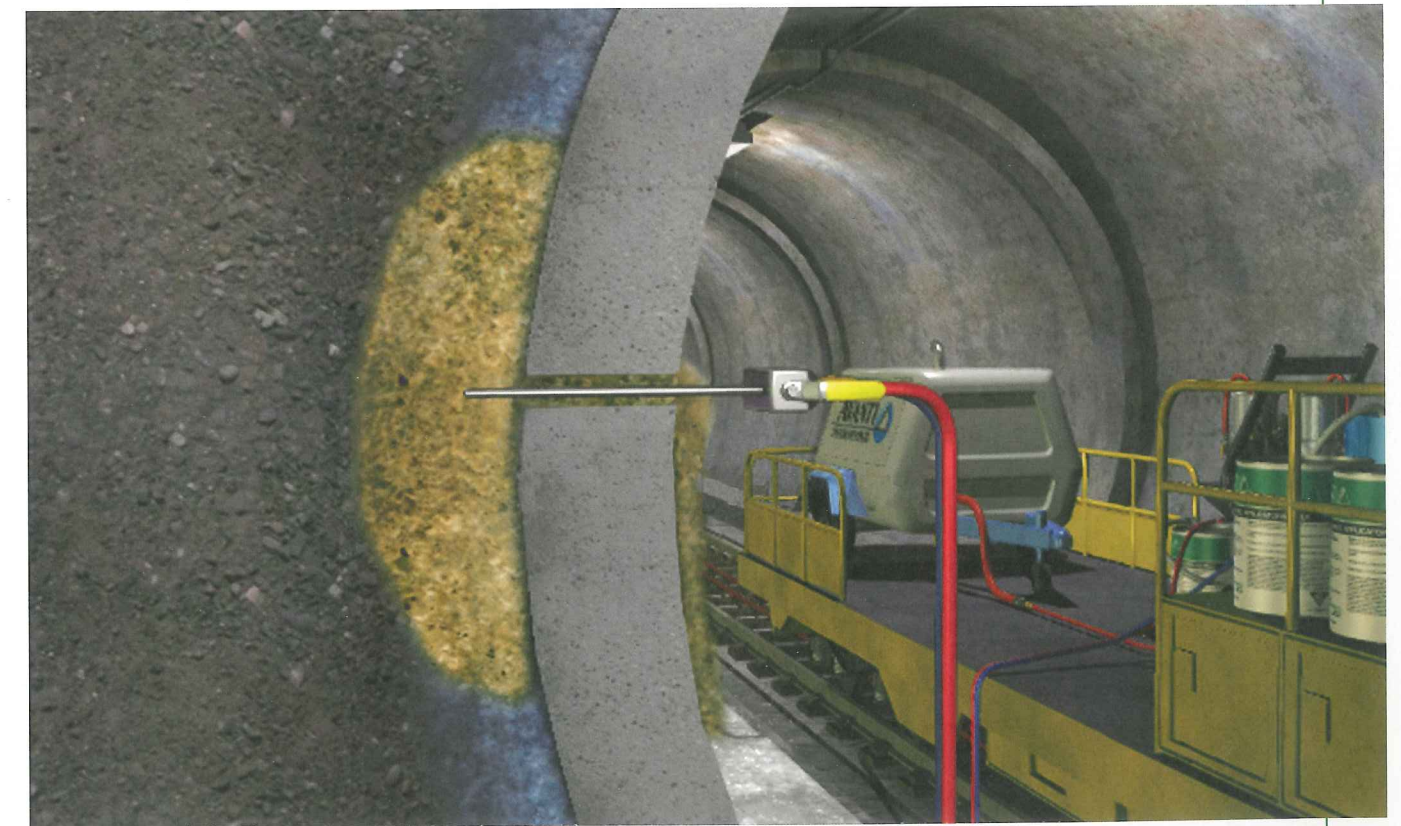
geology includes glacial till, rock, gravel and silt. The tunnels were constructed in 1954 using three different types of construction, concrete box, precast concrete circular lined and cast iron circular lined, and for years did not receive major restoration.

As a result, water infiltration had been a problem with the TTC since the time of construction and numerous water leaks had developed throughout the system. Only emergency repairs were done, on an as-needed basis to control the water infiltration problems. These problems included electrical and mechanical system problems and structural problems. It was determined that tunnel leak remediation was necessary as a result of these and other problems with water intrusion.

A regular program of maintenance was established in 1997 with the formation of a tunnel leak remediation crew. The crew is comprised of 13 TTC employees who perform all of their work during times that the subway is not in operation. TTC consulted with a number of experienced grouting professionals during the development of their program and elected to utilise an in-house design-build approach to address the large and complex scope of work. The mechanism for water infiltration into the tunnels is predominantly

via the expansion and construction joint systems. The groundwater table is typically above the tunnel roof and is the source for all of the water infiltration problems. The grouting repair technique that has been successfully used to stop the water infiltration into the tunnels is curtain grouting. Figure 3 below illustrates the curtain grouting technique. Curtain grouting creates a curtain of grout in the soil outside of the structure thereby preventing the water from contacting the structure surface. Acrylic grout is injected into the soil surrounding the tunnel structure where the grout permeates the voids in the soil and sets to form an impermeable soil/gel water barrier or curtain around the tunnel exterior. The grout was injected into the joints in the areas where the concrete box construction technique was used and holes were drilled through the walls into the surrounding soil in the other areas. Extensive testing revealed that acrylamide grout was the best product for use under the challenging geological and hydrological conditions. The tests included the viscosity of the product, permeability of the grouted soil, ability to control gel set times to accommodate the varying geological and hydrological conditions (a few seconds to several hours), the longevity of the applied grout and ease of application. The success of this program has been exceptional and is on-going.

