MAY 2009

tunnels & tunnelling INTERNATIONAL

CELEBRATING 40 YEARS

FOCUS ON THE 40TH ANNIVERSARY

First published in May 1969, *T&TI* celebrates 40 years of serving the tunnelling industry

WATERPROOFING

A unique spray applied waterproof membrane and its installation is described

NEW YORK SUBWAY: THE TUNNEL BENEATH THE TUNNELS.

Herrenknecht Double Shields are now being employed in the USA for the first time. Two identical machines, each with a diameter of 6.81 meters, are currently being prepared for the extension of Subway Line 7 beneath the New York Borough of Manhattan. Starting at Times Square, they will excavate two 2.8 kilometer long tunnels from early summer onwards, which will run parallel to the Hudson River, and from there beneath 11th Avenue further south. On their way through slate, granite and serpentinite, the two machines must cross beneath several existing tunnels, including the Eighth Avenue Subway Lines and the three tubes of the Lincoln Tunnel, connecting Manhattan with New Jersey. The tunnel construction team is optimally prepared for this job with the Herrenknecht Double Shield technology. So that one of the last gaps in the otherwise dense public transport network can be closed quickly. And so that New Yorkers remain loyal to the their subway in the future.

NEW YORK | USA

PROJECT DATA	CONTRACTOR
S-467, S-468 **2x Double Shield TBM** Diameter: 6,810mm Driving power: 2,100kW Tunnel length: 2,800m each Geology: slate, granite, serpentinite	J. F. Shea Construction Inc., Schiavone Construction Co., Skanska USA Civil

Herrenknecht AG
D-77963 Schwanau
Phone + 49 7824 302-0
Fax + 49 7824 3403
marketing@herrenknecht.com

Herrenknecht Tunnelling Systems USA, Inc.
USA-Sumner (WA) 98390
Phone +1 253 447 2300
Fax +1 253 863 9376

www.herrenknecht.com

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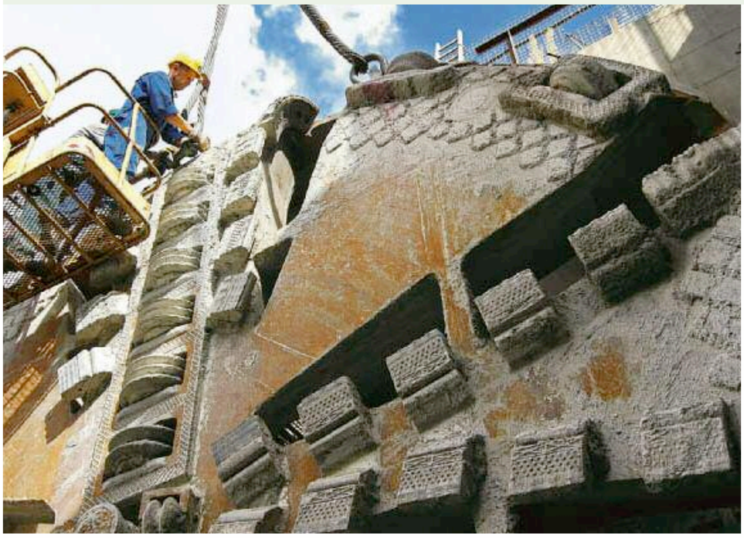


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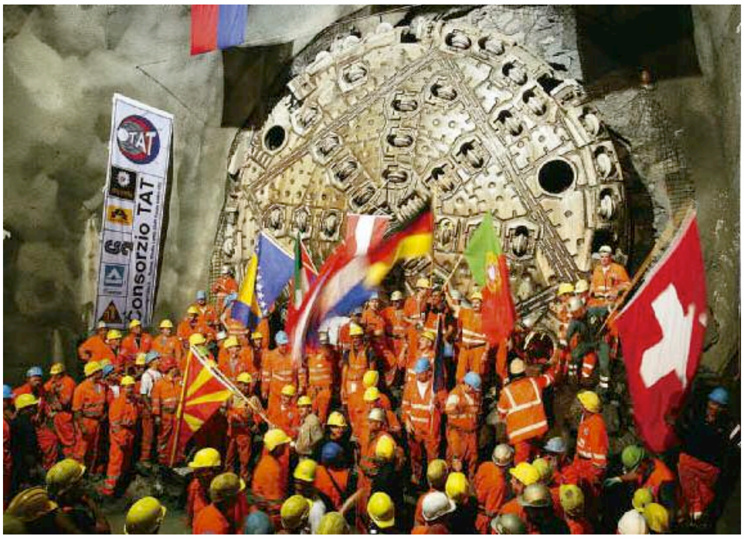
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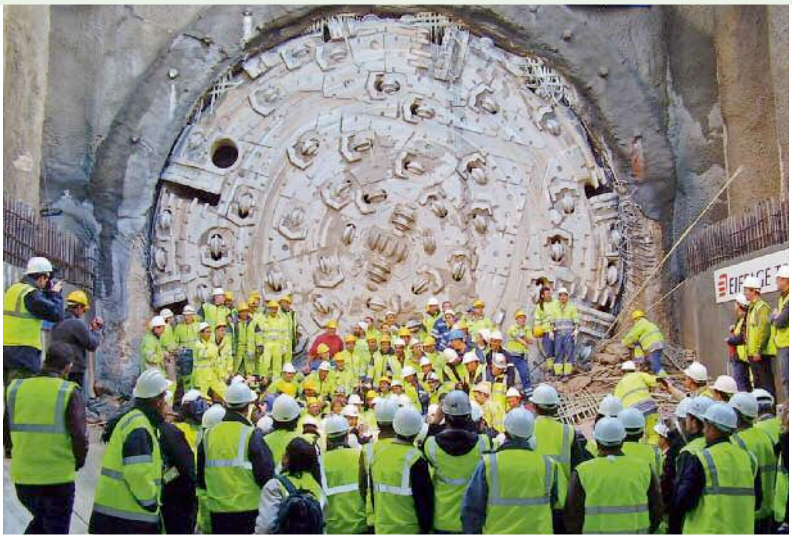

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A date to remember...

There's some very exciting news this month on p55 of the international magazine. We're proud to announce that Tunnels and Tunnelling and the British Tunnelling Society are bringing you the 'Tunnels & Tunnelling Conference 2009', to be held in London on September 29th.

You may be asking, "Do we need another conference?" Well, the truth is, yes. We're not organising this event because there aren't enough conferences, but because there are too many, too many that simply aren't technical, or specific enough for the requirements of the tunnelling engineer.

We've been to a multitude of conferences over the years, some quite excellent, some quite awful, and looked into what makes an event worth attending. We've asked a lot of delegates a lot of questions and come to a few conclusions:

1) There are too many 'brochure' events. These are the type where you spend hundreds of pounds to attend and learn very little that's new. They almost always lack technical information, and often turn into marketing platforms for the speakers.
2) A lack of content focus tends to make a conference feel disjointed, or even incomplete.
3) Way too much is crammed into a day. This goes hand in hand with point 1). Giving a speaker 15 - 20 minutes to present a whole project or technical subject is simply not enough, and something has to give. Unfortunately this is usually exactly the information an engineer is there to hear, the real meat of the subject.
4) There is not enough interaction between delegates and speakers in the form of questions and answers. Healthy debate is vital to ensure we don't keep re-inventing the wheel.
5) Exhibitors are asked to pay way too much, and then have to suffer the indignity of not being allowed into the talks!

So, we and the BTS are organising a day of presentations aimed specifically at you, with the sole aim of ensuring you leave at the end of day knowing more than you did when you arrived! There is also the added bonus of the excellent networking possibilities a crowd of delegates at a BTS/T&TI event will give you. In a nutshell the day will feature cutting edge international site reports, and technical presentations of extreme relevance to the here and now, each up to, or even over 40 minutes long, with time for some serious Q&A afterwards.

We've already lined up some of tunnelling's top names as speakers, and secured the QE II Conference Centre in Westminster, which is regarded as London's finest, to ensure the day runs smoothly for all. Make 29th September a date in your diary to spend with *T&TI* and the BTS, we'll make it worthwhile!

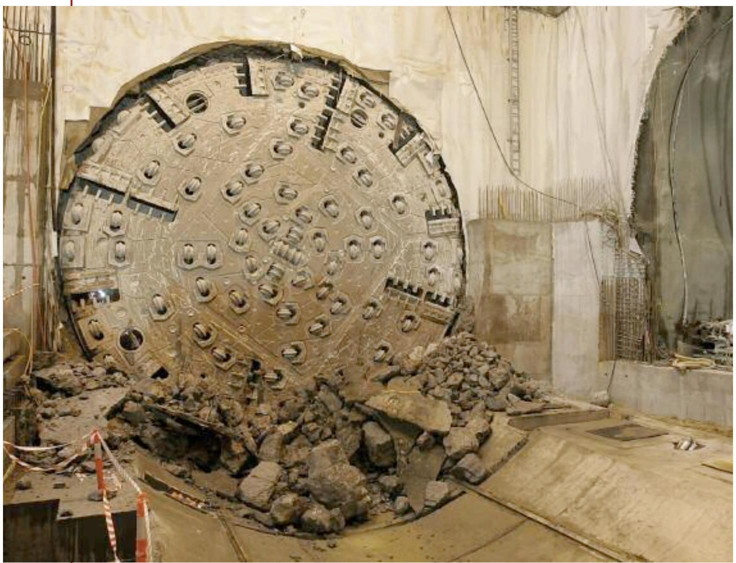
Finally, on another educational note, the BTS is holding its week long 'Course on Tunnel Design and Construction' from 15th - 19th June, at Brunel University, Middlesex, UK. This really is a cracking course for the young engineer. Places are going fast, so for more information go the BTS website: www.britishtunnelling.org.uk or email: lynn.richman@mottmac.com

See you in London on 29th September!

Tris Thomas

COMPANIES IN THIS ISSUE

Brisbane bore finish



Left: First tunnel bore completion at Clem7, Brisbane

The first of two TBMs on the North-South bypass in Brisbane, Australia, holed through last month to complete its 4.3km long drive, and its sister shield is due to finish the twin tunnel by early next month.

Launched in March last year, the 12.34m diameter double shield gripper – S-376, and named "Florence" – advanced 20m per day on average. The launch site was at Bowen Hills and the shield holed through at Kangaroo Point in early December, leaving the 1.5km long second, and last, section to drive to Woolloongabba.

Geology along the alignment comprises mainly tuff (80MPa-150MPa) with some arenites, phyllite with quartz veins, and faulted rock. The cover to the main tunnels varies from 6m to 30m. The contractor encountered less water than expected when passing below the river, *T&TI* was told.

Contractor on the project is LBB JV, a partnership of Leighton Contractors, Baulderstone Hornibrook and Bilfinger Berger. The JV has a fixed time and cost design and construct (D&C) contract with concessionaire RiverCity Motorway to build the 6.8km long North-South Bypass.

The sister Herrenknecht shield– S-375, or "Matilda" – had less than 800m left to bore in mid-April. The TBM was launched on its first, 2.5km long, drive in December 2007 and holed through at Kangaroo Point in January, shortly after Florence. The TBMs will be dismantled and returned to the manufacturer.

The main tunnels, which run up to 60m below Brisbane river, were renamed Clem Jones Tunnel ("Clem7") during the construction phase. Each tube of the toll route will carry two lanes plus safety shoulders.

Tunnel design was performed by Bilfinger. The geotechnical work was done by Golder Associates (*T&TI*, July 2008, p25-27).

Tunnelling work has also involved seven roadheaders for the access and slip road bores plus a short part of the main tubes, the majority of which – 90% – are being excavated by the TBMs.

Production of the 38,000 segments for the tunnels was completed in late March having started in August 2007. The average production rate for the 400mm thick, 2m wide segments over the period was 100 units per day. The precast production plant was supplied by Euroform, and the steel reinforcement fabrication plant for the segments by AWM.

More than 50 of the 60 cross passages and substation passages have been excavated.

Long run over at Dahuofang


Landov/PA Photos

With the completion of excavation last month, the main works on the 85.3km long Dahuofang water transfer tunnel in Liaoning province, China, are over and only some final inner lining work remains to be finished.

Left, below: At Dahuofang - close to finish; early TBM work

Excavation of the 8m wide bore began in September 2006, and was undertaken mostly by three TBM drives (two Robbins, one Wirth, all 8.03m diameter) while drill and blast was used for the other quarter.

The tunnel crosses 50 hills, 50 rivers and 29 faults in north west China.

Three local contractors have built the tunnel: Beijing Vibroflotation Engineering Co (BVEC) with TBM1, a Robbins shield; China Railway Tunnel Group (CRTG) with TBM2, the Wirth machine; and, Liaoning Water Conservancy Bureau (LWCB) with the other Robbins TBM. Each did almost a fifth of the overall tunnel.

In total, the tunnelling work on the project was undertaken through seven contracts, three for the TBMs and four for drill and blast work.

Two of the latter contracts were undertaken by China railway 13th Bureau Co, totalling 13.6km, and the others by Sino Hydro Engineering Bureau 6th and LWCB.

The construction work also required the excavation of 14 intermediate adits and two at the portals. The adit lengths varies from 278m to 2.6km, some of the shorter ones as steep slopes, and the shorter tunnels had cross sections of 5m by 5m while the longer went up to 6.6m by 6m.

The client agency is the Department of water Resources of Liaoning Province, and construction management was done by the Liaoning Runzhong Water Supply Co.

The tunnel was designed by the Design and Research Institute of Water Resources and Hydropower Group of the Water Conservancy Ministry of China for Liaoning Province.

The US$750M, gravity flow tunnel will convey water from the Hunjiang basin to the Dahuofang reservoir, boosting supplies for seven industrial cities - Shenyang, Fushun, Liaoyang, Anshan, Panjin, Yingkou and Dalian.

Left: Olafsfjordur road tunnel bore finished in Iceland

Success in Iceland

Metrostav last month holed through on the drill and blast drive for the second Icelandic state-funded road project undertaken by the Czech contractor.

The 6.9km long drive for the Olafsfjordur tunnel began in November 2006 and the contractor has bored through difficult geology with high groundwater pressures and inflows.

Geology along the alignment in the Trollaskagi peninsula is basalt and sedimentary interbeds, and of widely varying competency. Overburden was 5m-600m.

Although relatively little groundwater was met early on, the drive was to later encounter pressures up to 32 bar, and although there was risk of thermal waters the temperatures found were 2 degrees centigrade. Approximately 630 tonne of chemical grout was required.

The entire excavated length for the tunnel will be approximately 7.1km, including open cuts at each the portals. The cross section is 52.83m^2 (Norwegian profile T8.5) though it is larger at passing places, and the vertical alignment is a 3% incline for almost 5.45km downward and a 1.4km long stretch at 1% rise.

In September 2006, excavation of the first tunnel – Siglufjordur – began and Metrostav holed through to open air a year ago. The mined length was approximately 3.6km and open cuts of approximately 0.2km were excavated at each end.

Metrostav's project director is Ermin Stehlik. The company is in a JV for the project with local firm Hafell, which is doing roads and bridges. Geotek is project supervisor.

The project is being undertaken by the Icelandic Road Administration – Vegagerdin – to reduce the travelling time, and weather complications, for vehicles between the towns of Siglufjordur and Olafsfjordur. Following completion of the 14km long new link the travel distance will be reduced from 60km though it is often far longer because of poor weather in the area (T&TI, September 2007, p6).

Budapest re-start

The pair of TBMs on Line 4 of Budapest metro are set to drive across the river Danube shortly, the preparations also following an agreement between the client and JV contractor that enables suspended works to resume.

In a statement to *T&TI*, the JV contractor Bamco and client BKV said: 'After a series of high level talks between all stakeholders, arrangements have been found that enable work, previously suspended, to resume with the utmost dispatch.

'Preparations are in place to bore out of Saint Gellért Station and start the tunnel drive under the Danube. This will enable the TBM drive tunnels to reach Keleti Station (being the end of Phase 1 of Line 4) by 2010.'

Bamco is a JV led by Vinci with Strabag and Hungarian contractor Hidepito. The client's project implementation agent is DBR, and its representative is Eurometro on the twin tube metro scheme.

The first of the 6.05m diameter shields was launched just over two years ago, near Kelenfoldi main rail station, to drive across the heart of the city, and below the river, to reach Keleti station. Stage 1 of the project consists of eight intermediate stations and the parallel 5.2m i.d. tubes will each be approximately 5.5 km in length, and approximately half have been excavated.

An agreement to the dispute was reached two weeks after the contractor had suspended works and shortly before the client's threatened deadline of the end of April to terminate the contract. The client has said that the contractor was claiming a further US$171M though the contract value is US$304M, but the parties declined to comment on details of the claim nor the negotiations that have enabled work to resume.

Delays and difficulties in station construction, and access in some locations, have also hindered the progress of the project, such as

Above: Budapest metro Line 4-View of TBM south in Saint Gellert Station

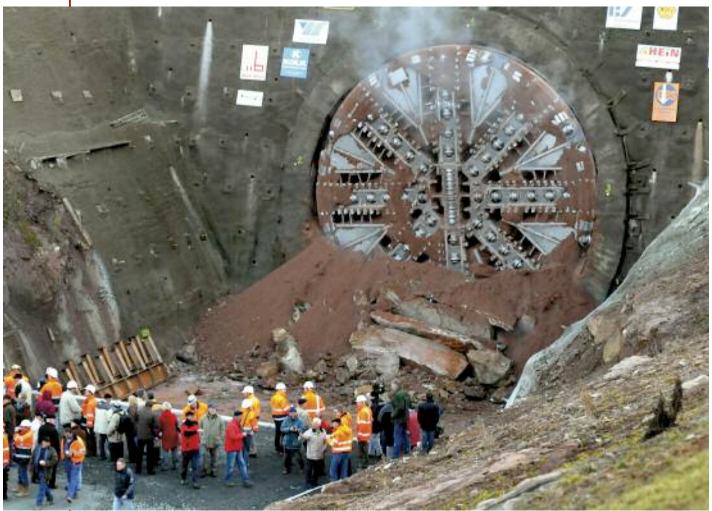
ground freezing treatment required at Fovam station where the TBMs will reach after boring below the river. Late last year, tunnelling was also delayed to await approval from the National Transport Authority over the construction method for the crossover structure at St Gellért station following track layout changes.

Geology along the alignment is different either side of the river, which itself is near a fault. On the Buda (west) side of the river, which has been excavated so far by the Herrenknecht TBMs, the ground is homogeneous with thick Oligocene clay deposits. However, the formations on the other side comprise sand, fine sand, silt and clays covered by river deposits, and combined with groundwater will present more challenging tunneling conditions.

Between Kelenfoldi and Keleti the stations are Tetenyi, Bocskai, Moricz Zsigmond, St Gellert, Fovam, Kalvin, Rakoczi and Nepszinhaz.

Schluechtern finish

The drive for the new, parallel tube for the Schluechtern rail tunnel in Germany has been completed with the breakthrough of Wirth's dual-mode TBM.



The existing Schluechtern tube, on the Frankfurt-Fulda section of the network, was built in 1914.

The 10.24m diameter TBM was launched in April 2007 and holed through in March, having bored the new 9m i.d. tunnel, built of 2m long rings, at a distance of 50m-70m from the existing tube.

The shield excavated the new, 3995m, long tunnel through alternating strata of sandstone and clay.

Equipped with 71 discs plus 268 rippers and teeth, it has a cutterhead torque of 6800kNm in open mode and 20,300kNm in closed mode. Thrust in the different modes are 17,750kN and 24,800kN, respectively.

Following installation of track, electrical and signalling equipment, rail services will switch from the existing 3576m long, twin-track tunnel over to the new tube. During that phase the new tube will also carry twin tracks but eventually both tunnels will be converted to single track operation.