Below: Figure 3, Chemical grout permeating the soil to create an impermeable curtain

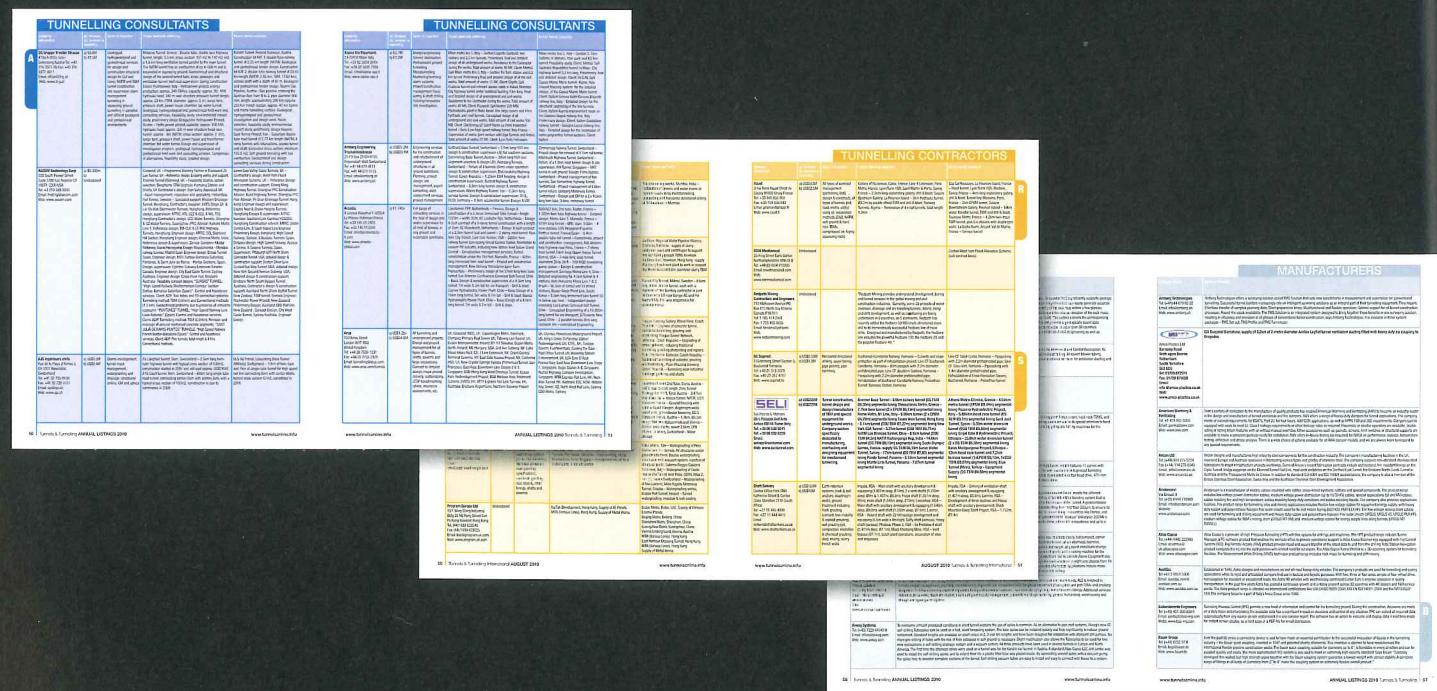
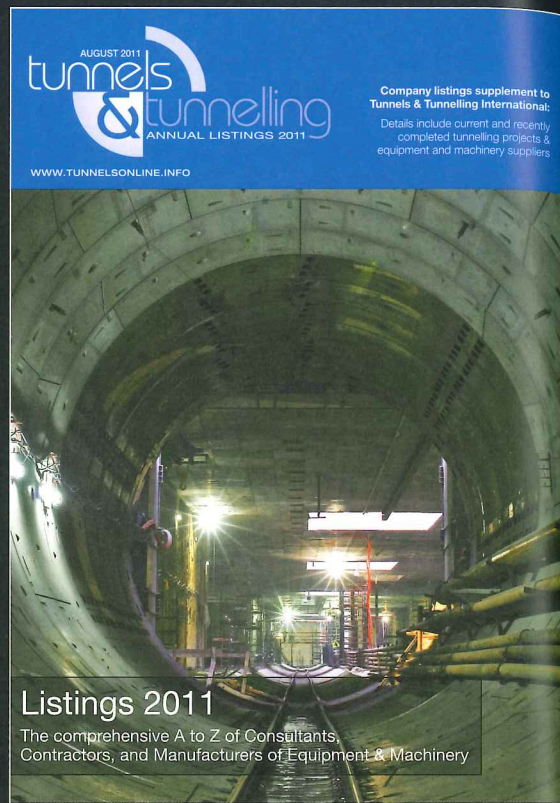


T&TI's annual company listing and rankings are back

All entries now need to be completed via the online entry form

Deadline for completion is 17th August 2012

The listings will be published with the October issue of T&TI



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Deep Interceptor

When finished the UK's deepest tunnel should intercept 16Mt of diluted sewer overflow discharge into the Thames, some 40 per cent. Deputy project manager Roger Mitchell, construction manager Scott McFadzen and design manager Jean-Christophe Gallan presented at the BTS meeting in June



Above: Figure 1, sites in London, UK

Compliance with the European Urban Waste Water Treatment Directive (UWWTD) is targeted at improving water quality through reducing the amount of untreated polluted water that is discharged into river catchment areas. In the case of the Thames and River Lee, 39Mt of diluted sewage are discharged directly into the river from combined sewer overflows (CSO's) annually. Renowned civil engineer Joseph Bazalgette pioneered the original London sewer system blueprint in the mid 19th century, which left a superb legacy. The system cannot cope with the current population, which is only set to rise. The original scheme far surpassed its intended design life, something to consider for the scope of the equivalent modern day scheme. The Lee Tunnel forms the first part of the parent GBP 4.2bn (USD 6.6bn) 'Tideway' scheme that will intercept CSO's along the urban river route. Thames Water's task is to intercept as many as possible

with the most efficient and cost effective solution. The resulting Thames and Lee Tunnel super sewers will act as a 48-hour storage reservoir and will channel the sewage to the country's largest treatment works at Beckton, East London. The Lee Tunnel will intercept the Abbey Mills overflow, which is solely responsible for around 40 per cent, or 16Mt of the discharge volume to be captured. The Lee Tunnel can be built and commissioned in far less time than the Thames Tunnel, for a fraction of the cost and with the most benefit. This is partly due to the fact that construction sites at each end of the job are within Thames Water land, which thus negates any compulsory land purchase. The route also follows the 'Northern Outfall Sewer' (NOS) route, a Thames Water asset.