The refurbishment project, which constitute Phase 2 of the project, will also see the old tunnel lengthened by 60m to be 3636m long. In addition, the base of the tunnel is to be excavated up to 2m for construction of a stabilising slab and the new, reinforced concrete inner lining.

The new rail tunnel and refurbishment of the older tube are being undertaken in a US$258M project by the network infrastructure company, DB Netz.

The client is beginning a similar new build and refurbishment project at the Kaiser Wilhelm tunnel (see p13).

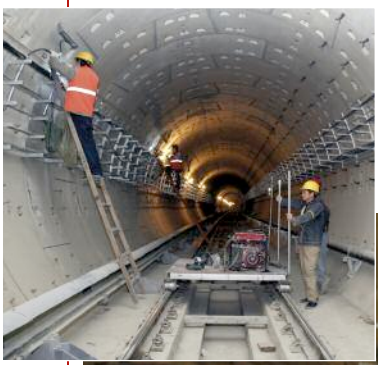
Readying Beijing metro Line 4

Workers making the finishing touches to Beijing's metro Line 4. The 29km long, mostly underground subway line with 24 stations (23 underground) cuts from the south to the north west of the capital, and is scheduled to be operational by September.

Line 4 is being developed under a public-private partnership (PPP) concession with a group that includes MTR Corp, Beijing Infrastructure Investment Co and Beijing Capital Group.

However, the group's funding is required to cover the electrical and mechanical systems as Beijing Municipal Government is financing the bulk of project costs, covering civil works, tracks and some station E&M systems.

The PPP concession for Line 4 was signed in February 2005 and has a term of 30 years from the start of operations. The line runs from Gongyixiqiao station to Anheqiao North station in Haidan District, in the north west of the city.



Landov/PA Photos

Singapore DTSS gets award

Singapore's deep tunnel sewerage system (DTSS), Phase 1, won a plaudit last month as "Water Project of the Year" in the Global Water Awards 2009.

Phase 1 of the scheme consists of a 48km long deep tunnel of up to 7.2m excavated diameter and 6m i.d. plus sewers up to 3m i.d., a deep sea outfall and a water reclamation plant.

Feasibility work was done by CH2M Hill and Parsons Brinckerhoff. Design and construction supervision services were by MWH.

The first phase comprises the 38.5km long North Tunnel and 9.6km long Spur Tunnel, which will link to the later South Tunnel (*T&TI*, October 2007, p23-26).

The project was picked from a shortlist by members of the International Private water Association (IPWA) and International Desalination Association (IDA), and subscribers to Global Water Intelligence and Water Desalination Report.

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Driving at Heathrow

Excavation of a new baggage tunnel at Heathrow airport is half way through using a Dosco roadheader boom.

The 1.8km long tunnel is the key element in airport owner BAA's US$1.35bn baggage improvement plans for the terminals, and will form a key link between Terminal 3 and 5.

The budget for the entire fitted out tunnel is US$390M.

Contractor Ferrovial Agroman, which is part of the Ferrovial group that owns BAA, is boring the tunnel through London Clay.

The 5.51m diameter TBM was launched in mid-February and is due to complete the drive by July.

The tunnel alignment runs on average at a depth of 14m, passing close to fuel lines and rail lines, including the Heathrow Express.

Most recently, it passed within a few metres of the Piccadilly Line. Below the airfield it will reach depths of 35m.

The roadheader boom - 'Beatrice' – is fitted with a hydraulically-operated flipper plate to help loading. The TBM cost US$5M, said BAA.

The 5.1m i.d. precast concrete lining comprises 1m long expanded rings formed of eight segments.

By 2012, following other technological improvements at the others terminals, BAA wants the automated baggage system to be handling 110M bags per year.

Above: Excavation at Heathrow airport for a tunnel that will be key to upgrading the baggage system

Robbins readies shield for Baku bore

Robbins EPBM for Azerbaijan project

Robbins is readying a 6.3m diameter EPBM to bore the first TBM-driven tunnel in Azerbaijan, for the Baku Canal Tunnels project.

In total, the project calls for 5.7km of tunnel excavation but the EPBM will be used only for a 3500m long bore on the government's Samur-Apsheron Irrigation Project.

Last year, when the contractor Azerkorpu was preparing for the job, the plan was for the shield to drive three tunnels – 3000m, 1380m and 1360m (*T&TI*, September 2008, p6).

The TBM's shield was manufactured in Guangzhou, China, where the assembly was also completed last month. The site was chosen for proximity to the central Asian country.

The main parts of the EPBM, however – the bearing, motors, gear boxes, cylinders, electric and hydraulic system – were manufactured in the US, Europe and Japan.

The cutterhead is fitted with discs, rippers and four foam injection points.

Along with the TBM, Robbins will supply the backup, tools, segment moulds and plant, rolling stock, ventilation, spares and operators to the contractor.

The shield is scheduled for a mid-year launch and the drive completed in eight to nine months.

Geology along the alignment comprises hard clay and silty sand with no groundwater. The tunnels are to be lined with 1.5m long, 6.0m o.d. universal rings (5+1) with 300mm thick segments.

The contractor plans to use the shield on several other projects in the country.

More in store for Crossrail

The surge of developments for the Crossrail project has continued with non-exec Chairman Terry Morgan starting half a year early, fewer shafts to be built, the award of Enabling Works Framework Agreements and plans unveiled for the Tunnelling Academy.

In addition, the Department for Transport (DfT) picked Jacobs Engineering UK (supported by KPMG) to be its Project Representative.

Morgan, formerly chief executive of Tube Lines, was to have joined Crossrail in November. His early arrival sees Douglas Oakervee leave after having taken the (US$24bn project through development to win Royal Assent and into procurement.

Chief executive of Crossrail Ltd is Rob Holden, formerly chief executive of London and Continental Railways (LCR) which built High Speed One. Crossrail Ltd was formerly Cross London Rail Links Ltd, and since last December is owned by Transport for London (TfL). Previously, it was an equal JV with DfT.

Crossrail involves excavation of a total of 41.5km of 6m i.d. in twin tube tunnels by an anticipated total of seven TBMs. Main construction work is to start in 2010, the first tunnel drives are programmed to start in 2011 for rail services to commence in 2017.

Eight shafts have been removed from the design following proposals put to London Fire Brigade (LFB). Last year, LFB agreed in principle to fewer of the approximately 9m diameter shafts for use as permanent access and ventilation structures. The key structures in emergency incidents will be cross passages to enable evacuation and also allow LFB and services get nearer to the site of any incident.

Enabling Works Framework Agreements have been awarded to 17 companies, grouped for bid opportunities in four areas – site facilities, demolition, civil structures and utilities. The firms with the four-year agreements are:

Site facilities: Select Plant Hire; BAM Nuttall; and, Fitzpatrick Contractors.

Demolition: Laing O'Rourke Construction; John F Hunt Demolition; Keltbray; Brown & Mason; PJ Carey (Contractors); BAM Nuttall; Kier Construction; and, McGee Group.

Civils: Laing O'Rourke Construction; Costain Skanska Construction JV UK; Carillion Civil Engineering; Kier Construction; Morgan Est; J Murphy & Sons; and, Balfour Beatty.

Utilities: Morgan Est; Costain Skanska Construction JV UK; McNicholas; J Murphy & Sons; Clancy Docwra; and, Laing O'Rourke Construction.

A Tunnelling Academy is to be launched in Spring 2010 as a partnership between the construction industry and Crossrail, and is to train about 1000 people to 2015.

Bechtel, recently named Project Delivery Partner is also to have similar role for Network Rail's involvement in the project (*T&TI*, April, p7).

Faber Maunsell now Aecom

Completion of the integration of Faber Maunsell in to the US-headquartered Aecom Group has seen the UK company restructured and rebranded to be Aecom Ltd.

Faber Maunsell was established over 2001-2 when Aecom bought the firms Oscar Faber and Maunsell. The business continued to grow, including by acquisition, and had three business division with the tunnelling activities in the transportation division. Following the full integration, Ken Dalton, the chief executive of Faber Maunsell, will become chief executive of Aecom Europe, which is a new position.

A series of other European units of the Aecom group have also been rebranded as part of the wider integration process. The restructure has seen the locally-based, but often globally reaching various firms move into a matrix management structure along both business and geographical lines. No job losses result from the changes.

Remaining in transportation, the tunnelling activities of Aecom Ltd are now part of the global management matrix. Aecom is part of the Transcend JV that recently was awarded the Programme Partner contract on Crossrail, and it is involved in the expansion of the 2nd Ave Subway in New York.

Patel at Bargi

A JV of Indian contractors Patel Engineering and SEW Infrastructure is to build a 12km long bored tunnel as part of a turnkey package of works for part of the Bargi Diversion Project in the state of Madhya Pradesh.

The 10m diameter tunnel is to be excavated by TBM, and Patel said it planned to use the shields to complete the key part of the major water project project ahead of schedule.

Details on the excavation programme for the project were not immediately available.

However, the JV expects to complete the package of works within 36 months. The client's pre-tender estimation of the construction period was 48 months.

The underground works on the Bargi Right Bank Canal (Sleemanabad Carrier Canal) section of the water resources project will also include approximately 900m, in total, of cut and cover reinforced concrete transition structures.

The Narmada Valley Development Authority (NVDA) awarded the JV an engineering, procurement and construction (EPC) contract worth US$162M to build the tunnels as well as approximately 13km of canals.

Patel's JV partner, SEW Infrastructure, was formerly SEW Constructions.

Robbins shield for Theun Hinboun

Robbins is to supply a single shield TBM to bore the headrace for the Theun Hinboun enlargement project in Lao PDR.

The 7.6m diameter machine has been designed for squeezing ground conditions with an articulated cutterhead to drive the 5.5km long tunnel for the hydro project. Robbins is assembling the shield in Ohio for shipment in July to Italian contractor CMC di Ravenna.

Geology along the alignment of the headrace comprises sandstone, siltstone and mudstone in alternative strata.

Tunnel lining will have 1.6m long rings (5+1) of 7.46m o.d. formed of 280mm thick segments. The finished diameter of the tunnel is to be 6.9m i.d.

Segment moulds and the carousel for the lining is being supplied by Italian firm Euroform, which is a subsidiary of Herrenknecht.

Cavico is building a 1km long starter tunnel and shaft for TBM retrieval (*T&TI*, February, p14).

The developer is Theun Hinboun Power Co, and the plant is to finished by 2012.

FCC bags German rail jobs

The FCC group has been awarded two contracts in Germany by the infrastructure arm of national network company, DB Netz, to build a new, parallel tube for the Kaiser Wilhelm tunnel west of Koblenz and the Baumleite tunnel near Erfurt.

A JV of Alpine Untertagbau, Alpine Bau Deutschland and FCC Construccion is to excavate the new 4.24km long, single-track tunnel alongside the existing Kaiser Wilhelm tunnel, which is on the route between Koblenz and Perl. The bore will be undertaken with a 10.12m diameter TBM.

Geology along the alignment consists partly of slate and clay-shale with a 250m long loose zone. Cover to the tunnel ranges from only about 10m up to 250m.

The existing tunnel was built in 1877 between Cochem and Ediger Eller stations, and is just over 4km long. It is to be refurbished with reinforced concrete lining to a width of approximately 9m as part of the upgrade. The new and refurbished tunnels are to be linked by eight cross passages, each 15m long.

The value of the awarded contract is approximately US$106M and construction is scheduled to be completed by late 2011. When procurement got underway, in 2007, the budget was estimated at about twice that level for a mid-2008 start and completion was expected by 2014.

A separate contract to build the 1.32km long Baumleite tunnel was awarded to Beton und Monierbau, which is a subsidiary of Alpine Bau, part of the FCC group.

The tunnel will be excavated by drill and blast through limestone and marl with up to 30m cover and the tunnel lined with shotcrete. The works on the three year job also includes a 40m deep emergency exit shaft.

HCC wins in Bhutan

A package of tunnelling works is to be done by Indian contractor Hindustan Construction Co (HCC) as part of major civils contract on the Punatsangchhu-I hydro project in Bhutan.

HCC is to excavate the headrace tunnel, surge shaft, butterfly valve chamber, pressure shafts, powerhouse and tailrace tunnel on the project. Combined with hydro-mechanical works, the contract package is valued at US$137M and is to be completed in five and a half years.

Separately, Larsen & Toubro (L&T) is building a diversion tunnel as part of the dam construction works package.

The plant is being built on the river Punatsangchhu in the west of Bhutan. The project is the first of 10 major hydro schemes that India is helping to develop in the country over the next 10 years.

In India, HCC was also recently awarded contracts involving tunnelling works on the Kashang, Kishanganga and Teesta VI hydro power projects.

For the Kashang project, in the state of Himachal Pradesh, the contract involves excavation of the headrace tunnel, an underground balancing reservoir, an underground powerhouse and a tailrace tunnel.

In addition, the package includes various of other civil works. The client is Himachal Pradesh Power Corp.

National Hydroelectric Power Corp (NHPC) awarded a turnkey contract to an HCC-led JV to build a 23.5km of headrace tunnel and an underground powerhouse as part of the civil works for the Kishanganga project. The plant is being built in Jammu & Kashmir, and the package also involves dam works.

Impregilo JV gets Milan job

A JV led by Impregilo has won a contract near Milan calling for tunnelling work along almost a quarter of the approximately 33km long toll route.

Tunnel excavation is to be undertaken over 5.5km of the new link road – the Milan Outer East Orbital. The project also calls for 2.1km of cut and cover tunnel construction.

The total budget for the project is approximately US$2.1bn. Design and construction is expected to take six years.

The client that awarded the contract is Concessioni Autostradali Lombarde, and a 50-year infrastructure management concession was agreed to run from the finish of the construction works.

The project promoter is Tangenziali Esterne di Milano, which includes a number of regional road concessionaires.

Impregilo's concession partners include Milano Serravalle Engineering, Spea, Sina, Proiter, Technital and Girpa plus finance and other companies.

Dublin metro hearing paused for evidence review

The oral hearing for Dublin Metro North was adjourned last month for evidence to be reviewed, and the procurement process still has bids from four shortlisted groups under consideration.

The client, the Railway Procurement Agency (RPA), commented that the decision to halt the break in the hearing was expected to last until late May. The adjournment came after the completion of RPA's evidence to the hearing.

The 18km long project will run north-south and involve construction of twin tunnels of 6.75m excavated diameter for part of the route.

A crossover cavern in limestone, and cross passages at nominal spacing of up to 250m are also to be built.

Geology along the alignment consists mostly of limestone bedrock overlain by glacial till gravel, sands, silts and clays. However, it was identified in early studies that tunnelling challenges would include weak ground in sections and also some shallow excavation to link with stations. EPB or slurry shield bores are expected.

The project is being developed on public-private partnership (PPP) basis, Tenders were received from:

* Cathro (Fluor Ireland, BAM, Siemens, Strabag and Veolia);
* Celtic Metro Group (Barclays Private Equity, Obrascon Huarte Lain, Mitsui, Soares da Costa, Iridium Concesionesde Infraestructuras, CAF and MTR);
* Dublin Express Link (HSBC Infrastructure Fund Management, Meridiam Infrastructure Finance, Acciona, Bouygues, SIAC, Alstom and Keolis); and,
* MetroExpress (Macquarie Capital, Global Via Infrastructuras, Allied Irish Bank, Bombardier and Transdev).

The winning concessionaire will have a 30-year concession to design, finance, build and operate the link from the Lissenhall area via the airport to the city centre.


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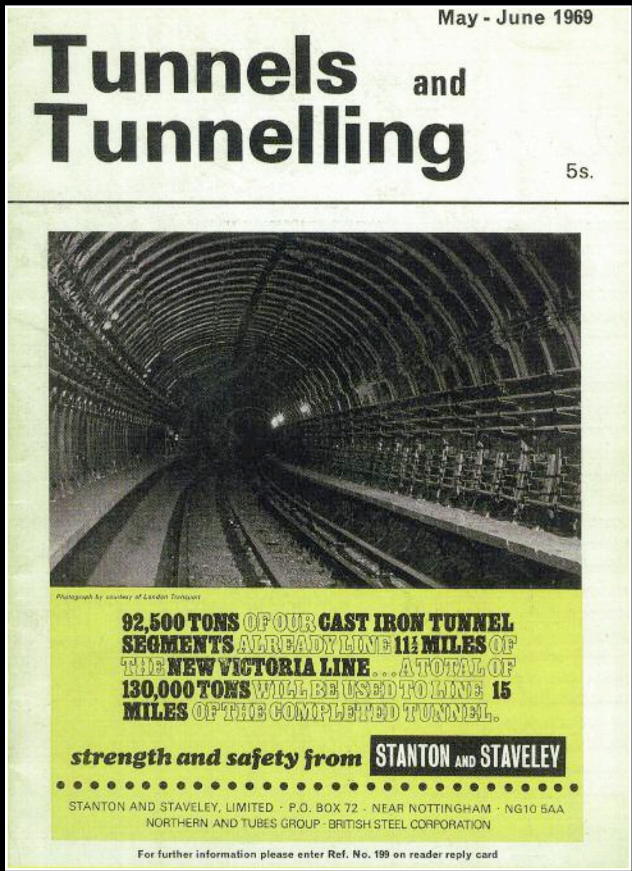
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Forty Years of Tunnels & Tunnelling

A retrospective view by Colin Mackenzie

When I reflect on the changes which have occurred in the UK tunnelling scene since the first issue of *T&T*, in 1969, the aspect which surprises me most is the virtual disappearance of the contractors and manufacturers who dominated the industry at that time.

Gone from the industry, as standalone companies, are the elite organisations such as Brand, Kinnear Moodie, Mitchell Brothers, and Mowlem, together with key equipment suppliers such as Markham, Priestley and Lawrence. Balfour Beatty is the sole independent survivor of the companies which constructed the first phase of the LUL Victoria Line, which was reaching completion at just about the time that *T&T* first saw the light of day. Consulting engineers have fared rather better. The two premier practices of Halcrow and Motts continue to thrive, but they now have to compete with numerous others for work which, forty years ago, important tunnel clients such as LUL used to award almost exclusively to them.

However, in my opinion, the damage wasn't done by LUL, or by its preferred Engineers, but rather by later policies and practices of bodies such as privatised and local authorities, government departments, and their associated professionals, who, collectively, did not conduct their affairs with the high levels of technical competence and contractual integrity of LUL, Halcrow and Motts. The "disappeared" contractors were themselves not blameless. Their engineers and managers were slow to adapt to the changes in the commercial environment, and took risks which gave rise to losses which disillusioned their Main Boards and shareholders, and caused them to withdraw from tunnelling. It is ironic that, in some cases, they were replaced by contractors whose Boards, after initial enthusiasm for tunnelling, gradually came to the view that the industry was not as attractive as they had imagined it to be, and who themselves withdrew from the scene.

But not all the newcomers quit. Those who have persisted, together with large international companies which have entered the UK, have benefited from the new forms of contract and project management which have been used on the large projects which have developed in the UK in the last twenty years, mainly in response to European water industry directives and a need to improve the general infrastructure of the UK. These projects have seen the introduction of formal Partnering procedures with more enlightened management and allocation of risk, and with close technical and commercial cooperation between all the contracting parties, the supply chain, the HSE and neighbours affected by the works.

The scale of these projects has also enabled the industry to apply very important developments in TBM technology from Japan and Europe which have greatly increased tunnelling productivity and which have made it possible to tunnel safely, reliably and economically in soils which were completely beyond the reach of earlier machines. Developments in tunnel linings have made it possible to construct watertight tunnels in soils with high water pressures. The recent very successful completion of the CTRL tunnels illustrates just how far the industry has advanced in these fields in recent years. In less challenging soils, developments in sprayed concrete linings have been reasonably successful and are encouraging.