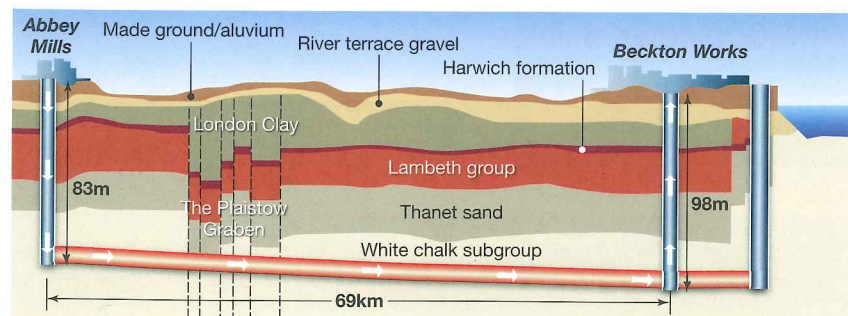
Project

A 6.9km, 7.2m internal diameter tunnel solution will provide 382,000m³ of storage. Sewage will be intercepted in the Abbey Mills shaft and will travel to the connection shaft. A small suction tunnel will transfer

sewage to the 38m diameter pumping shaft. The pumping shaft will house up to six 3.5MW pumps to transfer sewage at up to 3m³/s for treatment once tideway is fully connected. In the interim only four pumps will be installed as part of the Lee Tunnel's requirements and it is only expected to use one or occasionally two. Lastly the 20m diameter overflow shaft will connect to an outfall culvert to send excessive flows out in to the river via an outfall headwall.

A major factor to add to the complexity of the construction required is the 75m depth of the tunnel and shafts. This is to allow for a minimum flow gradient and to avoid existing underground infrastructure such as London Underground metro lines and cable tunnels in the vicinity.

The contract was awarded to the joint venture of Morgan Sindall, Bachy Soletanche and Vinci Construction Grands Projets (MVB) under NEC Target Cost Option C and is due to be fully operational by spring 2015. A capital investment of GBP 635M (USD 997M) is to be undertaken including upgrades to the treatment works.



Above: Figure 2, geological profile between the Abbey Mills and Beckton shafts

Site set-up

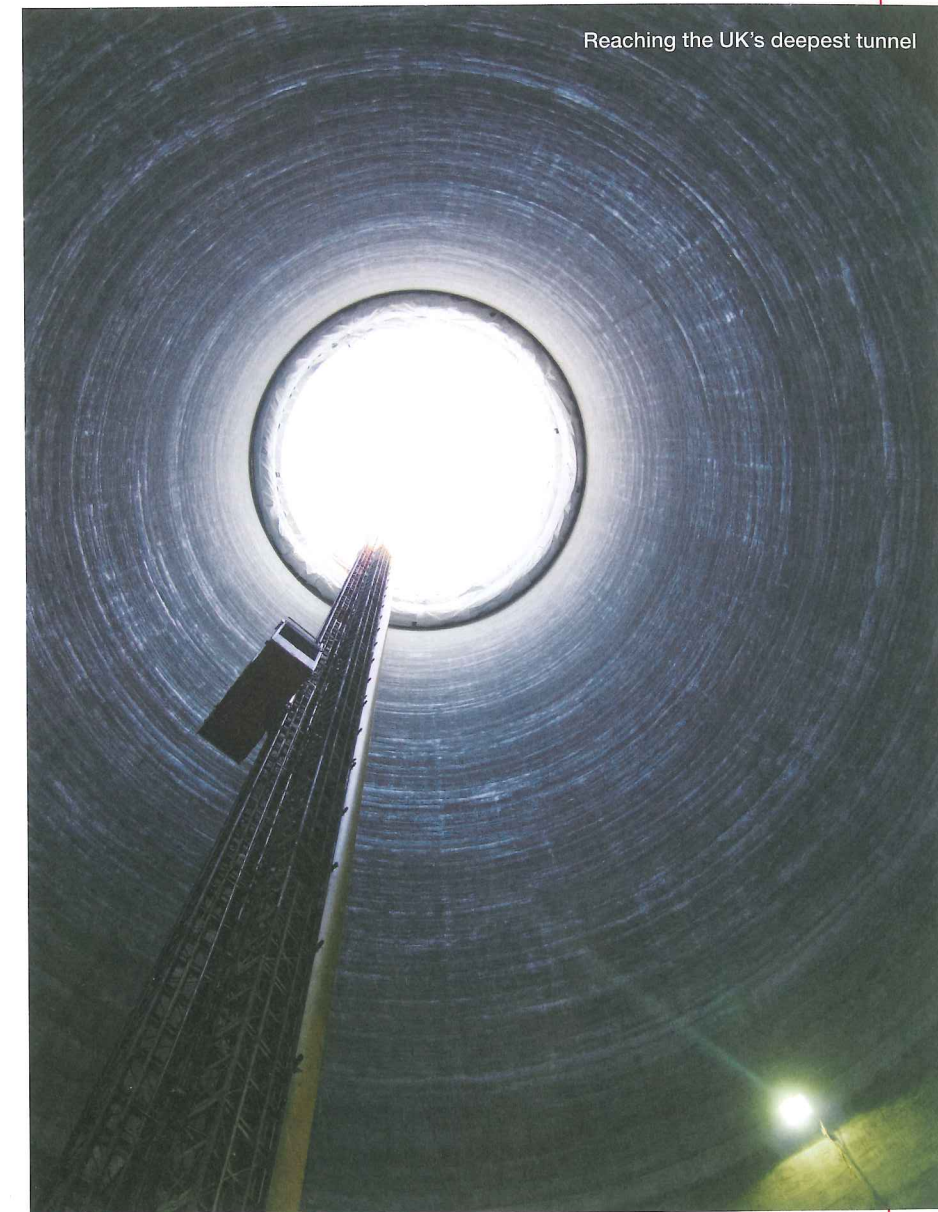
At the Beckton treatment works site there are three main sites of work. The overflow shaft where the TBM is to be launched from also encompasses a segment yard handling area, slurry treatment plant (STP), and a muck bin and a conveyor system stretching out into the Thames to load waiting ships capable of removing up to 1,600t each. The pumping shaft and connection shaft share a site and are joined with a 30m long, 2.54m diameter suction tunnel, a pumping house and power supply buildings are also being constructed. Other sites operated by the JV include a pair of dedicated concrete batchers capable of mixing 120m³/hr and a TBM/materials storage area. The Abbey Mills site near the Stratford Olympic park is where the interception shaft will be sunk beside the river Lee, which is also be utilised for much disposal via barges. Cargos are subject to the International Maritime Code in which transportable moisture limits are established for the different soil types. These TML's are rigorously adhered to thereby eliminating the risk of the cargo's liquefaction and the resulting load capsizing and sinking a vessel. Stockpiles are sampled daily, to check limits, and to certify the cargoes for transport and disposal.

Shaft construction - walls

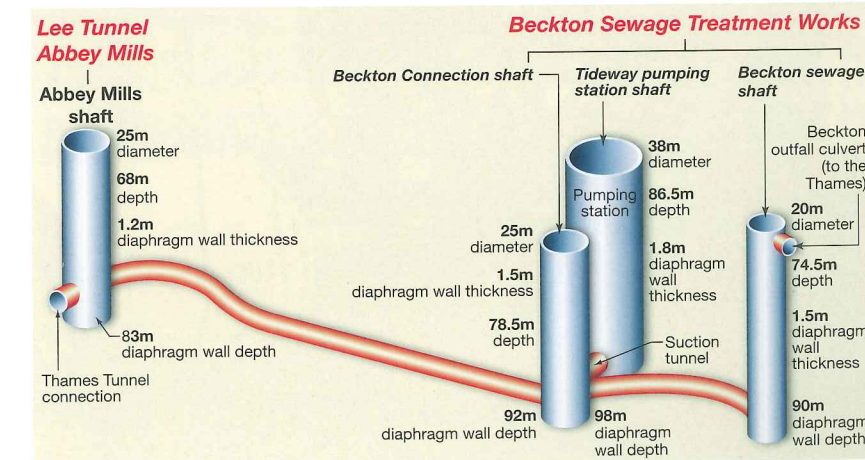
Shaft Construction started with the building of guide walls for each separate diaphragm wall panel. Wall excavation was carried out using a specialist hydrofraise machine. This machine uses two counter rotating cutting wheels to excavate the 1.2 to 1.8m wide trenches. Panels around the circumference are created in a primary and secondary pattern in order to achieve integrity between joints. The verticality is recorded using an inclinometer to give live readings to the hydrofraise operator to maintain an accuracy of 1:300. A bentonite slurry mix was used to support the excavation and required a back-up separation plant.

The work on the four shafts was carried out in sequence to give optimal use of the plant with two hydrofraises and three crawler cranes being used simultaneously at peak production on the connection and pumping shafts.

Once excavated, the panels (largest being 1.8m by 98m deep) were reinforced. Reinforcement cages were pre-fabricated off-site and delivered by flatbed wagons. The design of the panel sizes considered the transport logistics as well as all lifting requirements. Tandem cranes were attached to special welded lifting bars to raise each panel to a vertical orientation.



Reaching the UK's deepest tunnel



Above: Figure 3, shaft particulars and connecting tunnel on the Lee Valley project

Questions from the floor

Andy Crawford, McNichols Construction

Q: Have you considered the wear to the slurry lines due to flints?

A: Yes, lines will be ultrasonic tested and rotated accordingly. High wear locations such as bends may need to be replaced.

John Murphy, URS

Q: Is there anything special about the bentonite mix used for the diaphragm wall excavation?

A: Essentially no, just a good quality mix, though re-use is a problem with the chalk particles being a similar density / size.

Bob Ibell, London Bridge Associates

Q: Any particular problems from the construction of such deep shafts – logistics, pumping concrete or anything else?

A: Big lift crane rigging required 3.5km of rope. Tremie pipes used as out of reach of normal pumps. High pressure at depth. Largest ever diameter launch into ground at pressure while in short mode.

Ikesh Boron

Q: What are the long term implications of using a concrete mix with up to 60 per cent replacement materials.

A: Extensive industry research and trials have been carried out. It has been used for over 20 years and was considered in mix design. It's durable without reinforcement.

Andy Crawford, McNichols Construction

Q: Were there any problems obtaining Environment Agency approval for the use of bentonite in the London aquifer?

A: No, as the material is considered to be a natural product with no admixtures.

The section was lowered into the excavated trench and supported by hanging bars that span across each side. The next panel was then offered-up and a welded connection made. Following temporary works checks the cage assembly continued to full depth. The combined reinforcement cages weighed up to 55t. The largest panels required a

continuous concrete pour in the region of 1,500m³. The luxury of having a dedicated on-site batcher ensured a predictable delivery rate to three hoppers over a 15-hour period. The concrete was a 60 per cent replacement mix with a six hour retardation that is checked by on-site technicians. Extensive mix trials were carried out to ensure the correct workability and 60N strength gain. As the concrete was poured the replaced bentonite was piped

away using the hydroraise to 20m storage tanks. Bentonite that can no longer be used was sent to a processing plant and then disposed of.

De-watering

Each of the three different shaft sites present different conditions, geology, sizes, and surrounding influences when determining the best suited scheme to tackle ground water issues. The overflow shaft is in close proximity to the river Thames and overlies the local Greenwich Fault Zone likely to be connected to high water flows. Curtain grouting extending through the bottom of the diaphragm wall panels was carried out to cut off flow paths coming up from the shaft footprint. At the same time a 15 by 8m grout block was created for the TBM launch safe haven. At the pumping and connection shafts traditional well de-watering was used to lower ground water levels. The Abbey Mills shaft, in early stages of excavation as of June 2012, is being dewatered internally due to its proximity to contaminated ground previously encountered on the West Ham Flood Alleviation Scheme.

Excavation

The overflow shaft excavation was carried out using two 24t excavators loading a 14m³ bottom dump cone skip lifted by a tower crane. This was increased to three excavators with a tower crane and a 200t crawler crane lifting two skips for the 90,000m³ of muck to be taken out of the pumping shaft. At peak excavation rates up to 2,000m³ of ground a day were removed,

with up to 6m of progress in a week. Cone skips are automatically emptied by lowering onto a dedicated frame where the discharge is controlled through hydraulic doors to limit the quantity dropped into waiting moxy wagons for transport.