Long may this period of enlightenment continue. It is predicted that dramatically increased urbanisation will characterise life later this century as the world struggles with the consequences of global warming. Tunnellers will be called upon to make crucial contributions to the survival of the populations of these urban centres. It will be a struggle for life which will demand the best from all involved. On the basis of recent evidence, I am confident that tunnellers will not be found wanting. T&T

Colin Mackenzie retired in May 2001 after a 40-year career in Civil Engineering. Colin's first major project was as a graduate civil engineer working for Mitchell Construction on the Awe Hydro Electric project in Scotland. After three years on site, Colin swapped the hard rock environment for a soft ground challenge working for Mowlem on the Victoria Line Project in London. Colin remained at Mowlem for 24 years working on a vast array of major civil engineering schemes, becoming Director of Mowlem Civil Engineering Ltd from 1982 - 1988. In 1988 Amec engaged Colin as its Director for Tunnelling. He completed his career as Resident Project Director on Contract 102 of the Jubilee Line Extension Project.

Colin was on the British Tunnelling Society committee for nine years including two years as Chairman in the early 1990's, and was a recipient of the Telford Gold Medal of the Institution of Civil Engineers and the James Clarke Memorial Medal of the British Tunnelling Society.

T&TI and the ITA

ITA president Martin Knights reflects on the long-standing relationship between the ITA and *T&TI* and describes how the ITA has evolved

ITA and *T&TI* are contemporaries in many ways. We were both conceived in the halcyon days of major infrastructure activity in Europe in the late 60`s -early 70`s. Our conception was a union of the then significant tunnelling activity and the need to share knowledge in the international tunnelling community. Like any good partnership the founding values have held true and despite the ebb and flow of world events in the past 40 years the tunnelling industry is prospering, and I believe has a great future. That future is founded on the premise that we can attract the skills, talent and resource needed to identify, plan, design, construct and operate underground infrastructure. It is founded on continuing to respond to media and owners to proactively promote the use of underground space. And vitally on our collegiate efforts to make our industry safe in construction and operation, and attractive to owners and the public.

ITA evolution

The ITA has progressed from its formation in 1974 - when 19 nations met to hold the first Annual Congress - to a thriving organisation of 54 member nations - with prospective new members yet to be enrolled.

It has stayed true to its original founding tenants but the increased number, and needs of the member nations requires constant adjustment of strategy in a world that demands knowledge, forums and networking. An individual's needs can vary from requirements for technical and planning knowledge; benchmarking of world current best practise; identifying seminars, conferences etc where that knowledge can be shared; where contacts can be made, partnerships made and intelligence gained from industry, academia, clients and government and owners. Both ITA and *T&TI* meet that need. On a personal note I would congratulate *T&TI* on the way they have adapted the format and style over the years to meet the expectations of the readership

Communication is an important requirement for ITA members. We too have adapted to the needs of our members through our website, newsletter, forums, Working Groups and Committees. Year 2000 saw a major rethink of Strategy. We realised that over nearly 30 years our size, needs of membership and expectations of Associations like ITA had changed since our conception. Fundamental to this was electronic communications, which suited the International organisation. We grasped the opportunity, began to change the structure of the Secretariate and to add to the services that we were prepared to provide.

ITA aims

However, the core aims of the ITA had to be maintained and the value of the Working Groups has always been at the centre of our strategy and that of the subsequent updates to the strategy in 2007 (my mandate on being elected President in Prague 2007 was to make sure that we implemented and achieved the aims and objectives of the 2007 Strategy and the Excom monitor/correct our actions to achieving this at each quarterly meeting).

Some of the current aims of ITA include:

- To encourage new uses of underground space
- To encourage studies of underground alternatives to surface construction
- To stimulate the development of guidelines
- To raise the profile of our special committees on training, communication and operational safety
- To encourage the development of better and cheaper underground structures
- To improve training
- To arrange international exchange

These aims are basically those of the founding members, but the requirements to serve those aims have increased and are more complex and detailed.

New ITA Committees

Recently we have established 2 new Committees to focus on the evolving needs of members and their requests. We formed ITACUS (Committee for Underground Space launched in Amsterdam in January 2008) under the Chairmanship of Hann Admiraal. ITACUS will assist ITA to identify proactive means of communicating with Govt, Owners, Clients, Media, Industry, Profession and Public i.e., communicating our aims, demonstrating cost saving and sustainable subsurface options through Guidelines, Position Papers and offering a response to the media when events occur in our industry.

Above: **Martin Knights, ITA President**

Also we formed ITACET last year (Committee for Education and Training in Turin in May 2009). Chaired by Andre Assis, it will set up, manage and maintain a training organisation that will give week-long seminars on dedicated industry topics such as Sprayed Concrete Linings, Safety etc. The technical content will be based on the relevant Working Groups. There has been great interest in the formation of this Committee, with active interest from China, USA, Europe and South America and our recent meeting in Frankfurt maintained the enthusiasm for this Committee.

In 2005 we founded COSUF (Committee for Operational Safety) chaired by Felix Amberg. Again the momentum of interest is being maintained under Felix and COSUF meets 2-3 per year, where attendees can network with operators, owners, fire and emergency representatives, research bodies and suppliers/manufacturers and designers. It's an excellent forum for Operational Safety and to benchmark best practise.

Evolution and leaders

Perhaps the greatest advances in tunnelling over the past 40 years have been in the evolvement of the TBM. Three of the leaders of the the ITA's 13 valued sponsors have achieved memorable landmarks recently and their values demonstrate this.

Above: **ITA Presidents past and present, from the left, Alfred Haak, Martin Knights, Harvey Parker, and Andre Assis**

Richard Robbins was recently awarded (April 09) the Benjamin Franklin Award in Philadelphia for pioneering the TBM, Richard Lovat celebrated his 80th birthday and a long influential career in developing soft ground TBMs in Toronto in September last year, and Martin Herrenknecht was deservedly awarded the USA Tunnelling accolade from the US Moles in New York in January 2009. The citation was for extraordinary services to the heavy construction industry particularly for innovation and development of mechanised tunnelling. TBMs have certainly advanced over 40 years or so when John Bartlett first patented his ideas for building TBMs that could excavate and line tunnels in soft, varied, water bearing near surface, high hydrostatic conditions.

Of course it goes without saying that the profession lost a great leader earlier this year. The ITA founding President Sir Alan Muir Wood left a great legacy in ITA and he will be sorely missed. Alan wrote and spoke in an unequivocal language and was genuinely motivated to do what he thought was the right thing - compromise of principles was not his style!

Industry recognition

I can't deny recognition for developments and advances in hard rock tunnelling machines either. Nor can we ignore advances in telemetry, mucking and conveyancing systems, significant contribution of sprayed concrete linings in challenging complex environments, material improvements in durability, fire resistance and cost reduction. But the editor wouldn't give me more space!

So I applaud all the leaders of the designers, academic bodies, research organisations, constructors, plant, machinery, equipment, material suppliers and manufacturers for their innovation. They have responded to the market and sought to bring products that add value, reduce costs, and are sustainable. Without you the clients wouldn't be making the decisions to use the underground to solve infrastructure needs - especially where tunnelling and underground solutions are used in complex urban locations where a surface option might have been the traditional approach. Thank you.

Happy birthday!

T&TI owes thanks to its dedicated, good and relevant journalism and editorial team and its Advisory Board. They have responded to the growing market over the last 40 years. The Journal serves our industry well and will adapt in future as the needs and expectations of the readership require. ITA recognises the past 40 years of tunnel journalism shown by *T&TI* and wishes the journal a successful future. T&T

Life on the cutting edge: Dick Robbins

In recognition of his lifelong career as a key innovator and inventor of rapid tunnel boring technology, Richard J Robbins was recently awarded the prestigious Benjamin Franklin Medal for Engineering. On the eve of *T&T*'s 40th Anniversary, contributing editor Amanda Foley, spoke to the former president and CEO of The Robbins Company about some of the firm's key projects and developments, which have helped shape modern-day TBM tunnelling

It wasn't until the early-1950s, when the Robbins family made history designing a series of successful full-face rock boring machines for the Oahe Dam Project, in South Dakota, that conventional drill and blast excavation ceased to be the only construction method for tunnels in hard rock.

There had of course been previous attempts to develop mechanised rock tunnelling machines, the most notable being Henri-Joseph Maus' percussion drill locomotive, which was fabricated in 1846 for the Mont Cenis tunnel; and Charles Wilson's cast iron tunnelling machine, which was built in 1853 during the construction of the Hoosac Tunnel. But, by the 1920s, after the repeated failures of almost every rock tunnelling machine invented, interest in their development faded.

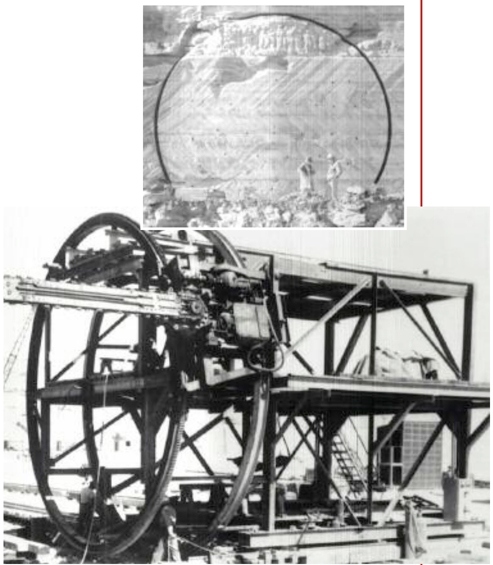
This remained the case until 1952, when the Oahe Dam Project began. The Oahe Dam involved four major contracts comprising seven diversion tunnels and five power tunnels in the 7.5-9m range. One of the project's initial contractors, FK Mittry, had witnessed a rotary pre-cutter being used on the nearby Fort Randall Reservoir Project, which was being used to carve out a smooth tunnel profile prior to blasting the remaining core. Mittry approached the fabricator of the unit, the Goodman Company, and asked if it would develop a similar machine for use on his diversion tunnel contract.

Goodman suggested James Robbins, the company's consulting engineer, as a candidate to design and oversee the machine build. After looking at the job however, Robbins convinced Mittry that it would be more practical to engineer a full-face rotary boring machine for the project.

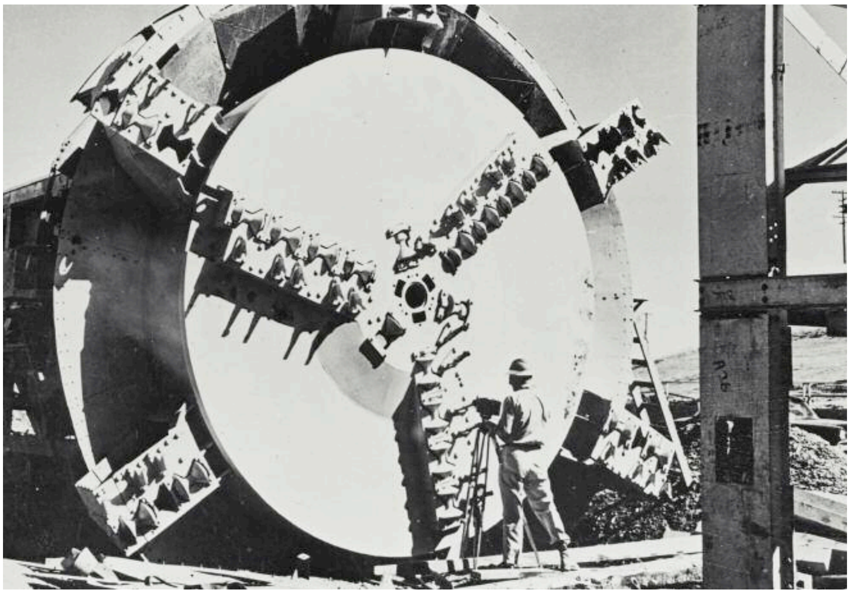
Designated Model 910-101, the resulting 7.8m diameter 'Mittry Mole' incorporated two circular counter-rotating heads. Both inner and outer cutterheads were dressed with rows of fixed tungsten carbide drag picks together with parallel rows of freely rolling steel discs, set slightly behind the fixed cutters, the idea being that the discs would fracture the ridges of rock left between the groves cut by the picks. TThe head was driven by two 149kW motors and mounted onto a structure called a jumbo that advanced hydraulically, installing ring beams as it went.

Despite a steep learning curve and a high pick replacement rate, the machine tackled the job superbly, achieving advance rates of about 45m per day in the region's soft Pierre shale. History was made, and so impressed were the project contractors that a second large diameter TBM was ordered.

Following the first two Oahe machines, Robbins produced a series of three much smaller TBMs for sewer tunnels in Pittsburgh and Chicago. However, the inter-bedded shales and hard crystalline limestone encountered on these jobs highlighted a



Below: **The Goodman pre-cutter, and (inset) profile cut prior blasting, used on the Fort Randal Reservoir Project**



Below: **James Robbins' history-making rock TBM (Model 910-101), commissioned by Mittry for the Oahe Dam project**

major problem with the machines. At the time, James' son Richard (better known as Dick) was home from college and working for his father during the holiday. So high was the failure rate of the picks that one of Dick's jobs was to count them passing by on the conveyor. None of these machines drove more than 30m.

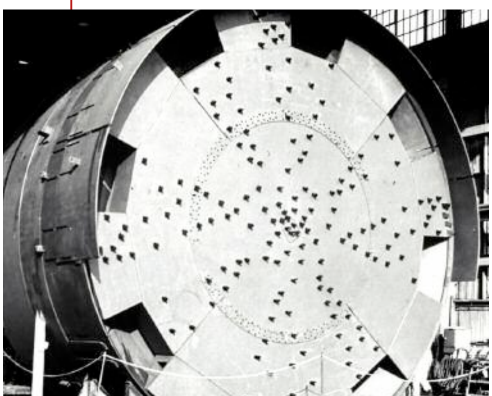
Therefore, in 1956 when a new 3.28m diameter machine was ordered for the Humber River sewer tunnel in Toronto, Canada, Robbins designed a cutterhead layout that allowed experimentation with the tool configuration. The cutterhead was designed so that the fixed picks could be removed altogether allowing the machine to bore using disc cutters alone. The machine worked just as effectively, but the discs actually wore far better in the harder material. It was a major breakthrough for the company. The machine successfully bored through 4.5km of inter-bedded sedimentary rocks with strengths of up to 200MPa.

In late-1958, two years after earning his degree in mechanical engineering from Michigan Technological University, Dick Robbins went to work with his father. Tragically, just a few months later, his father James died in a plane crash.

At the time the company had been working on its third large diameter machine for the Oahe Dam project and so in order to get the machine finished, aged just 25, Dick took over the management of the company. "It was tough," says Dick, "but there were about twenty-one people at the company then, a third of them engineers and the rest shop and field workers, so I had that group to help get the machine built and put into service." The third Oahe machine began tunnelling in 1959 and was an all-round success, but with the news of James' death having spread, work dried up.

It was then that Dick found some correspondence his father had started with

Above: The Robbins 'Etoile' pressurised bulkhead machine



the Hydro-Electric Commission (HEC) of Tasmania, who remained interested in purchasing a custom-designed tunnel boring machine. Dick followed this up and six months later, in June 1960, he got the contract to build a hard rock machine for the Great Lake Power Development, near Poatina in northern Tasmania.

The contract was a major turning point for the business. Dick had been forced to let go of nearly all the company's employees due to the lack of work, but he managed to pick up a team of engineers from a shipping crane firm and quickly got the company back on its feet. It took him just six months to build the Poatina machine, which featured a number of developments based on his father's ideas, including a new disc cutter design and a floating gripper system.

The machine was a huge triumph. It broke all existing excavation records at the time and convinced the world that, given the right machine, hard rock tunnelling machines could provide a viable alternative to drill and blast tunnelling.

The next major machines Robbins built were a 7.8m diameter unit for the Saskatewan Dam project, which Kiewit used to drive five diversion tunnels; and an 11m diameter machine for a water diversion project in Pakistan. These two machines went on to break further records, achieving speeds three to four times that possible with drill and blast. "These were the projects that really pushed contractors towards TBMs," says Dick. "Their speed, combined with the lack of overbreak, offered big potential cost savings." A lot of owners, designers and contractors went on to try and use machines in bad ground or very hard rock and those projects weren't so successful. "That was the next big step, the next frontier," says Dick. "Then, later, dealing with water."

The company didn't have to wait too long for this challenge. In 1964, French contractor, Etablissements Billard, ordered a 10.3m diameter machine to drive through highly variable ground below the watertable, for a metro tunnel in Paris. The resultant 'Etoile' machine was the first ever TBM to utilise a pressurised face. Located behind the machine's cutterhead was a steel bulkhead, which formed an airtight compartment at the tunnel face. Loading buckets within the chamber were used to direct the muck into a double-hopper airlock system, mounted on a dolly at the rear end of the conveyor, allowing minimum loss of compressed air. Despite some early problems, the 'Etoile' machine managed to complete its 2.8km drive through ground ranging from hard limestone, mixed limestone and clay and silty sand, averaging about 8m per day.

In 1967, Dick met Carlo Grandori, the founder of SELI, who had visited Seattle on a fact-finding mission. Grandori was planning to bid for the Orange-Fish project, in South Africa (featured on the cover of the first issue of T&T, in 1969) and was considering the possible use of a tunnelling machine. "We had lots of discussions, trying to convince the client to use a boring machine," says Dick. "In the end a machine wasn't chosen for the project, as the client wasn't convinced the machine would be able to handle the project's igneous dykes. But after that we collaborated on several other projects." (T&TI, October 2002).

Dick went to France in 1972 for a series of meetings regarding another attempt to bore the Channel Tunnel and it was these discussions that prompted an idea for installing pre-cast concrete segments while tunnel boring was in progress, using a double shielded machine with a telescopic head. Dick had already decided to visit Grandori while he was in Europe. "So I drew some sketches on the airplane and showed them to Carlo." Intrigued by the idea, Grandori immediately began to sketch a number of improvements to the concept with Dick. Later that year, SELI secured the Orichella and Timpagrande tunnels in Calabria, a 4km long, 4.3m diameter, complex of tunnels in partly decomposed granite. This was to be the first use of the Double Shield machine.

Following the signing of the Channel Tunnel treaty in 1973, Robbins constructed a machine for the French service tunnel in 1974. The Double Shield TBM had just been delivered to the site when the British Government once again pulled the plug on the scheme – the machine never made it into the ground. "It stayed there for a couple of years and finally the French and German contractors sold it on to a sewer project in Turkey," says Dick. "But I believe it performed well."

Over the next decade Robbins started making lots of machines for projects in Switzerland and Germany. "The problem was that the rock was much harder, particularly in the Grimsel tunnel, and we discovered we needed to use a very high amount of thrust to bore through the rock," says Dick. This created explosive rock failures, which in turn created problems with the machines, gearbox and main bearing failures in particular. "So we developed new types of bearings, new types of seals, larger cutters and many new mechanical systems. It was a big era of development." At the same time, the company also started selling machines to Australia and South Africa and

Above: **The Channel Tunnel was a landmark project for Robbins**

developing raise drills for the mining industry.

Another big step was made on machines in Saudi Arabia, where the company started experimenting with tool steel to develop cutters that could tackle very hard igneous black Trap rock; this eventually lead to the development of 15" disc cutters and the ability to bore through much harder rock. By the 1980s, Robbins had a good-sized team working on metallurgy and the company also started working on various areas of research with the Colorado School of Mines.