The overflow shaft excavation had the added complication of previous structures in the ground that had been backfilled with foamed concrete.

For the diaphragm walls to be constructed, 1.2m diameter cores were bored using a BG28 pilling rig down to 15m below ground level. Geological logging was carried out to confirm existing bore-hole data during the works.

The excavated material ranged from Alluvium, River Terrace Gravels, London Clay, Lambeth Group and Thanet Sand before entering the chalk strata.

Base Slabs

Both the connection shaft and overflow shaft base slabs have been poured. The structural element of the slab is 2m thick and forms a concave shape, which is capped flat with another 2m depth of mass fill concrete to a level surface.

French drains were installed in the chalk connected to four vertical relief wells into which pumps were placed to keep water out of the pour. Reinforcement consisted of a bottom mat supporting circular beam cages. These were pre-fabricated on the surface and lowered down to be spliced to the pervious cages to make complete circles. This saved a great deal of time and meant that the 40t of reinforcement was placed within one week. A reinforcement mat and chairs were used in the mass fill section solely for access purposes when

concrete finishing. A 10m fixed spider boom was installed in the centre of the shaft to distribute the concrete pumped from a static surface pump. Four volumes were 1,300m³ and 1,500m³ for the overflow and connection shaft respectively.

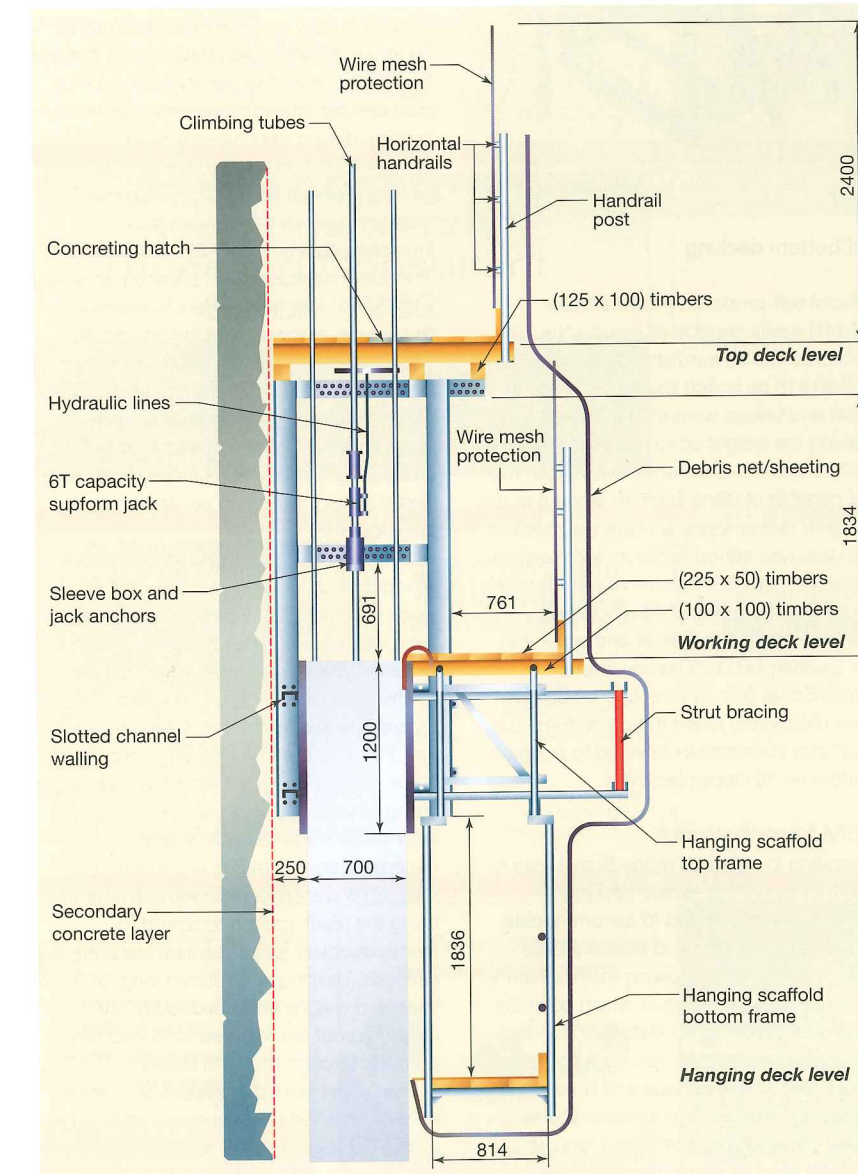
Shaft line – slipform/annulus infill

Most people are familiar with slip forming being used on high rise building cores but this methodology lends itself to new thinking in shaft waterproofing design and construction. Designers Underground Professional Services and Mott MacDonald devised a free-standing 700mm thick chimney solution. This design avoids interaction with the diaphragm wall surface and avoids differing shrinkage/expansion rates which lead to stress in the lining.

The contract specification imposed strict criteria for water ingress through the shaft lining which the diaphragm walls alone cannot meet by the nature of jointed panels. A continuous pour reduces the amount of cold joints and thus water paths. The key to the chimney working was the requirement for the concrete hoop to be compressed to close any micro cracks. This was to be carried out by utilising the hydrostatic head pressure of wet concrete poured around the annulus void.

The slipform shutter was pre-assembled into manageable segments on the surface, consisting of three decks for concrete delivery, placement, and finishing on the bottom hanging deck. A steel portal was fabricated to accommodate TBM launch seals which the face of the slipform shutters passed-by leaving a void for the machine. This was the only location where steel reinforcement was required locally. Using a fibre reinforced mix removed the need for continuous steel fixing. A spread of concrete mix designs were used giving a retardation time between 1-6hrs depending on supply and placement rates.