In 1986, Robbins embarked upon its biggest project yet, the construction of the 50km long Channel Tunnel between Sangatte, on the French Coast, and Shakespeare Cliff, on the English Coast. The company produced five double shield TBMs for the project; working in collaboration with Komatsu on a 5.6m diameter machine for the French service tunnel; Kawasaki for the twin 8.78m diameter machines that bored the French marine rail tunnels; and Markham for the twin 8.3m machines that bored the English marine rail tunnels. Robbins was instrumental in the design concepts for these machines, which brought together the best of hard rock and soft ground tunnel boring technology and successfully drove through highly-fractured and faulted water-bearing rock at pressures of up to 10 bar.

A few years after the completion of the Channel Tunnel, Dick decided to merge his company with a major competitor, Atlas Copco. Like many such mergers economic results were not as expected and in 1998 Atlas Copco decided to sell the company to Boretec, a group of engineers that included a number of former Robbins key personnel. Boretec quickly merged the two companies to form The Robbins Company and invited Dick to serve on the board of directors. Dick has also remained an active collaborator on R&D projects for the company.

Looking to the future, Dick believes the next step is to develop machines that can be used in areas with extreme overburden, such as the Andes and the Alps, where squeezing ground and rock bursts have traditionally created problems for TBMs. "There is definitely potential there," says Dick. T&T

Below: **The 9.7m Robbins TBM that recently completed a drive for the Ceneri Base Tunnel, in Switzerland**

Tunnel driving and station excavation

Victoria Line extension to Brixton

R. J. Walters, B.Sc.(Eng.), M.I.C.E., ***Deputy Resident Engineer, Vauxhall station contract 325***
Messrs. Mott, Hay and Anderson, consulting engineers

Parliamentary powers for the southern extension of the Victoria Line through Vauxhall and Stockwell to Brixton were obtained during 1966, and authorisation for the work to proceed was given in 1967. Work started immediately, providing the maximum opportunity for continuity of work for the specialist contractors hitherto engaged on the Victoria Line.

The extension as originally planned involves the construction of $3\frac{1}{4}$ miles of twin running and station tunnels with draught relief and cable shafts, cross passages and crossover tunnel, together with three new ticket halls and associated escalator and concourse tunnels at Vauxhall, Stockwell and Brixton. It was subsequently decided to provide a fourth station at Pimlico and it is expected that work on the ticket hall and escalators there will begin later this year.

Work is being carried out under the direction of Mr. H. G. Follenfant, Chief Civil Engineer of the London Transport Board. The consulting engineers to the Board for the civil engineering work on this project are Messrs. Mott, Hay and Anderson, 10 Buckingham Place, London S.W.1.

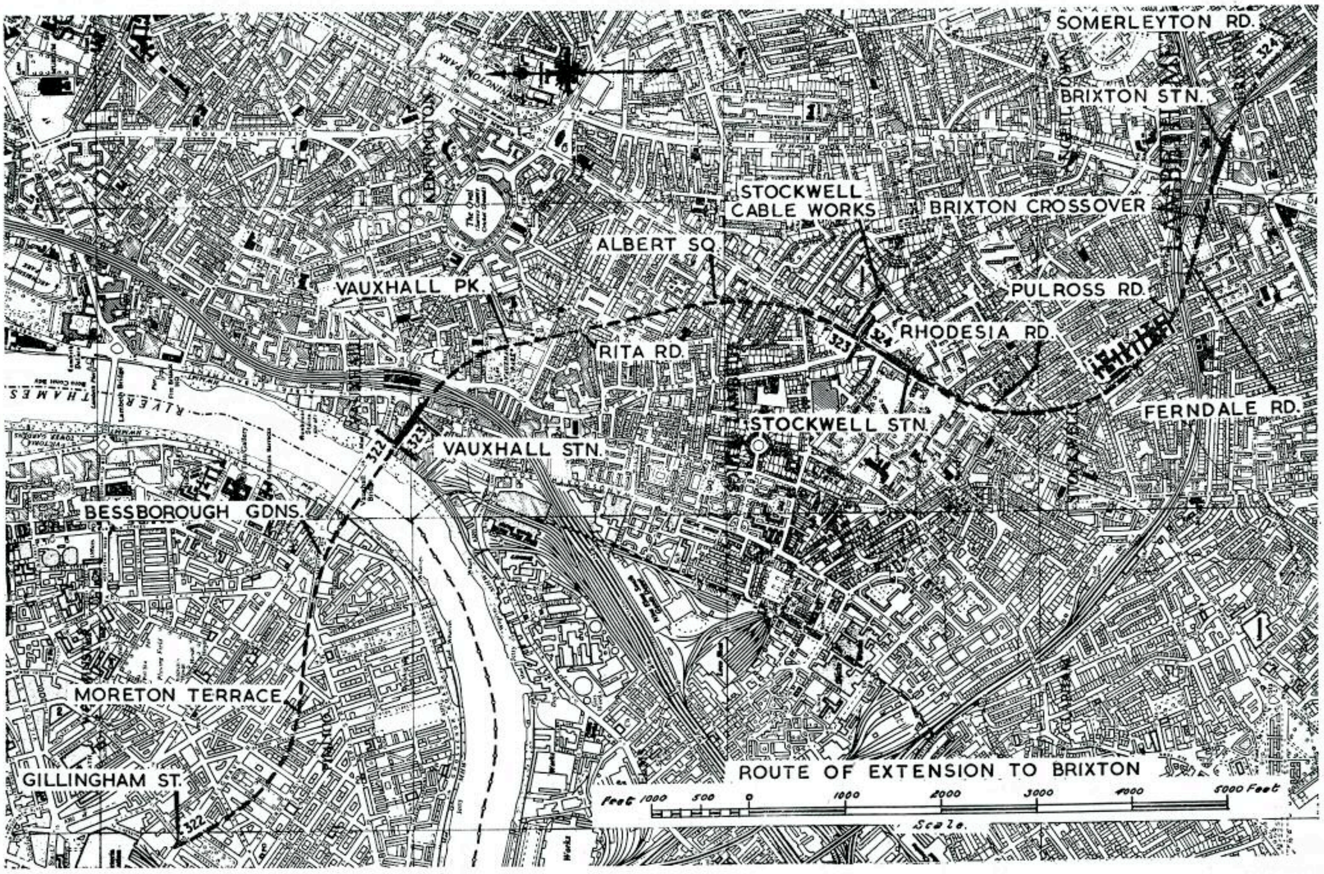
The running tunnels

The construction of the running tunnels has been divided into three main contracts, with separate contracts for the ticket halls at Vauxhall, Stockwell and Brixton. The contract for the northern section of running tunnels from Victoria under the Thames to Vauxhall – which has been extended to include the station tunnels at Pimlico – was awarded to Balfour Beatty & Co. Ltd. Mitchell Bros. Sons & Co. Ltd. were awarded the contract for the central section, Vauxhall to Stockwell, including Vauxhall station tunnels, whilst A. Waddington & Son Ltd. were awarded the southern section from Stockwell to Brixton, including Stockwell and Brixton station tunnels. The construction of the ticket hall, escalator shaft and concourse at Vauxhall is being carried out by Kinnear Moodie & Co. Ltd. and at Stockwell and Brixton the work is being executed by A. Waddington & Son Ltd.

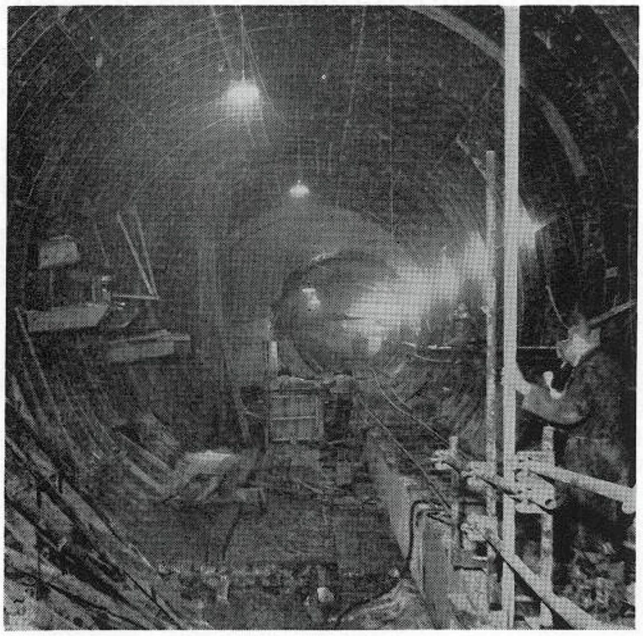
Driving of the running tunnels between Victoria and Vauxhall is being executed from a working site at Bessborough Gardens, on the north bank of the Thames. From this site a shaft was sunk and short lengths of tunnel driven by hand to establish four shield chambers, the water bearing gravel overlying the clay being consolidated by ground treatment for the shaft sinking.

Greathead shields were installed in the chambers and the tunnels driven northward in London Clay, to connect with the existing Victoria Line just south of Victoria, this section of the works being lined with articulated precast concrete rings of 12ft 6in int. dia. On completion of these drives, the shields were dismantled and re-assembled in the southern shield chambers for the drives under the Thames to Vauxhall.

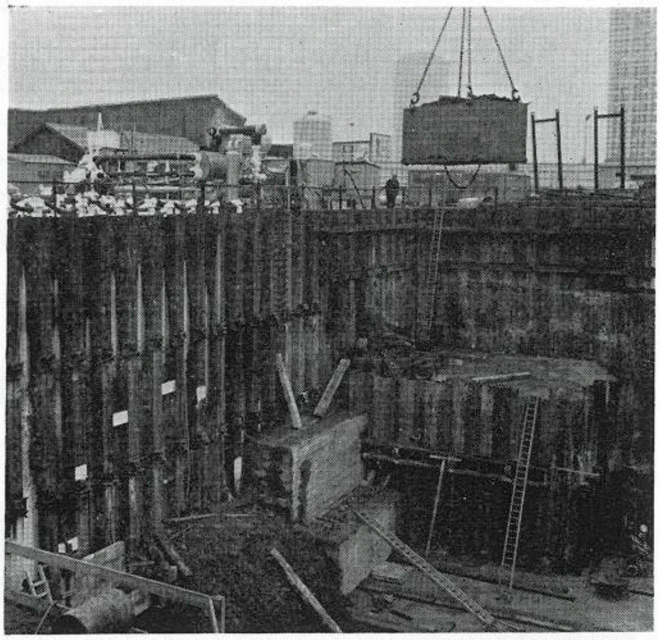
Precautionary measures against any unforeseen difficulties arising from unconformities in the clay under the river included the installation of compressed air locks and equipment. In addition to the extensive borehole investigation carried out at the planning stage of the project, continuous profiling of the clay beneath the River at the site of the



General map of the area of the Extension of the Victoria Line to Brixton, showing station locations as described in the article.



The station tunnel under construction at Vauxhall with the running tunnel (smaller diameter) entering at the far end.



The excavation for the station ticket hall and subways at Vauxhall, showing equipment for ground freezing at the left.

tunnel crossing was carried out using the Sparker survey technique. Although no uncomformities in the clay level were revealed by this survey, a precautionary pressure of 8lb/in² was maintained in the tunnels as driving proceeded. In the event no faults appeared in the clay, and the drives were completed using 12ft 7in int. dia bolted grouted cast iron lining. During the contract period it was decided to construct the additional station tunnels at Pimlico and these are at present being driven using a 21ft 2½in int. dia Greathead shield.

Two main working sites, in Vauxhall Park and at Albert Square were established for driving the tunnels on the central section.

Whilst the northern section of tunnelling had been completed throughout in London Clay, borehole investigation revealed the presence of two buried channels on the section between Vauxhall and Stockwell. These occur in the area where the Extension crosses beneath the existing Northern Line north of Stockwell, and north of the working site at Albert Square near Vauxhall Park. It was thus decided to drive north and south from this working site using conventional hand shields with compressed air plant installed at the surface and air locks installed in the tunnels, to cope with the expected adverse ground conditions. As driving proceeded these ground conditions were overcome as anticipated by the application of compressed air, combined with some ground consolidation carried out from the face of the shield as the work proceeded. Both 12ft 6in int. dia articulated concrete and 12ft 7in int. dia cast iron bolted grouted linings were used on the running tunnel drives on this section.

During the drives north from the working site at Vauxhall Park to Vauxhall Station, a third buried channel, not revealed by the boreholes, was encountered, and it was found necessary to install compressed air plant and air locks to drive through the bad ground using compressed air and chemical ground treatment and complete the drives to Vauxhall. At present all running tunnels and station tunnels have been completed, and apart from some cross passages only track concreting and other ancillary works remain to be done.

During the tender stage for the section of the line from Stockwell to Brixton, two 1metre dia boreholes were sunk to supplement information on the ground conditions obtained in the original borehole survey. As a result the level of the southern end of the tunnels was raised by some 7ft to give increased clay cover to the Woolwich and Reading Beds beneath the tunnels. Construction was carried out using four shields. The first pair were installed at the working site at Somerleyton Road and driven north past the working site at Ferndale Road between Brixton and Stockwell to the shaft at Rhodesia road, 100yd south of Stockwell.

The second pair of shields were driven northwards from Rhodesia Road through the site of Stockwell Station to points just north to junction with the central section. It had been predicted that the London Clay in which the tunnels were to be built would become progressively more friable from south to north between Somerleyton Road and Ferndale Road sites, but as construction proceeded it was found that there was no definite pattern in this respect in the clay. As a result it was again found necessary to change from the 12ft 6in int. dia articulated concrete rings originally envisaged to 12ft 7in int. dia cast iron bolted grouted rings as the ground tended to drop away behind the tailless shield employed with articulated expanded linings, making it impossible to maintain the circular profile necessary for the successful employment of this type of lining. The running tunnel drives and station tunnels at Stockwell are now complete and work is proceeding on the completion of station tunnels at Brixton. The crossover tunnel north of Brixton, employing flat bottom cast iron lining, has just been finished.

While work proceeded on the running tunnels, design of the ticket halls, escalator shafts and concourses was being finished and work began in 1968. The stations at Brixton and Vauxhall are completely new, the latter's moving subway connecting with the existing Southern Region stations of British Rail and with a pedestrian subway system. The new ticket hall at Stockwell is being constructed as an extension to the existing Northern Line one, with a new escalator tunnel to the northbound station tunnels. The new layout at low level provides direct platform interchange between the Northern and the Victoria Lines platforms.

Work is now well advanced on the first stage of construction of the new ticket hall at Vauxhall. Complications arise on this site due to the high density traffic flow using the Vauxhall road system at the southern end of Vauxhall bridge, and beneath which part of the ticket hall and the subways have to be built. Stage I involves construction of the western end of the ticket hall and the escalator shaft and lower concourse. When this stage of the ticket hall roof has been completed a road slab will be constructed above and traffic diverted away from the existing road system, enabling the second stage to be started. Extensive service diversions will then be undertaken by the various statutory authorities before the completion of work on the remainder of the ticket hall and construction of the connecting subways. The road slab constructed above the western section of the ticket hall in the first stage will be incorporated in a new road layout at Vauxhall Cross, which will be completed after London Transport Board's station construction is finished.

Two particular points of interest arise from the contract at this stage. Firstly, in order to avoid the use of walings and struts to support the sheet pile cofferdam during construction of the first stage of the ticket hall, the contractor has used the latest ground anchoring technique, recently developed by Cementation Limited, to support the sheet piles. Also of interest is the use of ground freezing to consolidate the hood of ballast which overlays the clay in the area of the escalator shaft. As a result of soil tests it was found that the grading of the ballast made it unsuitable for ground consolidation by chemical injection and the method of ground water freezing was specified. The freezing is being done by Foraky Ltd.

The contract for the construction of the ticket hall and escalator at Stockwell was negotiated with A. Waddington & Son Ltd. and includes the provision of a draught relief tunnel to the Northern Line. Work has been designed so that the existing escalator for the Northern Line will serve the southbound tunnels of the Northern and Victoria Lines, while the new escalator will serve the Northbound of both lines. The extension to the ticket hall is at surface level, the work below ground level consisting of the construction of the upper machinery chamber for the new escalator.

The cofferdam has been constructed using 35ft long Benoto piles, which cantilever from the ground to support the sides of the excavation. Before construction could start on the escalator tunnel, an existing block of shops and maisonettes had to be underpinned to take the column loads, and this was achieved using bored piles and ground beams. Ballast through which the escalator tunnel is to be driven has been consolidated using conventional chemical injection techniques. At present the second wall piling is complete and work is starting on the escalator tunnel drive and ticket hall excavation.

The contract for Brixton station comprises the construction of a new ticket hall with escalator shaft and access concourse to the station tunnels at low level. A notable feature of the work at Brixton is the very close proximity of existing buildings; the station is being constructed between two existing blocks of buildings during re-development of the site.

The escalator together with the lower concourse is at present under construction, and has been driven from a sheet pile cofferdam, situated within the ticket hall, and to avoid noise and vibration to the adjacent buildings these piles were driven using the Taywood hydraulic piledriver.

In order to maintain support to these buildings surrounding the site their flank walls bordering the site have been underpinned by sinking a series of pits down to ticket hall formation level adjacent to and beneath the foundations and supporting them with concrete. Construction of the ticket hall walls follows, being built within the line of the underpinning pits. In addition, an existing building across the entrance to the ticket hall has been underpinned to accommodate the new ticket hall and access stairs. At the present stage of construction, work is well advanced on the underpinning and the escalator and concourse tunnels are virtually complete.

The programming for the whole project is being carried out using critical path network techniques, which allows full integration of equipment and finishing work with the civil engineering programme. It is planned to open the Extension to the public in the early 1970's.

Opening sets - the flat arch theory

Michele Mangione, Senior Tunnel Engineer, Arup describes here in his BTS Harding Prize winning paper how the flat arch theory was used to create openings in cast iron tunnels with minimal disruption

This paper illustrates an innovative design of openings in existing cast iron tunnels and describes the challenges during their installation. These openings were formed within the existing station tunnels served by the Piccadilly and Northern Lines at King's Cross St. Pancras Underground Station.

The "flat arch" theory has been used as the conceptual basis for this design. Flat arches rely on the transfer of vertical loads through a thrust force which leads to large compressive stresses but minimal tensile and shear forces. The immediate benefits of this solution are the optimization of the size and depth of the segments, with no complicated connections and allowing simplified and staged installation.

The load-bearing elements of the opening frames including lintels, sills and jambs have been sized to fit within the width of an existing ring. The choice of this method facilitated the gradual installation of the frames in order to ensure minimal impact on the stability and structural integrity of the station tunnel rings. A significant benefit was the avoidance of temporary internal props that would have severely affected the platform space for passenger usage and therefore led to platform closures.

The project

King's Cross St. Pancras Underground Station is one of the busiest stations of the London Underground network and is served by 6 tube lines and acts as an interchange for St. Pancras and King's Cross Mainline railway stations. Its redevelopment was planned in conjunction with the renovation of St Pancras Station for the Channel Tunnel Rail Link (CTRL) and comprises improvement to the existing facilities of the station, two new ticket halls, the refurbishment of the existing ticket hall and new tunnelled passageways to the deep tube lines to relieve congestion due to the projected increase in usage by 2012.

New routes to the Northern and Piccadilly lines are provided by a network of pedestrian tunnels connecting one of the new ticket halls to the existing station tunnels. Two pairs of openings within the existing cast iron rings were formed to provide access from the existing platforms to new concourse areas. The size of the existing station tunnels is 6464mm i.d. The required new structural opening is 2.6m wide and 2.8m high.

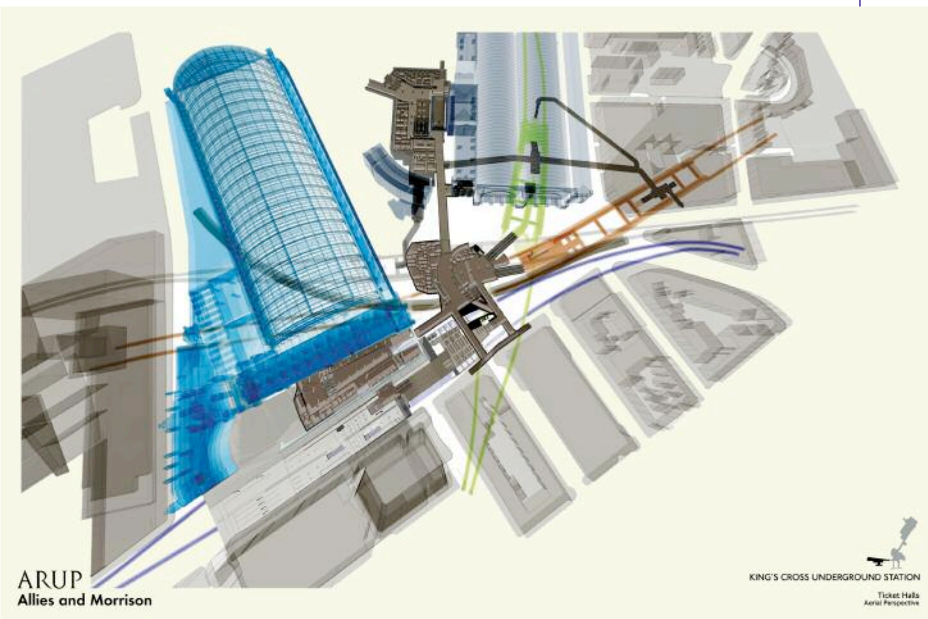
Traditionally, opening sets are built by fitting deep beams and jambs within the station tunnel rings or bolting the beams at the back of the rings after excavating and exposing the external tunnel face. These require significant temporary support including the use of vertical props within the station tunnels. This is because a large number of segments need to be dismantled or left laterally unsupported compromising the structural integrity of the cast iron rings and leading to significant deformations of the lining. The props would impinge on the available space within the platform hindering passenger flow and safety leading to a closure of the station for several weeks.

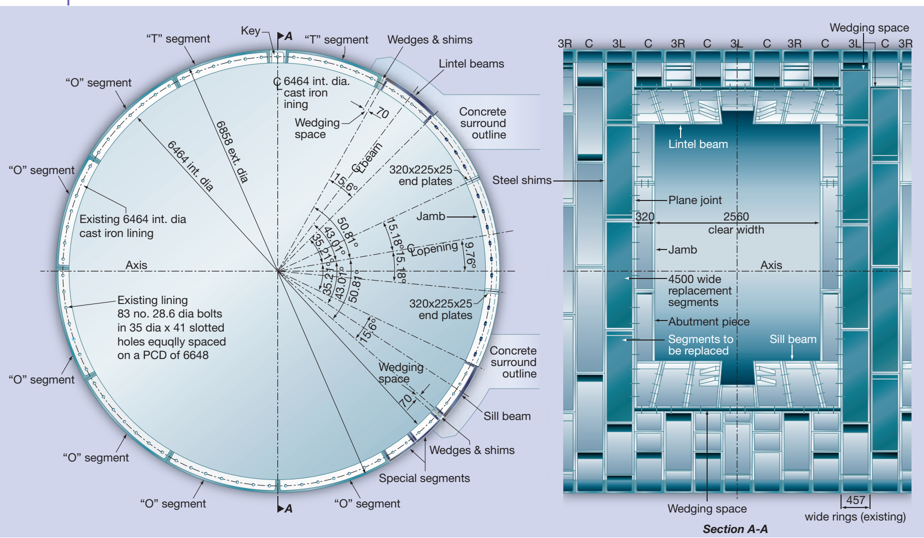
Due to the key importance of this underground station for the operation of the London Underground network, all works needed to be designed and staged to maintain the operation of the tube lines at all times. The only acceptable disruption to the operation of the line was the closure of the platform tunnels to the public during a limited number of '52 hour' weekend possessions. While the work was carried out within the station tunnel, safe clearances had to be maintained to the track to allow London Underground to run through passenger and engineering trains.

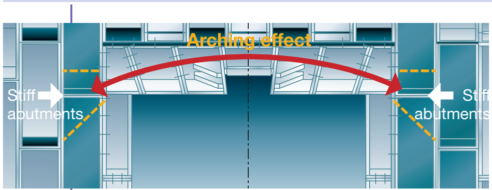
Design

In order to safeguard the integrity of the existing lining and to maintain operational

Below: Fig 1 – Layout of the redeveloped King's Cross St. Pancras underground station







Above: **Fig 2 – Cross section and long section of a segmental opening set**
Left: **Fig 3 – Arching action on lintel beam and abutment location**

services a different approach was considered for the design of the openings in the existing station tunnels. With this approach, the opening frames were formed by progressively removing existing segments within the lining and replacing them with new segments intended to support the hoop load through the opening. These segments, bolted to all adjacent existing and newly replaced segments, formed the lintel, jambs and sill of the opening set.

Simple beam theory would have led to a considerable depth of section in order to provide sufficient structural capacity and allow for full bending moment connections capable of maintaining the structural continuity of the lintel and sill.

To minimize the depth of the section and to reduce the complexity of the segment connections, the lintel and sill beams were designed as flat arches. The inbuilt hoop load within the affected tunnel rings is redistributed to the segmented lintel and sill beams through the thrust force created by the arching action within their web plates. This eliminates tensile stresses as all the forces are resolved into compressive stresses. By using the arch theory, significant loads can be carried by relatively shallow elements since the compressive stresses hold the segments together in a state of equilibrium. Therefore, the internal forces transferred between the bolted segments are mainly compressive stresses and the bolted connections need to carry nominal temporary loads. The segments were designed in Spheroidal Graphite Iron (SGI) due to its very high compressive characteristic strength.

The new segments (figure 2), were installed systematically to ensure minimal impact on present load paths. Works were carried out on a maximum of two rings of the existing tunnel lining at any time and the new segments were grouted into place immediately after installation. Sacrificial segments were used to infill the space of the actual opening to provide continuity of the lining until the opening set is constructed and capable of carrying the loads.

A flat arch depends on the rigidity of the lateral elements, hereafter named abutments, which need to absorb the considerable lateral thrust force and maintain any resulting lateral movement to a minimum. Figure 3 indicates the forces that are created within the lintel/sill and the reaction required by the abutments. Significant longitudinal movements would lead to large vertical displacements of the lintel and sill beams and corresponding failure to comply with serviceability deflection requirements. As the arch finds a new equilibrium after these movements, structural failure of the SGI opening set is not expected. However, large vertical movements would compromise the structural integrity of the existing lining supported by the opening lintel and sill causing cracks in the cast iron segments.

The stiffness of the lateral support of the opening sets may be affected by several factors. Defects in the original construction (dated 1900), presence of soft packing such as deteriorated timber or voids and possible weak material properties of the cast iron may lead to unexpected movements and distortions of the adjacent cast iron segments. Significant movements may also lead to undesirable cracking.

This risk has been mitigated by injecting high-strength grout in the joints between the adjacent 5 existing cast iron tunnels. To reduce the stresses in the adjacent cast iron rings, the abutments were strengthened by replacing the segments next to the lintel/sill with stiffer and more ductile SGI segments. These additional segments allowed for the redistribution of the compressive stresses over a larger width of the first affected existing cast iron segments.

To ensure the lateral load capacity and stiffness of the supports were consistent with the design requirements, the Designer proposed a simulation of the arch thrust force transferred from the abutment to the lateral support provided by the cast iron segments. This force was induced by means of 4 hydraulic jacks. The jacks were placed in specifically designed recesses at the centre of the opening set lintel and sill, below the central key segment. The jacks were pressurised to impart a large compressive force in the segments. This force was transferred to the abutments where the design thrust force is expected to act when the opening sets are engaged.

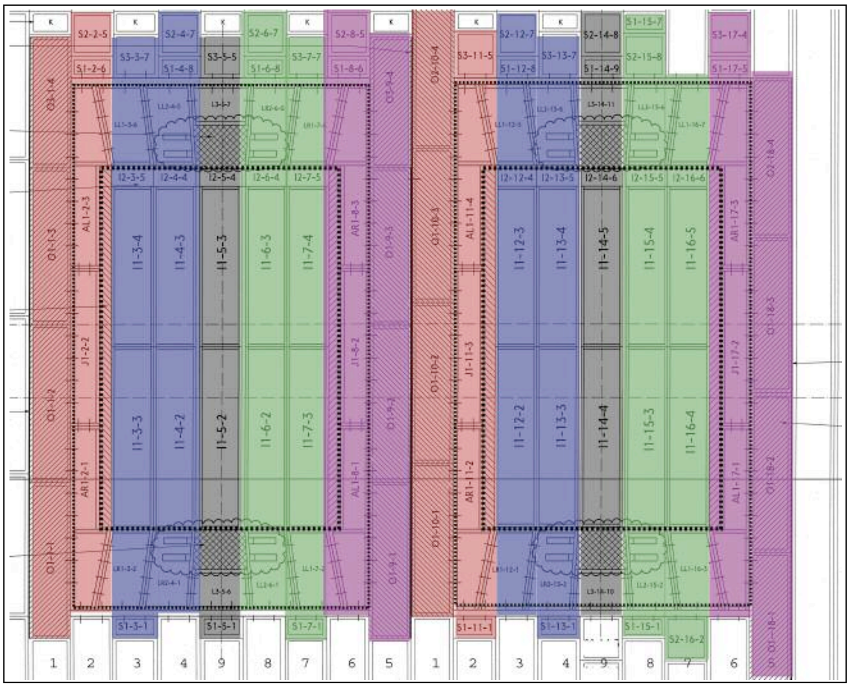
The benefit of this simulation was to force the opening set elements to move and impart all the possible non-elastic deformations due to imprecision in assembling the new opening sets, soft packing/voids and existing defects in the build. As the load was increased to the expected serviceability value, a bespoke instrumentation system monitored the elastic behaviour of the opening set elements and the adjacent existing segments to validate the structural ability of the system.

Plastic deformations were compensated by the provision of steel shims installed in the gaps formed between the key and the adjacent segments. Elastic deformations were released but they were small and accounted for in the design.

Installation of new segments

The installation of the new segments was carried out during five '52 hour' weekend possessions. To safely replace the old segments with the new SGI segments, the work was carried out within a hoarding protection to maintain safe working clearances to allow passenger and engineering trains through.

The preparatory works ahead of the segment replacement works included stripping of finishes, accurate survey of the



Left: Fig 4 – Sequence and replaced segments

existing lining, circle joint packing and ring roll, diversion of services around the opening areas above and below the platforms. To install the sill beams, the existing platform was modified in proximity of the openings. The concrete platform structure was replaced by a steelwork solution with prefabricated steel panels so that it was possible to temporarily remove the panels during the installation works to gain access to the invert of the tunnel. The panels were then restored to reinstate the platform for public use the next day.

Figure 4 shows the sequence of the replacement of the old cast iron segments with new SGI segments. During each weekend possession, 8 segments within a pair of rings per opening were replaced. The segments were replaced from the abutments towards the centre, fit tight to the far side in order to minimise any gap between segments. The last segments to be installed were the key segments. Any gap formed between the key and the adjacent segments was filled with shims. The rings 1 and 5 are replacements to the existing lining and provide a stiffer support at the abutments and facilitate the dispersion of load onto the adjacent cast iron segments. Some smaller segments were designed and installed between the lintel/sill and the existing segments within rings 1 to 9 to account for the different roll of the rings. The segments marked I1 are infill segments that temporarily reinstate the continuity of the rings.

The existing segments were removed by grinding two strips in the middle of the segment and pulling out the two remaining sides. The new segments were installed with winches. Once the segments were in place, the site engineer reviewed the orientation and the contact with the adjacent segments. Spirit level and strings were employed to ensure the segments were orientated in the design position in order to build the lintel segments on a straight line. Where required, shims or wedges ensured full contact between the flange plates of the segments in both circumferential and radial joints.

At the completion, the 3D movements of the existing segments around the opening frame were reviewed. Apart from a segment, which moved 7mm for what is believed to be a mechanical reason (load imparted from a winch connected to one of the bolt holes), all segment movements were maximum 3mm - within the allowable 7mm displacement.

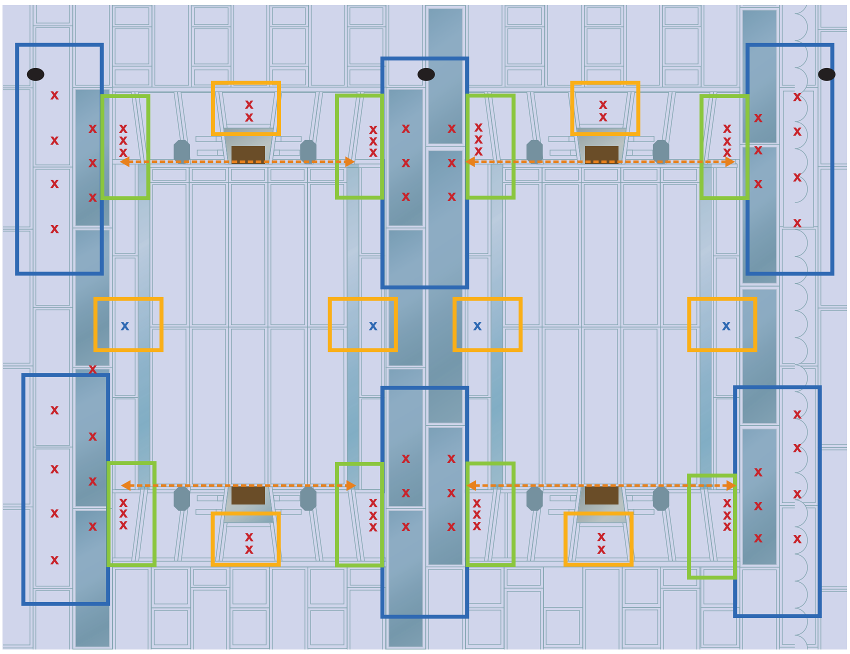
Instrumentation and monitoring

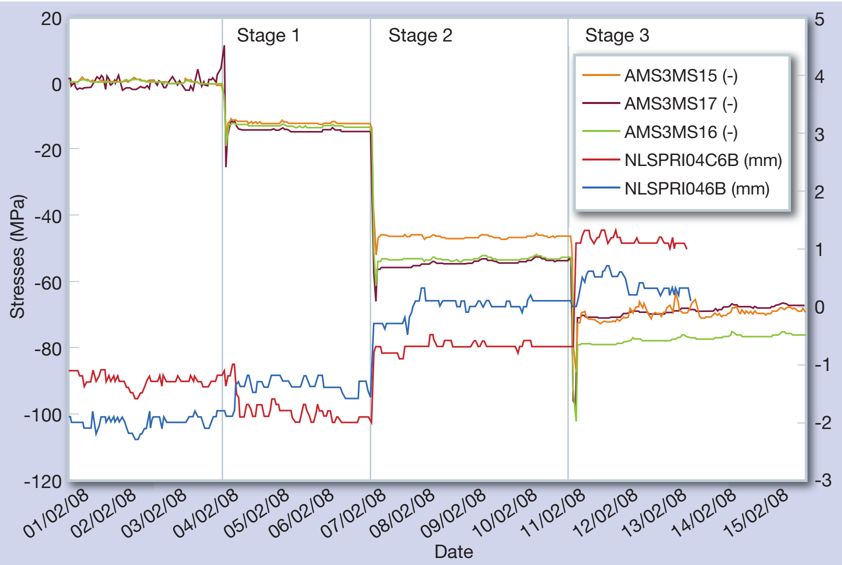
The critical assumption made during the design is that, to act as a flat arch, the opening sets must be longitudinally restrained by the existing rings to the immediate right and left of the newly installed segments. Construction was staged to create an opportunity to validate this assumption through the analysis of two fundamental characteristics during the application of a force simulating the thrust action: Rigid body movement and internal force distribution. This was achieved through an instrumentation and measurement scheme designed to provide stresses and movements of the segments at critical locations, and changes in value over time.

The monitoring of the stresses, via strain readings, within the newly installed SGI segments and the existing cast iron rings was carried out by means of Vibration Wire Strain Gauges (VWSG) applied directly to the exposed surface of the tunnel segment skin plate (figure 5). Real-time data providing a full understanding of the compressive stresses within the lining were recorded at a frequency of 10 minutes. The monitoring of the movement of the segments was undertaken by three methods:

- The overall lateral movement (longitudinally) of the abutments was monitored through 3D prism targets mounted on the external rings and in the centre of the pair of openings. The targets were read every 10 minutes by a theodolite

Below: Fig 5 – Position of strain gauges around a pair of opening sets. The red marks (72No.) shown indicate strain gauges aligned horizontally. The blue marks (4No.) indicate strain gauges aligned vertically. The 4 hydraulic jacks are shown in brown within the central key segments. The black marks (3No.) indicate the location of the 3D prisms for the theodolite. The orange arrows (4No.) show the tape measurements. The grey dots (8No.) show the location of the dial gauges.





Above: Fig 6 – Movement of abutments (NLS-VEC-04B6B, 04C6B) and stresses calculated from the strain gauge readings in the vicinity of an abutment

installed in the station tunnels
- To backup data from the theodolite, the movement between abutments was monitored through tape measurements using a laser meter. This was carried out at every step of the jacking procedure to record longitudinal movements
- The out of plane movement of the segment (radial, towards the centre of the tunnel) was monitored through some dial gauges fixed on a build bar. The device is a spring connected to a bar which records relative movements with a 0.1mm precision. The built bar, a few centimetres offset from the opening set components and independent from the opening set, provided a reference point to the location of the segments. Movements were recorded at every increment of jack pressure

The recorded movements were checked against pre-defined control trigger levels. The trigger levels were defined as a control measure to avoid damage of any affected element and provide the designer with hold points to suspend the procedure and review the collected data in the event of unforeseen behaviour of the segments. The control trigger levels for the longitudinal movement of the two abutments at the far sides of both opening sets based on the laser measurements were a Green Level of 5mm, an Amber Level of 15mm and a Red Level of 25mm, the design allowable movement of the opening set components.

The pressure in the hydraulic jacks was monitored through gauges included between the jacks and the pumps that inject the fluid that operates the jacks. This precaution was necessary to ensure there was no unexpected drop in pressure and therefore load in the hydraulic jacks due to unexpected movements of the set.

Validation - jacking procedure

Four hydraulic jacks per pair of openings were employed to validate the design. The jacks were some 450mm deep with a 360mm diameter piston. The design load of the jacks was 500 tons, the value of the thrust force expected in the deepest opening sets in service. Prior to jacking, several preliminary checks were carried out. The opening sets were inspected from the cross passage connected to the new lower concourse. The purpose was to avoid any gap between the lintel/sill and the newly built concrete structure forming the cross adit. Any gap was filled with high strength grout to provide a lateral restraint to outwards movements of the jacked segments.

The jack's position and shimming were inspected prior to the start of jacking. To minimise any risk of inwards movement of the segments, packing between the jacks and the segments connected to the jacks included wedges to impart a slight eccentric load to force the segments towards the external cross passage structure.

Predefined bolts, the top and bottom of the sill, lintel and abutment pieces, were loosened. This avoided overstressing the bolted connection in the event of any significant movement of the opening set elements. The bolt holes were slotted to allow for a maximum lateral movement of 25mm. The key bolts were replaced with longer bolts and loosened at one side to allow for the longitudinal movement of the abutments and any gap opening between the key and the adjacent segments.