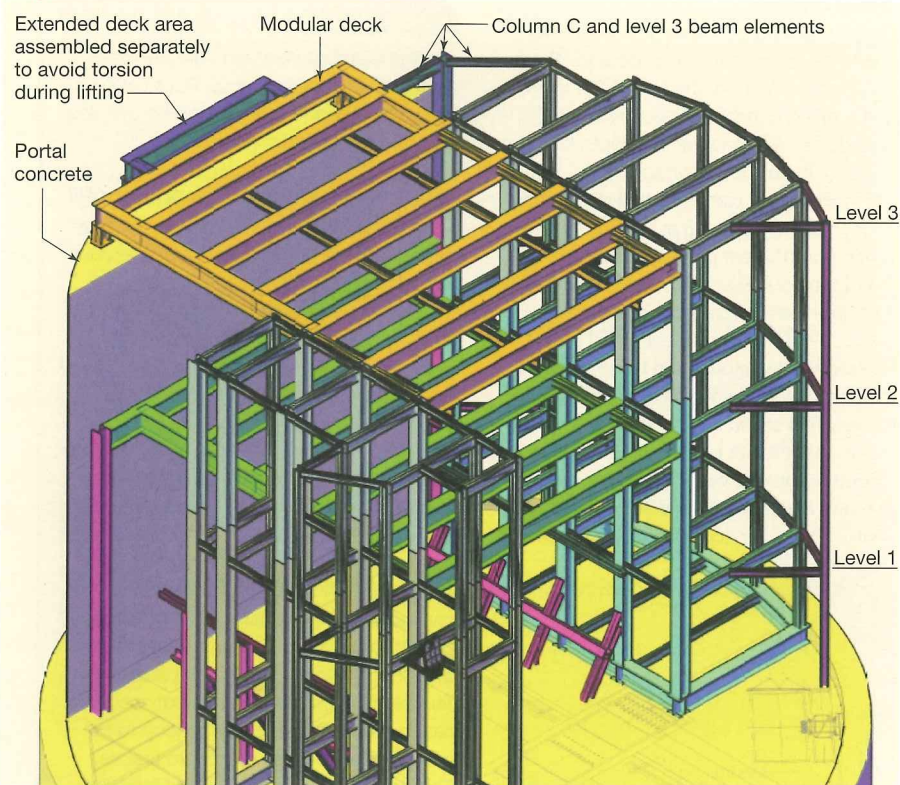
It took five days to pour 16m from the pit bottom to the top of the portal at an average rate of 130mm/h. Modification to the shutter profile took three days before restarting the final 56m height gain taking 12 days at an average rate of 190mm/hr. The 3,300m³ was poured using up to three cranes simultaneously. The entire shuttering system was fully enclosed due to the risks of working at height. Approximately 700t of re-bar was saved using this method. In order to achieve the required hydrostatic concrete pressure when pouring the annulus, the duration of curing was paramount to success. Placing 3,300m³ of



Left: Figure 4, Slipform shutter section



Below: Lowering the TBM



Above: Figure 5, modular components of the pit bottom decking

concrete into a 700mm gap around the top of a congested shaft 75m deep within 36 hours was a logistical headache.

Four tremie pipes and hoppers were distributed evenly around the circumference of the shaft. Each position had to be served by two concrete wagons and a crane for lifting pipes. Trials were carried out to ensure the concrete flow was sufficient to spread out evenly around a quarter of the shaft perimeter so that no uneven loading occurred. Pressure sensors were embedded in the pour at varying levels to give live readings and data logging. This information, along with the experience gained at the overflow shaft will be passed on to assist with the three future pours of this nature.

TBM transport SPMT and big lift

With the launch shaft complete attention was focused on the TBM assembly. Rather than having heavy cranes in attendance for an extended period it was decided to build the main TBM shield body on the surface adjacent to the shaft to be lowered down in one complete lift.

A traditional back-shunt was not a viable option due to the nature of the surrounding ground discussed earlier. TBM sections stored across the site since delivery from Herrenknecht were transported using a

special self-propelled modular trailer (SPMT) easily capable of moving the 150t sections. The forward shield came in four quarters to be bolted together. The cutter head and tailcan were then attached making the weight up to approximately 800t. There are few cranes available in the UK capable of lifting such an amount at the required radius. Once a crane was booked the date was added to the projects critical path to be met at all costs. Assembly was on time and the first of 46 articulated wagons required to deliver and assemble the Liebherr LR11350 crane started to arrive. Some 3km of wire rope on 32 falls were required to reach the pit bottom. The TBM was successfully lowered to the pit bottom on 15 December 2011.

TBM launch works

Operating in standard mode Busy Lizzie is 120m long. A three-storey decking structure was designed to accommodate all the required plant and crucially three umbilical cassettes allowing the machine to mine the required 120m at which point the main gantries could be installed. The decks were designed so that they could be pre-assembled on the surface and lifted down in modular form to fit around the shove frame. Once again programme time was reduced through assembly on the surface.

In addition to the shove frame, a complete steel ring was used along with 15 traditional reinforced concrete rings due to the high thrust pressures. Launch seal brushes and Proserve grout bagging stemmed the water ingress successfully. Once the machine had advanced 20m, a temporary gantry was installed to accommodate flexible slurry hoses allowing up to 6m of mining between pipe extensions. Segments were handled using a launch bogey and winch. A monorail support system was devised to handle the umbilical cables which were extended on top of the temporary gantry.

Particulars

The machine was launched on 26 March on its 6.9km drive. It is due to be completed early 2014. The Herrenknecht Mixshield has an 8.85m diameter, is designed for a maximum 8bar working pressure and has 30 thrust cylinders with a combined force of 84,446kN. Other features include a 4.6bar man lock for interventions and a forward probing drill rig to be used if head interventions prove to be difficult. Further ground investigation and grouting may be mobilised, which serves as a good insurance against the TBM being stranded. The cutter head weighs 120t and is covered with 20 no. 19in disc cutters to manage the flint bands, along with 88 knives and 16 buckets feeding muck to a stone crusher prior to entering the 450mm diameter slurry circuit. The slurry treatment plant is an integral part of the machine capable of processing 1,600m³ of slurry per hour. It was supplied by French separation plant specialist MS.

Segments are produced off-site at Morgan Sindall's precast facility Ridham Dock (see feature, T&T October 2011). The facility features a concrete batching plant by Skako Denmark and moulds by CBE.

The wedge-block ring consists of five tapered segments, two counter keys and key. PDT Profiles EDPM gaskets are cast in place, without the need for adhesives and giving better seating at the corners, and laser checking of the tight segment dimension specifications is provided by VMT. OTB Concrete provided software that, using the readings from embedded thermocouples, gives accurate concrete strength. The ring is 1,700mm long, 350mm thick and weighs 45t. Some 8.8m³ of annulus grout are required to fill each ring pumped through the TBM tailskin.

The tunnel guidance system is provided by VMT and TBM data is captured by IRIS and CAP programmes.

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dates & events

10-11 SEPTEMBER 2012

Baku Tunnelling Congress, Azerbaijan
'Tunnels & Underground Infrastructure of Urban Areas' including extension of metros and tunnels in Azerbaijan, Russia, Kazakhstan, etc. Full paper submission deadline 1 June. Organised by the Azerbaijan Tunneling Assoc with the French Tunneling and Underground Space Association (AFTES). For more info email baku.conference2012@azta-asso.com or view www.azta-asso.com.

18-21 SEPTEMBER 2012

'The Tunnel Connects' Eastern European Tunnelling Congress, Budapest, Hungary
The Hungarian Tunnelling Association is organising this 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> or contact Diamond Congress Ltd., tel.: +36 1 2250210 or email diamond@diamond-congress.hu.

2-4 OCTOBER 2012

No-dig Live 2012, Coventry, UK
The UK's major biennial event showcasing trenchless technology and the best products and services applied to the new installation and refurbishment of underground utilities. 2012 marks the eleventh exhibition. More information at: www.nodiglive.co.uk or for visitor and exhibition enquiries, tel: Tel: +44 (0) 20 8876 1881.

8-10 OCTOBER 2012

Intermat Middle East, Abu Dhabi National Exhibition Centre
See www.intermat-middleeast.com or tel.: +33 1 76 77 12 08.

17-20 OCTOBER 2012

Montreal TAC 2012, Canada
'Tunnels & Underground Spaces: Sustainability & Innovations: Sustainability & Innovations', organised by the Tunneling Association of Canada. For more info contact Wayne Gibson, conference manager, c/o Gibson Group Association Management, Richmond, BC, tel: +(604) 241-1297, email info@tac2012.ca or see www.tac2012.ca.

23-24 OCTOBER 2012

Trenchless Live 2012, Royal Melbourne Showgrounds, Australia
Live event for the Australasian trenchless industry, featuring hands-on and live exhibition and demonstrations of trenchless equipment. Info at: www.trenchless2012.com, or tel: +61 3 9248 5100.

7 - 9 NOVEMBER 2012

13th World Conference of ACUUS, Marina Bay Sands, Singapore
ACUUS presents 'Underground Space Development - Opportunities and Challenges' to focus on new opportunities in developing underground space as sustainable development. More info from E-Quezt Concierge, Singapore tel.: +(65) 6271 2453, email info@acuus2012.com or see <http://www.acuus2012.com>.

22 JANUARY 2013

11th George A Fox NY Construction Conference
Graduate Center, City University of New York, US. Organised by the SME - Society for Mining, Metallurgy & Exploration and sponsored by the Underground Construction Assoc of the SME. For more details tel.: +1 (303) 948-4200, fax: +1 (303) 979-3461, email meetings@smenet.org or see www.smenet.org

28-29 FEBRUARY 2013

Tunnel Design & Construction Asia 2013, Hong Kong
The conference is a platform for tunnelling industry stakeholders to discuss and share best practices in constructing efficient and sustainable tunnel infrastructure. More info at: <http://www.tunneldesignconstruction.com>, or email: enquiry@iqpc.com.sg

18-20 MARCH 2013

TU-Seoul 2013
Intl Symp on Tunnelling & Underground Space Construction for Sustainable Development. Full papers due 31 July 2012. Visit: www.tunnel.or.kr.

22-24 APRIL 2013

12th International Conference - Underground Construction Prague 2013, Czech Republic
The conference consists of technical exhibition, poster session and technical excursions. More info at: www.ita-aites.cz, or tel: +420 296 337 181.

27-29 MAY 2013

Suissetraffic, Geneva, Switzerland
Switzerland will host the 60th International Association of Public Transport world congress in Geneva. The trade fair brings together the railway, aerial cableway and tunnel construction sectors under one roof. More info at: www.suissetraffic-expo.ch, further info at: www.uitp-geneva2013.org, or tel: +41 31 340 11 11.

31 MAY - 7 JUNE 2013

WTC 2013, Geneva, Switzerland
World Tunnel Congress at International Conference Centre. Organised by Swiss Tunnelling Society. For more information tel.: +41 (0)81 725 31 32, email sia-fgu@swisstunnel.ch or see www.wtc2013.ch.

16-19 JUNE 2013

Strait Crossings Conf, Norway
At Radisson Blu Royal Hotel, Bergen. Organised by Norwegian Public Roads Administration and features extreme crossings and new technologies. For more details tel: +47 22 94 75 00, email siri.engen@tekna.no or see www.SC2013.no.

23-26 JUNE 2013

Rapid Excavation & Tunneling Conf (RETC), Washington DC, US
Wardman Park Marriott. Organised by the Society for Mining, Metallurgy & Exploration. For more details tel: +1 (303) 948-4200 or email: meetings@smenet.org.

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.

20 SEPTEMBER 2012

URUP - Ultra Rapid Under Pass - An innovative shield tunnelling technology

Makoto Kanai - vice-president - & Akhiro Nichimori - senior tunnel engineer, both of Obayashi, present the URUP shaftless shield method, especially for congested area, challenging ground conditions and stringent physical and environmental constraints. The presentation will describe how the URUP concept was developed, mechanisms of ground control under shallow cover and review projects where it has been successfully used. The critical issues in 'URUP' technology are tunnel face stability and ground movement control. Innovative methods are used that have been developed through extensive technical research and development.

OCTOBER/NOVEMBER

Annual Health & Safety Course

At ICE, London. Details to be announced.

4 OCTOBER 2012

BTS Young Members: Numerical modelling

Speakers: Anmol Bedi (Imperial College, London), Panagiotis Spyridis (Dr. Sauer & Partners) and Angelos Gakis (Dr. Sauer & Partners).

1 NOVEMBER 2012

BTS Young Members: AGM and Design of openings in tunnels and shafts

18 OCTOBER 2012

Tunnel Security and Blast Analysis

Blast protection design of transport tunnels. Speaker to be announced.

15 NOVEMBER 2012

EPBM & Slurry Tunnelling Principles

Safe operational protocols for full-face TBMs. Speaker to be announced.