Jacking of the opening sets was programmed over 3 stages to monitor behaviour of the opening sets with different levels of stress and review internal stresses and movements over a period of time with the jacks in a position and time period to maintain stresses within the segments. At the first stage the jack pressure was increased to 1000kN. The difference in pressure between each jack was maintained within 100kN. The expectation was to impart sufficient load to correct any imprecision in the build of the new segment and start viewing any other plastic deformation. To monitor these effects, the load was applied at small increments of 50kN per jack, about 1% of the target force. Measurements of the rigid movements were carried out at each stage. Following completion of these increments, the jack were locked and left in position for a minimum of 3 days.

As the pressure was applied to the jacks, the affected lintel and sill beams were visually inspected. Minor movements, some 1mm, were noted at the first increments. The recorded inwards movements of the segments were very small. After expected movement due to the build, the segments were stable. Figure 6 shows the behaviour of one of the abutments of the opening sets. Three strain gauges records are attached. At stage one, the load imparted was 20% of the total. The stresses peaked at 25MPa, reducing to less than 20MPa when the jack was locked. To lock the jack, the pressure was released maintaining the piston in position. Although movements of the segments were still restrained, since the elastic strains were very small, the lack of pressure in the jacks led to a slight drop in strains that translated in a reduction in stress within the monitored segments.

At the second stage the jack pressure was increased to 3000kN. After every increment of 100kN of all jacks, measurements of the longitudinal and lateral movements were recorded. The jacks were then locked and left in position for a minimum of 3 days.

The force at this stage simulated about 60% of the thrust force produced by the hoop load at serviceability state. The effects of this force produced some recorded movement of the segments. This was sufficient to mobilise the abutments. The maximum movements were in the region of 2mm. The stresses recorded by the strain gauges increased linearly as expected to a value in the region of 65MPa to then slightly reduce after the jacks were locked. Similarly at the third stage, increments of 100kN were applied to the jacks until the load reached the back-calculated maximum force of 5000kN. The maximum lateral movements were small also at this stage, between 1 and 2mm. The stresses reached a maximum 102MPa before stabilising to between 70 and 80MPa. During the 5 days the jacks were left in position, the stresses in the new segments decayed only 5%. This proved the opening set was stable and capable of carrying a relevant percentage of the imparted load over a length of time with minor expected losses in strain.

The jack pressure was then reduced to 1000kN to reduce any elastic deformation in the opening set while maintaining any plastic deformation. Shims were applied in the gap between the key and adjacent segments. Now the infill segments could be removed and the opening set signed off.

Conclusions

The design and construction works proved it was possible to form an opening in a tunnel using the flat arch theory, without any delay to the service. Although the procedure had no precedent, every stage was completed as planned. The installation and jacking imparted movements in the region of 3mm in longitudinal and radial direction - within the control measure defined ahead of the works.

The service load expected by the set components was imparted without causing any major deformation or sign of distress in the existing lining. The recorded strains and stresses in the lintel segments confirmed the Designer's expectations.

This solution can be very efficient especially in large tunnels (i.d.>5m). The benefits are a structural system within the thickness of the lining with resulting internal forces transferred in pure compression and not in bending and shear. The segmented lintel and sill also make possible a gradual installation with minimal impact and deformations to the tunnel.

Other openings in King's Cross have been designed to be bolted onto the extrados as described. However these have been on smaller tunnels with lower hoop forces. The deformations produced by this method if proportioned to the tunnel size were much larger. The 'bolted at the back' solution on a station tunnel would have required larger beams and significant excavated volumes behind the lining to form sufficient space to install the lintel and sill beams. The extensive excavation and the time required to fix the lintel beam would have significantly increased the risks of undesirable deformations to the station tunnels.

The mitigations provided by the flat arch approach to the risks of damaging the lining of a cast iron tunnel were a critical benefit for a tunnel with historical deformations and reduced capacity to tolerate further deformations due to excavation works. T&T

ACKNOWLEDGEMENTS

The Author wishes to thank London Underground Limited for their permission to publish this article. In addition he wishes to acknowledge the teamwork of Morgan Est/Beton und Monierbau Joint Venture, Metronet Rail SSL, London Underground, Soldata and his colleagues in Arup in delivering this innovative solution and the successful completion of these major tunnelling works at King's Cross St Pancras

Speed up a long way.

Niagara Falls/Canada. For the construction of the 10,500m long Hydro Power Tunnel the conveyor providing company H+E supplies a continuous conveyor system allowing a fast transport of the excavated material. One Booster is used to reduce the forces exerted on the belt along the route; with the pleasant side effect to guide the belt save in front of a vertical curve.

The naked facts:

Tunnel diameter:	14.4m
Conveyor length:	10,500m
Belt width:	1,000mm
Capacity:	1,600 t/h
Installed power:	4 x 360kW (head) 2 x 360kW (booster)
Belt storage capacity:	600m of belt
TBM:	Hard Rock Gripper
Installation:	2006
Contractor:	Strabag Inc.

H+E LOGISTIK GMBH

H+E Logistik GmbH
Weg am Kötterberg 11a
D-44807 Bochum
Germany
phone + 49 (0)234 | 950 23 60
fax + 49 (0)234 | 950 23 89
www.helogistik.de

Canada Line's ground stability in EPBM

At January's British Tunnelling Society meeting, Jeff Hewitt SVP of Canada Line Rapid Transit Inc, Professor Dan Eisenstein of the University of Alberta, and Marco Moccichino of SELI contractors presented the challenges of EPBM tunnelling and the interaction on soil conditioning

The speakers presented results from their detail analysis on EPBM tunnelling and how changes to the conditioning of the excavated soil cope with the varying challenges presented by the highly permeable soil layers on the Canada Line Transit Tunnels, in Vancouver, BC.

The Canada Line is a 19km long automated light rapid transit system with 16 stations in Vancouver, BC, Canada. The Concession was awarded to InTransitBC to design, build, partially finance, operate, and maintain the system for 35 years. The project must be complete by November 2009 to be ready for the 2010 Winter Olympics to be held in Vancouver and Whistler, BC. The bored tunnel section consists of 2.45km of twin-bored tunnel and 3 stations (figure 1).

The tunnels were driven using a Lovat 6m diameter EPBM and lined with 250mm thick, 5.3m i.d. precast concrete segments. Seven hundred and fifty meters of each tunnel were driven through glacial and interglacial deposits of sand, silt, and clay with granitic boulders.

The station work is limited to the excavations and temporary support necessary to facilitate the bored tunnel works. A joint venture between SNC-Lavalin Constructors Pacific and SELI has recently completed the design and construction of this section.

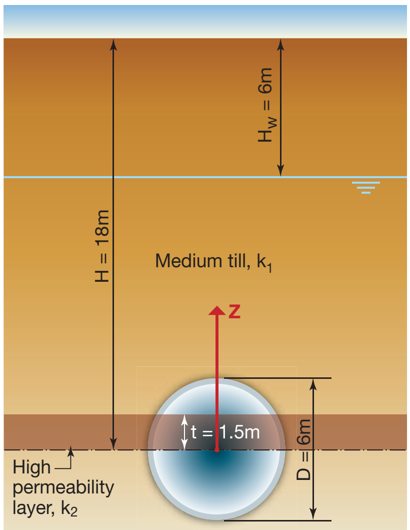
Approximately in the middle of the False Creek, the geology changes from sandstone into the overlying till (a glacial deposit of silt and sands). The transition is foreseen through a discontinuity having a sub–vertical immersion.

The geomechanical conditions considered in the analyses correspond to a situation frequently faced while boring the stretch of twin tunnels from False Creek to Granville Street, which was characterised by the presence of significantly continuous layers of high permeability loose till.

Although it is likely that more than a single layer exists, possibly with additional minor inclusions and lenses of limited extent, to keep the model as simple as possible a unique layer was considered. The thickness of the soft layer was fixed equal to 1.5m, that is D/4 (where D is the tunnel diameter, equal to 6m), while its position within the face was varied: i.e., four cases were considered, corresponding to a relative elevation z of the base of the layer, with respect to the tunnel axis, of -3, -1.5, 0 and 1.5m. The set of performed analyses include also two situations of entirely homogeneous soil, i.e., without a soft layer and with a soil mass formed only of soft material, respectively.

The behaviour of the water-saturated porous medium during excavation advance was represented by a two-phase approach. Only the drained elastic moduli and the drained strength parameters are therefore required, while the undrained behaviour is governed by the water bulk modulus (Kw = 2GPa), porosity and the skeleton bulk modulus. The geomechanical properties of soils from site report and additional investigations are shown in Table 1 (p39).

Above: Fig 1 – Canada Line TBM tunnels alignment



Below: Fig 2 – Typical section of analysis

BOMBELA

GAUTRAIN SITE DEMOBILIZATION

Bombela Civil Joints Venture consortium, that consists out of Bouygues Civil Works, Murray & Roberts and SPG is currently busy with site demobilization and the following equipment / plant is available:

- COGEMACOUSTIC Tunnel ventilation fan: 30 to 250 kW
- Shotcrete Robot PUTZMEISTER model: PM407 - PM500
- PAUS Dumper ITC 10000 20t payload interchangeable with Concrete mixer CIFA
- Basket NORMET 9915 BA
- LHD GHH Model 6.3
- Batching Plant COUVROT and ARCEN: capacity from 40 to 60 m3/h
- Rolling Stock 900 MM
- FERMEL Utility vehicle
- BOART LONGYEAR Charging Unit
- Grout Pumps CLIVIO
- Agitator Hopper SECATOL: 7m3 - 10 m3
- Gantry Crane: 30 - 40t
- Side tipping bucket GERSTADT. Capacity (3m3 - 4m3)

For more information contact:
christophe.ollivier@bombelacjv.com
Telephone: 0027 (0)11 997 8141
Mobile: 0027 (0) 83 632 9116
Address: 22 Milky Way Avenue
Linbro Business Park
Johannesburg
P.O. Box 1177
South Africa

GAUTRAIN
FOR PEOPLE ON THE MOVE

Into the till

In Drive 1 the transition from sandstone to till went smoothly without any geological anomalies becoming apparent. Once the machine was wholly in the till, face inspections under atmospheric pressure showed it to be comprised of strong impermeable till. Regular cutter head inspections and tool changes could be made in normal (atmospheric) conditions. Surface and building settlements were limited to 1 or 2mm with minimum cover of 12m to the crown of the tunnel and water table approximately 8m below surface. A face support pressure of approximately 1bar was maintained throughout. However, after 120m the muck was noted to contain higher proportions of wet sand and silt.

From this point on the total thrust of the TBM and the cutter head torque began to steadily increase with a steady decrease in penetration rate. However, extracted muck weights and settlement stayed at, or slightly above, normal so the TBM was advanced to find suitable ground for a face intervention, but the muck exhibited higher percentages of cohesionless sand showing the waterlogged permeably material was not confined to a pocket, but was a layer with recharging water.

It became clear that the cutting tools were at the end of their useful life. Face interventions were still not possible and sensor observations made during lowering the pressure in the excavation chamber showed that even with compressed air inside the chamber the water level would increase.

The increasing coarseness of the material combined with the high water pressure meant the foaming agent was not effective. In these instances, the muck was permeable and would allow water to flow through the screw conveyor.

However, this conditioning was less than ideal and the material would flow through the screw conveyor if not mechanically managed by partial closure of the guillotine door. With the cutting tools in such poor condition, there was significant concern that the machine could become immobilized as it entered the sandstone under a significant building.

The decision on how to continue the drive under the highest risk section with a machine of reduced capacity due to excessive wear and probable damage was based on a number of factors. The settlement readings in all buildings along this section had remained very low (less than 4mm) and surface settlements had remained less than 3mm in all but one section.

Experience had shown that adequate ground control could be achieved even with worn cutting tools and very poor ground conditions unsuited to normal EPBM operations.

Considering all the facts, a calculated risk was taken to continue the drive. The TBM under-passed the building (34 advances) in less than 5 days with the penetration rates reducing from 50 to 30mm/min. The maximum settlement experienced at any footing was 6mm with 3 or 4mm being normal for other footings directly over the alignment.

For the entire section of till, the cutter head was dressed with disc cutters that were required for two reasons; to bore within the rock at each end of the soil section and to bore through the boulders that are confined in the stiff/hard till matrix. Through the wet sands and silts, the scraper teeth at the cutter head openings will have done most of the "cutting".

Drive two

Before Drive 2 and following a specific risk evaluation report an additional package of improvements, refinements, and modifications was introduced as risk mitigation measures to enhance the operational and functional efficiency of the TBM in the reassessed geology.

Due to the unfavourable geological conditions and the dense urban environment in this section several mitigation measures have been taken, such as:

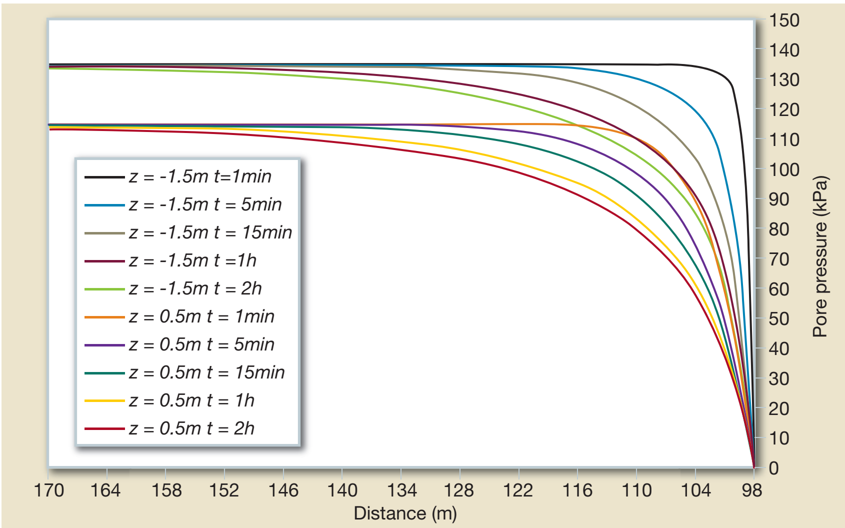
- Tunnel separation increased by 1 diameter (from 12m to 18m) under significant buildings to minimize their interaction
- Use of long-life and high wear resistance cutting tools with a mixed-face configuration (ripper teeth and cutters)

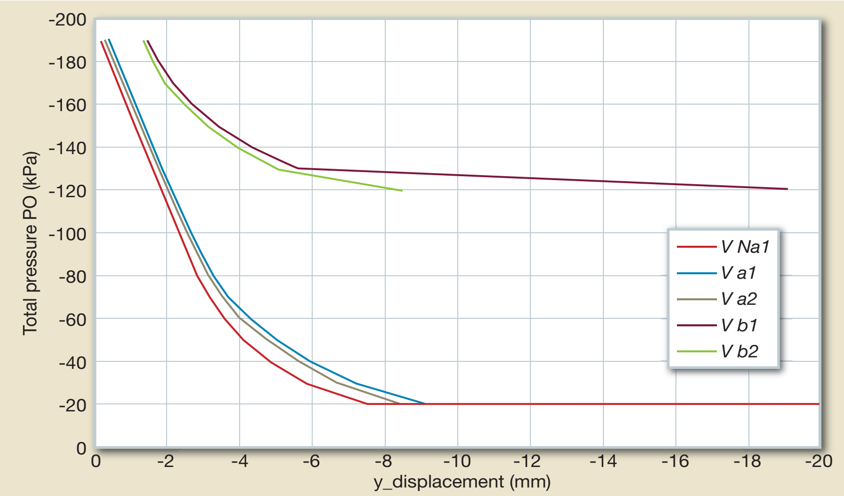
Table 1

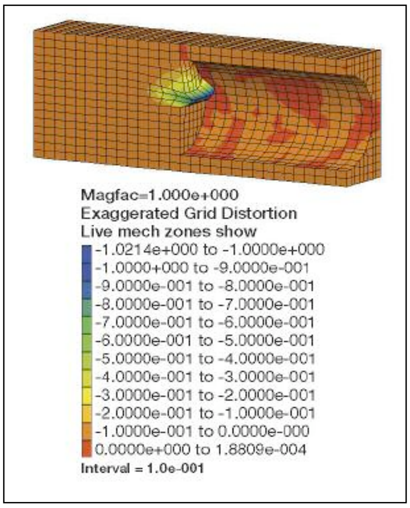
		Strong till	Weak till	Silt	Weak, loose till
Bulk unit weight, γ	(kN/m^3)	21.5	21.5		
Porosity, n	(-)	0.3	0.3		
Shear modulus, G	(MPa)	170	60		
Elastic modulus, E'	(MPa)	425	150	65	
Cohesion, c'	(kPa)	100	25		30
Friction angle, ϕ'	(°)	40	38		32
Undrained cohesion, c_u	(kPa)	800	200		
Permeability, k	(m/s)	10^{-8}, 10^{-7}	10^{-8}, 10^{-7}		10^{-5}

- Automatic grout line cleaning at the end of each stroke by a shot of hydraulic oil
- Polymer injection: the addition of an automatic integrated Polymer System pump to the original conditioning foaming system
- Additional monitoring instrumentation and 24-hour monitoring (surface, buildings, and extensometers) during the most critical sections
- Locating maintenance areas based on the Drive 1 reassessed geological mapping and records, where safe and "open face" cutting head maintenance might be possible
- Hyperbaric crew: Specialised crews for hyperbaric intervention available on site (until the tunnel is fully into the sandstone formation)
- Operations and boring parameter control: phases and values checked daily based on shift reports and PLC automatic data

Below: Fig 3 – Pore pressure profiles at different times







Above: Fig 4 – The demand of pressure to stabilise the face, **Above left:** Fig 5 - Displacement confinement curve (z=0.5m)

logger. Daily toolbox meeting for coordination and planning

- More frequent calibration of weight scales as the belt scales are adversely affected by very wet soils and the vertical and horizontal curves

The mitigation measures and the scheduled maintenance areas were instrumental in the efficacy of the excavation through the entire till section, and the reduction of risks from Drive 1 greatly enhanced the performance of the TBM, particularly the ability to keep the proper face support pressure and assure the right conditioning reducing the soil permeability. These two aspects were thoroughly studied before approaching the sand layer during Drive 2. In Drive 2 the ground control confirmed by the surface, building, and soil monitoring instruments were very similar to Drive 1.

The machine advanced at an average of 12 rings per day (17m), at 2.2 bar face support pressure at the top of the cutting chamber. The penetration rates, total thrust, torque, grout injection pressures and volumes all remained within expected limits with the torque and thrust increasing and penetration rate dropping as the machine entered the sandstone. The ability to maintain the design face support pressure (not having to drop the pressure to allow forward advance), thus balancing the hydrostatic pressure (therefore not mobilizing any ground water through the sand) allowed the soil to be conditioned only by the injection of foam. Conditioning of granular material, to make the muck into the required impermeable consistency, was therefore achieved at chamber pressures of 2.7 bar (at inlet to screw conveyor).

The soil conditioning system had been checked and continuously updated along a 200m trial section of Drive 2.

Several tests had been performed on spoil material removed from the screw conveyor screening:

- Slump
- Density
- Permeability
- Moisture content

QUESTIONS FROM THE FLOOR

David Baker (Balfour Beatty) stated that BB had tendered for this project & that the original tunnels were longer due to traffic disruption restrictions.

Jeff Hewitt replied that he had no knowledge of that phase of the procurement but stated that during construction they had complied with all of the Municipal traffic considerations. [Post meeting note: The original tunnel requirements were not restricted by traffic considerations.]

Phillip Wilson (Metronet) asked what percentage of construction cost was spent on SI & emphasised the more spent he felt resulted in reduced cost overruns.

Jeff responded saying he had no exact figure but believed it to be just in excess of 1%. He added that boreholes were spaced at 150m to 200m centres & adjacent building basement constructions also aided SI investigation.