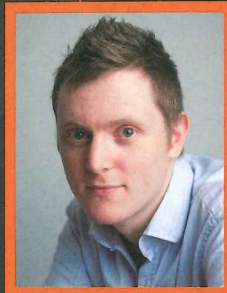
13 DECEMBER 2012

Debate: 'This house believes tunnel projects in the UK are over-staffed and over-specified'

A DATE TO REMEMBER...

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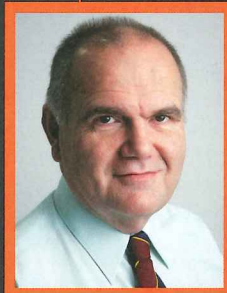
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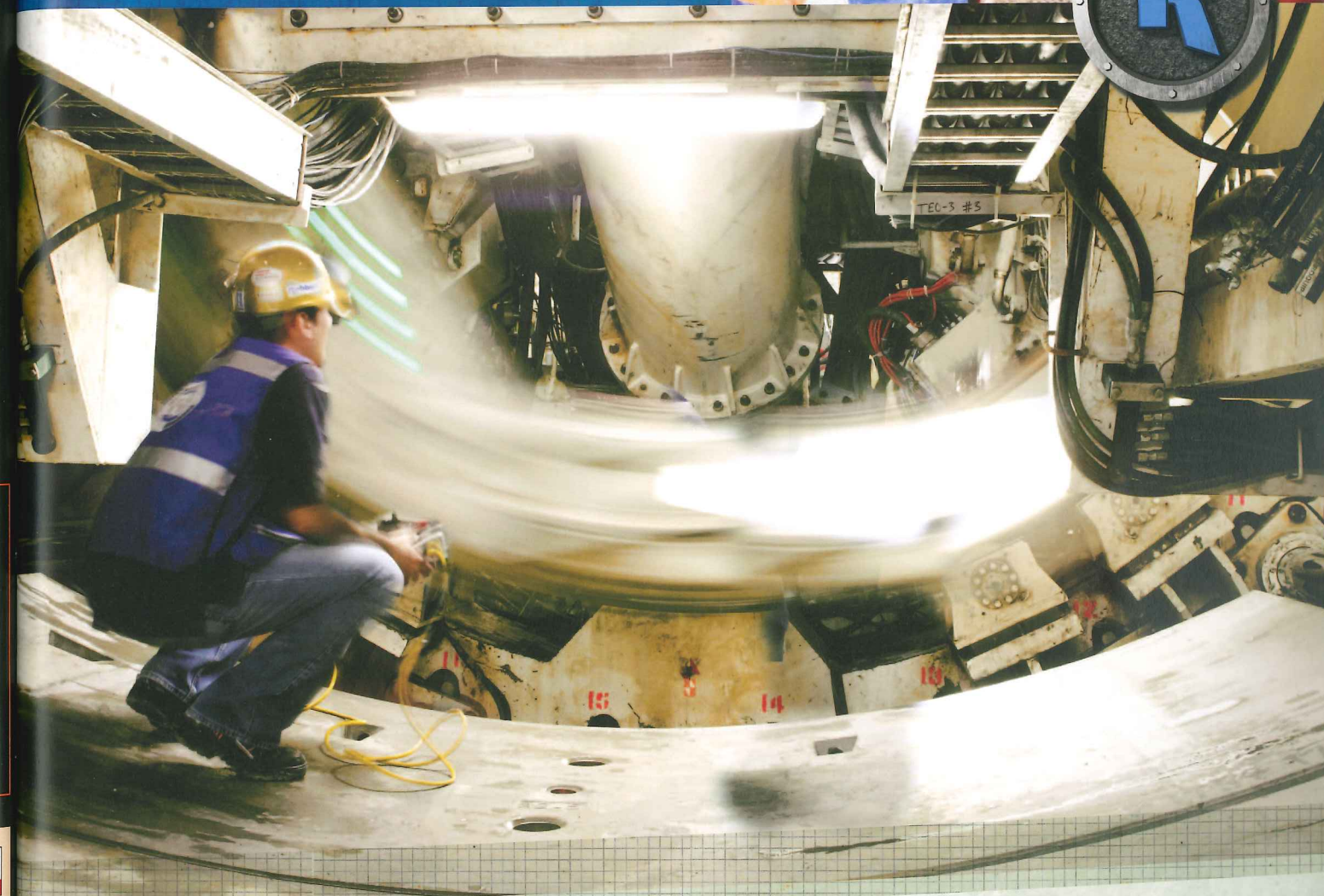
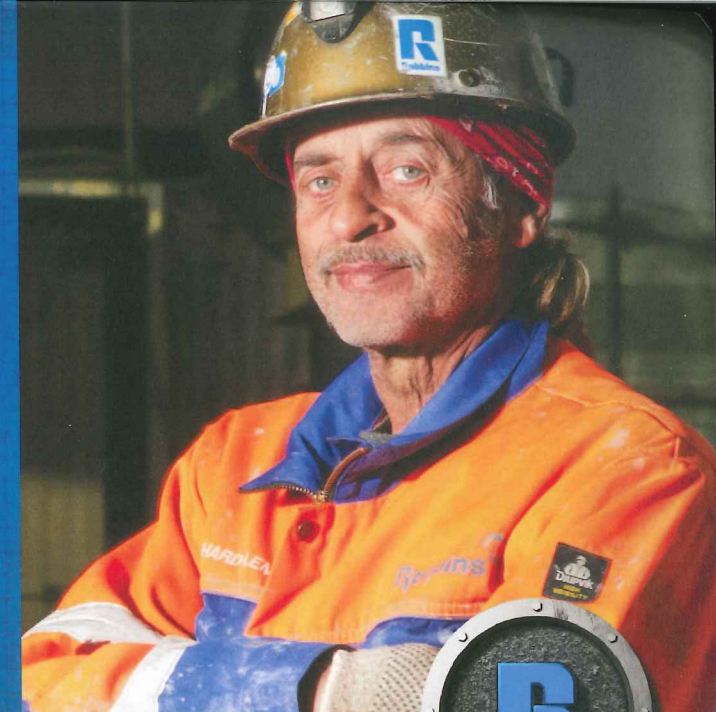
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