Martin Knight (Jacobs) asked why there were no details in the presentation of the practical tunnel construction logistics.

Jeff responded stating the speakers wanted to concentrate the presentation on the linkage between experience and trying to maintain pressure & conditioning of the material and the subsequent modelling analysis. Jeff believes this is a way forward for our TBM manufactures to aid future material control within the face & screw.

Michael Francis (Parsons Brinckerhoff) asked what was the average face loss & the worst.

Marco responded stating the best was 0.1% ground loss & the worst area in drive 1 was 0.9% at an unexpected soft layer. The average was 0.3%, which resulted in a ground slope of 1/1000, which was acceptable to the buildings above & insurers.

Peter Townsend (KBR) asked if the project had tunnelled under any historic buildings.

Jeff responded that numerous buildings were passed by the tunnels, but none were historic.

Peter South (Jacobs) noticed the presentation pictures showed disc cutters on the TBM. Were these changed when entering softer ground.

Marco responded that the disc were not changed. After the first drive tungsten inserts were added to remove flattening encountered on drive 1. Regular face inspections were undertaken.

Bob Allen (London Bridge Associates) asked if there were any issues with re-radiated noise at the surface when cutting in the sandstone.

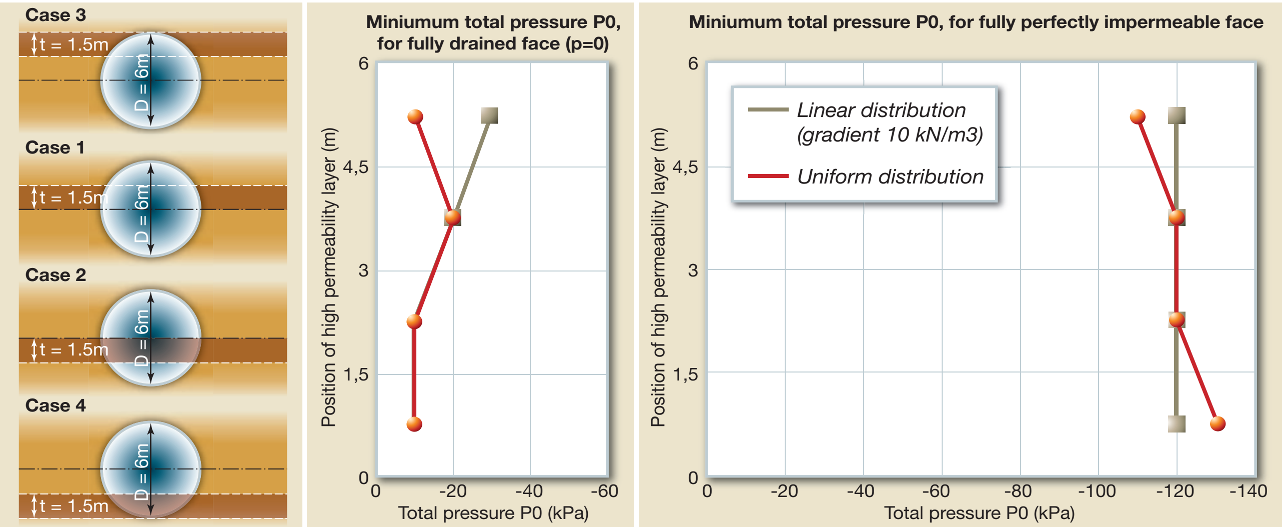
Jeff responded no, not with the TBM but added that the permanent rail system has special track fastener pads fitted when under buildings whose foundations are located within the sandstone.

Shani Wallis (Journalist) asked about ring grouting.

Jeff confirmed that it was through the tailskin grouting & was interlocked to the TBM advance.

Dan finally stated that a more detailed paper on this presentation would be forthcoming.

Rapporteur: Steve Parker



Above: **Fig 6 – The average pressure P0 as a function of layer position stabilise the face**

All the parameters related to every TBM stroke had been filed and analysed. On the trial stretch, face foam flow, surfactant percentage (TA%) and water flow in the chamber have been modified to verify the TBM behaviour under different conditions (high or low excavation pressure, till matrix with or without sandy inclusions, etc).

Besides laboratory tests on till mixed with sand had been made. Addition of polymer agents had been studied too. Eventually the most effective conditioning parameters granted reaching a permeability of the excavation spoil ranging from 10^{-7} to 10^{-8}m/s.

A thorough preliminary analysis of face stability was undertaken reviewing spatial stress redistribution in the vicinity of the advancing face.

A sensitivity was aimed at evaluating the influence of the following factors; the position of the high permeability layer inside the face, the shape of the total pressure distribution upon the face and the amount of pore pressure reduction inside the chamber with respect to the undisturbed ground.

A further analysis was devoted to the study of a simplifying modelling approach in which the flow domain is limited to the high permeability layer, while the medium till portion of the model is assumed to display a fully undrained response during excavation advance.

A set of figures showing some results of the preliminary analyses is thereafter included: most figures refer to the situation where the high permeability layer is located in the upper half of the face ($0 < z < 1.5$m), chosen as the reference case.

In the limit case of fully drainage (p=0), the distance of influence of the face on flow conditions is about 6D, i.e., at greater distances the reduction in pore pressure is less than 5% (figure 3). This situation represents the worst-case scenario for the assessment of the impact of the excavation process (excessive drawdown of water table, risk of large settlements). On the other hand, this case corresponds to the demand of total pressure to stabilize the face (P0 = 20kPa).

In case of no disturbance of the initial hydrostatic pore pressures, the minimum total pressure necessary for face stability corresponds to P0 = 120kPa, which indicates that almost the whole amount of pressure is required to counterbalance the water pressure.

The influence of the vertical gradient γf of face pressure seems modest, at least within the limits posed by the accuracy (±5kPa) in the determination of the collapse load (figure 4). This result can be explained considering the small thickness of the low strength layer with respect to the tunnel diameter: The response of the face to unloading of original stress is therefore markedly different, and more advantageous, from the case of homogeneous soil.

The soft layer

The position of the soft layer within the tunnel face (4 different situations were analyzed and compared to each other) has a limited, but significant influence on the minimum pressure necessary to avoid instability. Figure 5 show the situation in terms of average pressure P0 as a function of layer position: the maximum variation in P0 is of about 20kPa. A less important variation would be obtained if the pressure value at the middle of the soft layer were considered instead of the pressure P0 at the centre of the tunnel face.

A further refinement introduced in the model is the possibility of directly representing the conditioned soil inside the excavation chamber and the screw conveyor, again by adopting a two-phase model for the conditioned soil as well as for the natural soil surrounding the tunnel. This approach eliminates the need of an a-priori assumed distribution of pore pressure over the tunnel face but require an appropriate assessment of the permeability of conditioned and fully remoulded soil inside the machine.

Again, the analysis has been split down in two phases: a first "flow" only calculation, up to steady state, and then a "mechanical" phase, in which a progressive decrease in total stress applied to the face has been performed.

It is sufficient to guarantee a muck permeability KEPB as low as 10^{-6}m/s, that is, equal to the assumed in-situ permeability of the soft ground layer, in order to virtually eliminate the drawdown effect associated to the excavation advance.

If the permeability of the conditioned muck is increase to10^{-5}m/s, steady-state pore pressure at face decrease significantly below the original undisturbed value. Correspondingly, the "characteristic curve" of the face indicates a stiffer behaviour than the previous case.

A more thorough analysis of the construction process could be achieved by applying a step-by-step approach, in which each round of excavation (i.e., removal of tunnel core elements) is followed by the installation of a new slice of lining (i.e., activation of a new set of liner elements).

In closing the speakers thanked the client for its support in the implementation and execution of the scheme to date. T&T

1 End of the main conveyor system along the gorges in the disposal area platform.
2 Jetty from tunnel conveyor to apron conveyor feeding the two conveyor lines in the access tunnel.

Conveyor belts along steep slopes at Jinping

At the Jinping II hydropower scheme in Sichuan Province, China, Marti Technik supplies a complex system of two 1.2 km conveying lines installed in the access tunnels that lead to the headrace and drainage tunnels, a 14.7 km conveyor belt behind the TBM in headrace tunnel #3, a 6.3 km external belt in the gorges including a belt in a 2 km tunnel until the final dump site.

Powered at 2,800 kW and driven by a booster and tail drive, the TBM conveyor has capacity for 1,800 t/hour to evacuate 4.44 million tonnes of rock. The 6.3 km external conveyor line carries aggregates on the return run belt until the access tunnel portal. The system will negotiate a 1,100 m curve radius. Its capacity is for 5,600 t/hour and it is powered at about 12,000 kW to transport 11 million tonnes.

Four conveyors per line are also installed at the dump site and another conveyor links to the concrete plant. The two lines have the advantage to transport up to 2,800 t/hour each and it is possible to switch the initial loading.

Marti Technik AG Lochackerweg 2 CH-3302 Moosseedorf
Tel. +41 31 858 33 88 Fax +41 31 858 33 89 info@martitechnik.ch www.martitechnik.ch

Protecting LUL's assets

Paul Steen, Mohsen Vaziri, and Tim Hartlib of consultants Ramboll UK, describe the protection works undertaken to protect LUL assets close to the construction of a large-scale basement

The project demonstrates the creation of value from a successful basement construction in a difficult urban site. A key challenge on this city centre site was to construct a basement over the LUL Victoria line tunnel within its exclusion zone. This set an engineering design challenge that combined innovative methods of construction, computer modelling of the problem, and negotiation of the solution with key stakeholders. This project innovated in circumstances where heavy penalties for failure were in place to protect the underground network.

Site Setting

The site is in the London Borough of Westminster. It is about 200m to the north of Oxford Circus and bounded by Portland Place to the west and Hallam Street and Great Portland Street to the east. The site's northern boundary is delineated by Duchess Street, and the southern boundary by All Souls Place. Langham Street bisects the site and forms the boundary between Phases I and II of the development.

The proposed headquarters for the BBC consolidates a number of separate buildings into a unified structure to support their Radio, News and World Service broadcasting services.

The development is constructed in two phases (figure 1) to allow continuous broadcasting operation. Phase I comprises refurbishment and alteration of the existing OBH building which occurred concurrently with the demolition of Egton House and 16-28 Langham Street and redevelopment of this part of the site. The new Phase I building is known as the Egton Wing and comprises a three level deep basement on raft foundation and a five to seven storey above ground structure.

The Egton Wing basement is contained within a secant pile retaining wall on three sides and a sheet pile retaining wall to the north. The sheet pile wall provides a temporary function and has been removed during Phase II of the development to create a unified basement.

Ground conditions and the Victoria Line

The stratigraphy encountered at the site generally consisted of Made Ground overlying Lynch Hill Gravel, London Clay, Lambeth Group and Chalk (BGS, 1994). The Thanet Sand stratum was not identified during the site investigation (FES, 2002). The general geological progression identified (whitbybird, 2002) is summarised schematically in Figure 2.

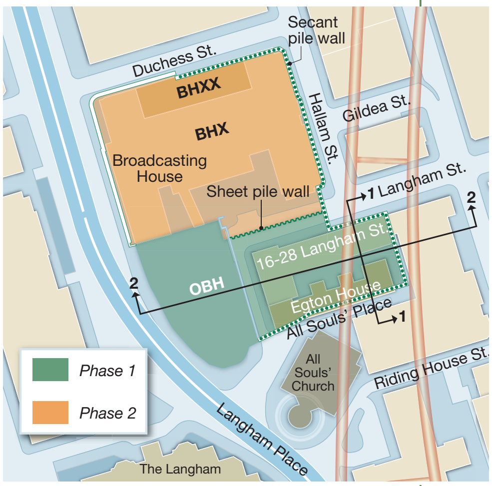
The results of groundwater monitoring undertaken during the site investigation show that the groundwater level is at +20.0mOD, near the base of the Terrace Deposits. The pore water pressure increases hydrostatically with depth within the London Clay. The pore water pressure identified from piezometers in the Lambeth Group suggest that the stratum is under-drained by the chalk strata and the pore water pressures reduce to 0kPa at the interface between the Lambeth Group and the chalk.

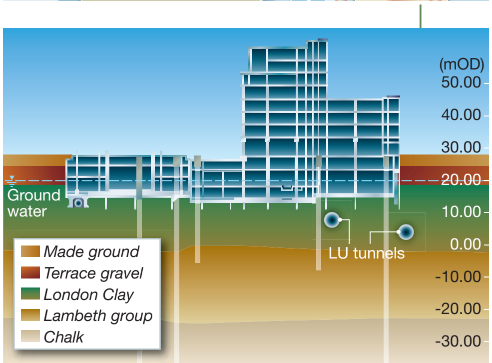
The Victoria line northbound tunnel runs directly beneath the Phase 1 site. The crown of the tunnel is at +9.5mOD (approximately 18m below street level and approximately 5.1m below the bottom of the new basement raft (figure 3). The Victoria line southbound tunnel passes close to the east of 6-28 Langham Street and Egton House with the tunnel crown at a depth of about 24m below ground level.

The northbound tunnel section below the site consists of a knuckle jointed, flexible (i.e. no bolts), cast-iron lining whereas the southbound tunnel is of bolted cast-iron. In both tunnels a bituminous material was applied to radial and circumferential joints in order to prevent water ingress.

Inspections of the north and southbound tunnels were carried out during the summer of 2001. The northbound tunnel generally appeared to be in good condition with limited local signs of minor ingress of water. In the southbound tunnel numerous wet and actively seeping joints were observed throughout the section of expanded lining.

Ground movement as a result of changes in overburden pressure during demolition

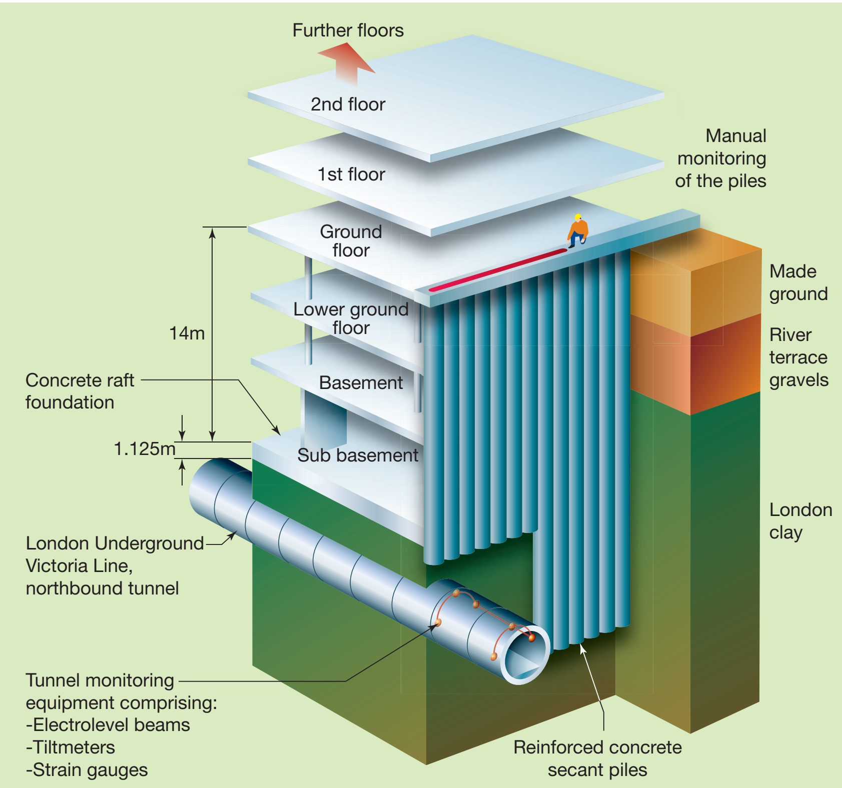


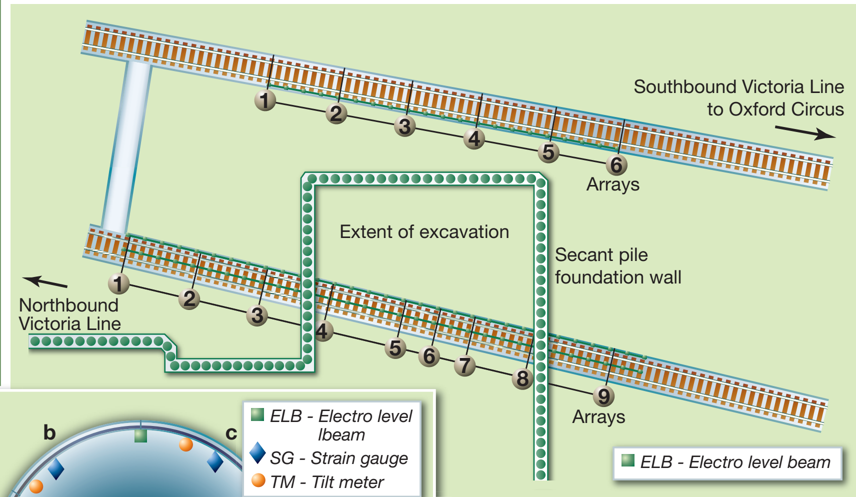


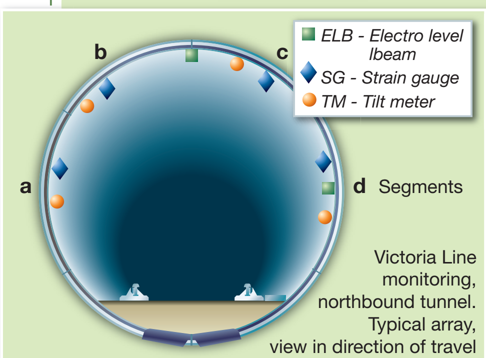
Top: Fig 1 – Plan of original site layout showing LUL tunnels and proposed development phases
Above: Fig 2 – Geological cross section of the site

and excavation represented a significant hazard to the tunnels. The key risks were identified as:

- delays to construction programme due to approvals associated with excavation and construction within the LUL exclusion zones (exclusion zone is defined as 3m to either side of the tunnel and 6m above the tunnel crown)
- tunnel movement causing encroachment into the dynamic envelope of Victoria line tunnel trains in the tunnels and disruption to the operation of the Victoria line tunnel trains







Top: **Fig 3 – Victoria line northbound tunnel below Egton Wing substructure**
Above and left: **Fig 4 – Locations of instrumentation in the tunnel**

- catastrophic failure by undermining the integrity of the tunnel
- construction activities causing physical damage to the tunnel lining
- train-excited vibrations transmitted into building and affecting broadcasting operation

Managing geotechnical risks

The main activities and deliverables that were undertaken to manage the geotechnical risks during the design and construction of Phase I of the development are summarized in Table 1.

Early on in the scheme design the risks of development on LUL assets were identified. A series of meetings and site inspections were arranged (RIBA Stage B) to discuss the scheme and to identify issues, which could impact the operation and integrity of the tunnels. This was very beneficial and a continuous dialogue was maintained with LUL and their engineers throughout design development.

In order to create the ground model and to be able to assess the impact of development on the tunnels and adjacent structures the site investigation for the works was carried out early in the design phase (RIBA Stage C).

A Conceptual Design Statement (CDS) was written for LUL to ensure that design work for the BBC W1 Project met the LUL requirements for safety and quality and that unnecessary risk was not transferred to LUL (whitbybird, 2002). The report also describes the methodology adopted by whitbybird in their engineering design of the proposed development.

Metronet was commissioned to carry out a line and level survey to confirm the exact location of the tunnels. Gauging surveys were also undertaken to establish the gap available between the sides of tunnel and the train for both Victoria line tunnels. A condition survey was completed and showed that the tunnel was in good condition with some minor water seepages.

Considering the risks to the operation of running tunnels it was recognised that any disruption to the operation of Victoria line tunnels would have had serious consequences on Oxford Circus Station, one of the busiest underground stations in London.

Considering the extent of construction activities in relation to the Victoria line tunnels and in order to minimize the risks and provide an early indication of potential construction hazards on the tunnel it was agreed to monitor the tunnels. The other two main objectives of the monitoring were to: verify design assumption by means of constantly comparing measured and predicted ground movements; and identify and prevent adverse impacts when and if they occurred.

Electrolevels, strain gauges and tiltmeters were installed in the tunnels. The locations of the instrumentation in the tunnel are shown in Figure 4. Survey targets were also installed in the tunnels for back-up manual monitoring.

The electrolevel beams were installed to record a longitudinal heave profile for the tunnel. The tiltmeters record the magnitude of rotation of the individual tunnel segments. The strain gauges similarly record the trend of changes to the magnitude of hoop forces in the tunnel lining. Track surveys were also used as a check on the automated monitoring.

The controls applied to the construction process were determined by Metronet, who prepared an Emergency Preparedness Plan (MRBCV, 2003) that defined trigger levels for movement of the tunnel. The trigger levels are listed in Table 2 and the monitoring equipment was used to verify that deflections were controlled below these limits.

Numerical Analysis

Numerical analyses using the Plaxis software package were carried out to predict the displacement magnitude of the Victoria line tunnels, both during construction and in the long term following project completion. Two sections were used to assess the effects of the redevelopment on these tunnels. The location of these sections is indicated with arrows on Figure 1.

The elasto-plastic Mohr-Coulomb soil model was used to simulate the behaviour of the majority of the strata underlying the site. However, the London Clay was modelled using a higher order (Hardening-Soil) model to simulate the difference in behaviour between primary loading and the subsequent unloading and reloading of the strata. A detailed model of the stress history of the site was prepared to simulate the complex locked-in stresses in the ground.

The results from the Section 1 finite element model were used to predict the longitudinal profiles of the northbound Victoria line tunnel at various stages of construction.

Figure 5 shows the predicted vertical tunnel movement profile at three stages of construction:

- following the maximum excavation depth being achieved (formation level – 14.5mOD)
- construction completed
- long-term conditions (pore-water pressures equalised)

The prediction indicates that, whereas the tunnel inside the footprint of the excavation heaves up to a maximum of 30mm, that outside it settles slightly.

Figure 5 indicates that the analysis predicted about 8mm of tunnel deformation directly beneath the secant piles. Given the lining flexibility in the longitudinal direction, the predicted deflected profile did not give rise for concern. Section 2 modelled both the north and southbound Victoria line tunnels. As with the previous analysis, heave was predicted in the northbound tunnel.

Deformation of the tunnel section was also expected causing stresses in the lining. In general, the lining was predicted to behave in a flexible manner (small bending moments were predicted). The hoop forces in the lining were predicted to drop as the excavation proceeds while the bending moments increase. In the long term, as load is added, the axial forces in the lining increase again, while the bending moments remain approximately the same. Based on the guidance included within LUL Engineering Standard E 3322 A2, Deep tunnels and shafts – assessment, an interaction diagram was produced for the Victoria line northbound tunnel lining (Figure 6).

Moment and axial force predictions for the northbound tunnel are plotted in Figure 6. It can be seen that the plotted values are within the limiting resistance curves of the tunnel lining. The lining structure was therefore not considered to be at risk from the stresses associated with transverse distortion.

Monitoring results

The monitoring equipment was installed in October 2002 and monitoring started on 13 November 2002. This allowed background monitoring to be completed before demolition and piling commenced. A summary of the construction programme is shown in Table 3.

The tunnel monitoring results for the period from pre-construction background monitoring to completion of excavation and raft construction were presented in a final report (whitbybird, 2004). The important conclusions from the report that describe the tunnel movement are discussed below:

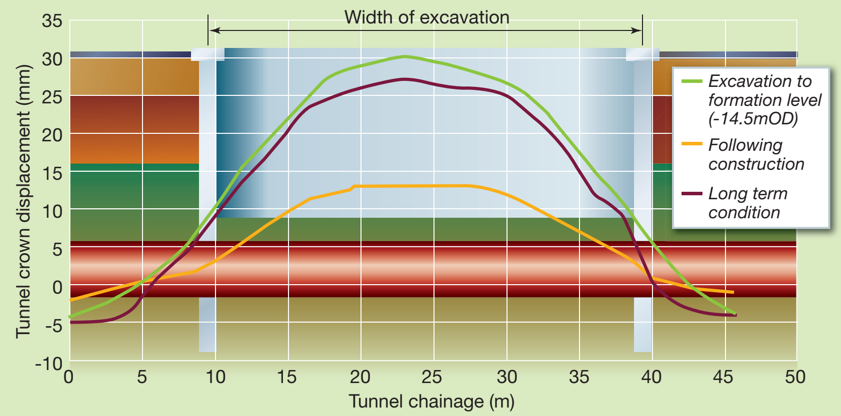
Electrolevel Beam 17 at the crown of the tunnel is located at the centre of the excavation and showed the greatest

Table 1: Project deliverable schedule

RIBA Stage	Activity	Deliverable
A	-	-
B Feasibility	Initial consultation and constraint studies	• Desk study • LUL plan room search report • Preliminary project risk register
C/D Planning/ Scheme design	Construction impact assessment on tunnnels	• Preliminary study of the effect of construction on the Victoria Line tunnels • Tunnel condition survey • LUL conceptual design statement (CDS)
E/F detail design & tender	Detail numerical analyses and implementation	• Ground investigation interpretative report • Contract specification • Emergency preparedness plan • Tunnel monitoring scope of works • Monitoring and reporting strategy report
Construction	Tunnel inspection and review	• Monthly tunnel movement monitorig report

Table 2: Metronet Rail emergency preparedness plan trigger level

Nature of movement	Green	Amber	Red
Relative vertical movement between left and right rails between 5m section (5m twist)	5mm	9mm	12mm
Relative track level movement between 5m sections	10mm	15mm	20mm
Tunnel deformation- Movement of tunnel wall relative to track level	44mm	54mm	69mm



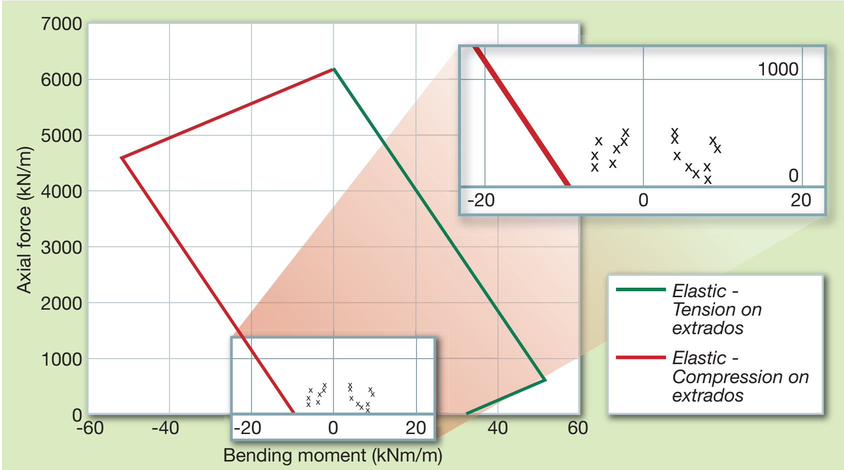
Right: **Fig 5 – Predicted crown movement of the Victoria Line northbound tunnel during and after construction**

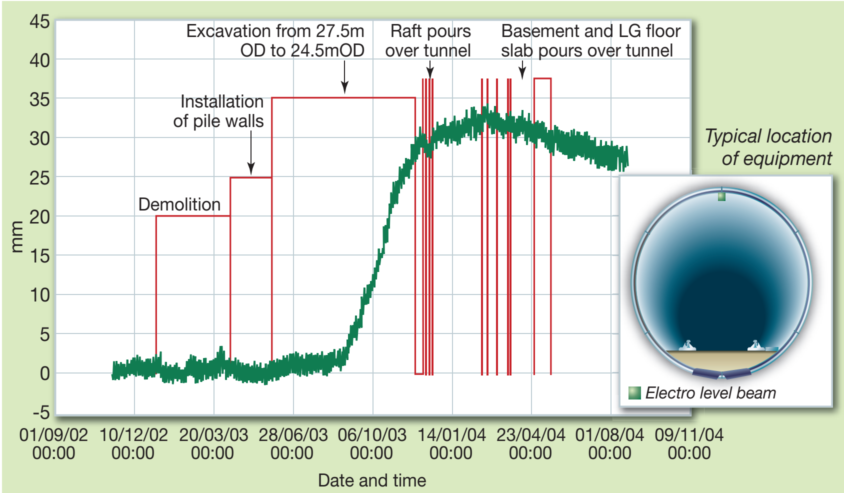
Table 3: Summary of construction programme

Start date	End date	Description of milestone
Jan 2003	Mar 2003	Demolition of existing buildings
Apr 2003	Jun 2003	Installation of secant pile wall
Jun 2003	Dec 2003	Excavation of 3 level basement
Dec 2003	Dec 2003	Construction of raft over the tunnel
Jan 2004	Jan 2005	Construction of sub and superstructure

Table 4: Peak movements recorded on 8/9 Nov 2003 and 4/5 December 2003

Date	Live monitoring		Manual survey	
	Crown	Sidewall	Left rail	Right rail
08-09/11/03	25.5mm	22.5mm	19mm	19mm
04-05/12/03	29mm	25mm	21mm	20mm





Top: **Fig 6 – Moment and thrust diagram for the northbound Victoria line tunnel lining**
Above: **Fig 7 – Trend of movement of electrolevel beam 17 at the crown of the northbound Victoria line tunnel.**

magnitude of heave during the works. The movement trend of this electrolevel beam is shown on Figure 7. This shows minor movement during background monitoring period of 13 November 2002 to 06 January 2003. The demolition of the buildings did not cause any significant movement. The first distinctive movement occurred towards the end of March and early April. This was when sheet piling was installed and water jetting was used to install the piles through the London Clay.

During June 2003, 3m of overburden was removed, reducing the site level to 24.5mOD. The monitoring equipment reflected this unloading with a heave of approximately 1mm. The bulk of the excavation occurred between September and November 2003. The monitoring results show a gradual heave of up to 30mm to 27 November as a further 10m of overburden was excavated over the tunnel. This heave occurred at a rate of approximately 3-4mm per week during this stage of the works. The raft foundation was poured between 27 November and 19 December 2003 and this caused a 1-2mm settlement of the crown of the tunnel. Subsequently, the tunnel continued to heave up to 34mm at a rate of 1mm per week. The remaining raft foundation, basement and ground floor pours over the tunnel started in February 2004 and continued until June 2004. Over this period the crown settled by 1-2mm to 30mm by June 2004. The crown continued to settle in this way during the pours of the 1st floor to 28mm by 23 August 2004. The tunnel shows signs of continuing settlement at the rate of 1mm per month, as more slabs are added. The maximum heave was 34mm. This was recorded during December 2003, when the excavation reached its maximum depth.

Two manual surveys of the tunnel and rails were carried out by Metronet BCV during the works. These visits were made during engineering hours on 8-9 November 2003 and 4-5 December 2003. Both sets of results show that the rails moved by a smaller magnitude than the crown and sidewall of the tunnel. The surveys showed that the rail movement was within the amber trigger level zone for relative track movement between 5m sections.

The peak movement recorded by the live monitoring and manual survey on the dates of the Metronet tunnel visits is shown in Table 4.

The magnitude of movement of the electrolevel beams in the crown of the tunnel remained within the amber trigger level zone for relative track movement between 5m sections.

In general, the profile of movement in the rails and sidewall of the tunnel showed a smaller magnitude of vertical deflection than the crown of the tunnel.

Conclusions

This paper summarised the processes by which geotechnical risks were addressed on a challenging project in a difficult urban environment. In particular the impact of construction activities on the Victoria line northbound tunnel were accurately quantified by numerical analysis and this was later confirmed by continuous live monitoring of the tunnels. The monitoring results have been reviewed consistently since November 2002 and now that construction works have been completed for Phase I, the client no longer sees the business need to continue monitoring. Since the data is so valuable, it was agreed to transfer the package to Southampton University to continue the monitoring, carry out research into the long-term response of the ground and the tunnel and make the data available to the industry. T&T

Composite solution

Claire A Verani, Design Interface Manager, Meyco Global Underground Construction, BASF Construction Chemicals describes a fully bonded waterproofing membrane

Robust waterproofing of underground structures is one of the most cost effective ways to enhance safety and function as well as increase design life of new and existing structures.

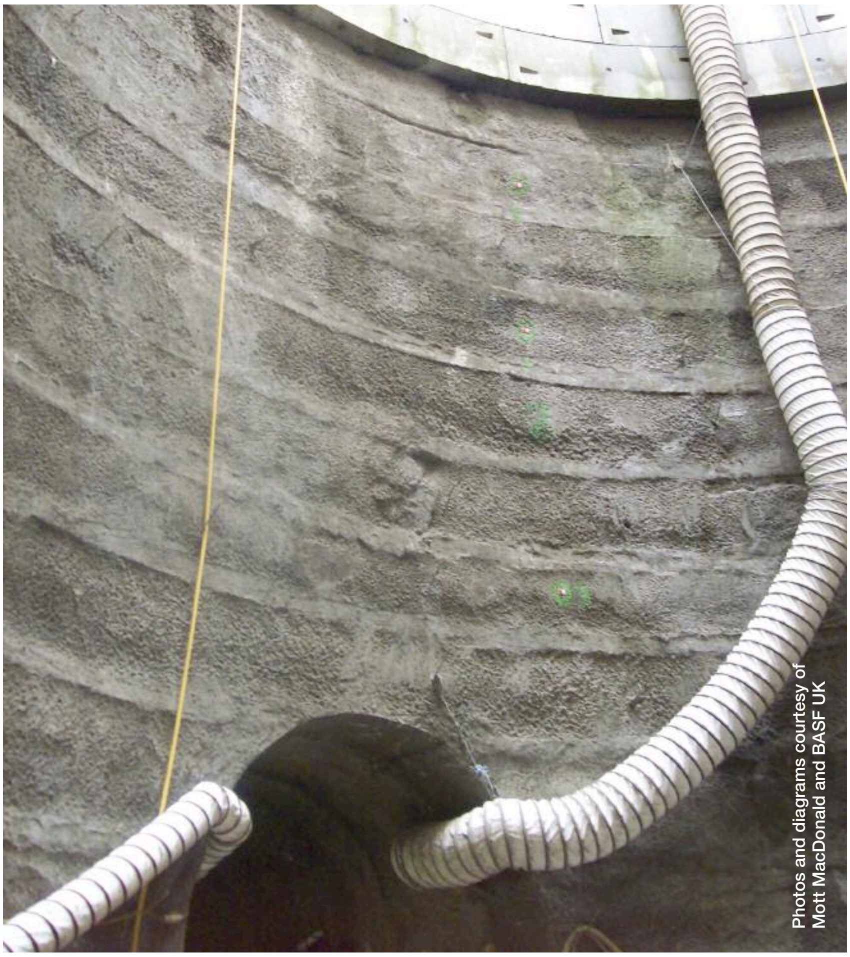
Meyco has conceived a method for supporting ground by integrating a state-of-the-art fully bonded cementitious polymer-based spray-applied membrane (Masterseal 345) into concrete linings thereby establishing a thinner monolithic waterproof structure that relies on the primary lining as a permanent solution and prevents water migration behind the membrane. This unique system consists of a first layer of sprayed concrete, a fully bonded intermediate layer of spray-applied impermeable membrane and a second layer of sprayed or cast in place concrete. It provides both a rapid and economical alternative to the more traditional sprayed concrete support systems in a number of situations and particularly where the traditional system faces difficulties such as complex geometries or space limitations.

The membrane consists of a polymer-rich cement base imperative in preventing de-bonding and ensuring the long-term stability of the system. The strong bond is given by crystals produced during the hydration of the cement. These crystals are embedded on the surface of cured concrete and grow into fresh applied Masterseal 345 paste. The crystals are also embedded in the open exposed surface of the cured Masterseal 345 membrane and grow into fresh applied concrete, providing the chemical and mechanical bond.

The membrane bonds equally to the primary and secondary concrete layers with significant adhesive and shear bond strength, giving the system unique mechanical properties and waterproofing features. The bond is unaltered by the concrete placement, be it sprayed or cast insitu, or the presence of fibres, and allows the lining to act as a composite structure.

The adhesive (normal) bond strength to concrete is significant and easily reaches 1.2MPa ± 0.2MPa when dry but reduces to 0.5MPa locally when water saturated. Even in this eventuality watertightness is not compromised because of the bond to the inner lining. (The bond strength to metals ranges from 0.5 to 1.2MPa.) The tensile strength of the membrane is greater than 1.5MPa (at +20°C) with elasticity values between 80% and 140% (between -20°C and +20°C). Thanks to this, the membrane provides crack bridging capability some hours after application. Since hardening of the membrane reduces the elasticity, the minimum crack bridging ability is achieved once fully cured. For a 3mm thick membrane layer this ability is 3mm. Due to the tensile strength of the entire structure, the membrane does not delaminate.

When a shearing load is slowly applied to the structure, the membrane, thanks to its particular chemistry, has sufficient time to adapt to the imposed deformation through the rearrangement of its molecules. In this case the membrane behaves in a viscous manner, i.e. like a fluid, and is not comprised (maximum load at maximum rate of load application need to be established). However, when load deformations are applied at a higher rate, the composite lining resists with shear strength parameters in the following ranges: 20 = T = 45 and 0.5MPa = T = 1.05MPa. These shear strength parameters are taken from direct shear tests carried out under zero normal displacement conditions to a 2mm thick membrane applied to a smooth substrate and a 5mm



Photos and diagrams courtesy of Mott MacDonald and BASF UK

Left: The lower segmental lining ring and primary sprayed concrete lining

Above, left: **Meyco Oruga in operation during the first SCL section of the shaft**
Above: **Hand spraying the membrane**

thick membrane applied to a rough substrate. These two specimen conditions represent two ends of a spectrum. The minimum average flexural strength is 3MPa (tested in accordance with EN 12390: Part 1 and 5) when the membrane is installed centrally with respect to the composite system. Analyses conducted by Mott MacDonald, have shown that these outstanding properties of the Meyco system, lead to loads being transferred from outer/primary lining to inner/secondary lining so that the full lining acts compositely.

Typically designers consider the primary lining to carry the ground loads and the secondary lining to carry the hydrostatic loads. This new system allows the full thickness of the composite lining, primary and secondary layers together, to take the combined applied loads. In a real life situation this is carried out either as a true "single shell" or by acting monolithically through the deformation of the membrane, depending on the magnitude and direction of the applied loads (radial and tangential) and subsequent relative deformation of each lining layer. The two layers of concrete are both to be considered as permanent and durable elements that will fulfill the structural requirements both during construction and throughout the designed life of the structure.

Advances in sprayed concrete technology have made it possible to rely on sprayed concrete as a permanent solution. Durability issues derived from poor mix design, involving inappropriate admixtures, and poor application have been overcome thanks to better understanding of sprayed concrete, advances in chemical formulations and robotic applications and approved guidelines and certification for hand applicators.

The membrane itself should have a nominal thickness of 3mm (localized minimum of 2mm can be accepted and maximum of 10mm) in order to be watertight. Laboratory tests show that the composite system has excellent resistance to water ingress and can sustain up to 20bar pressure over 1 year.

Thanks to the fully bonded nature of Meyco's combined ground support and waterproofing system the location of any potential leakage can be easily identified, as water cannot migrate along the membrane-concrete interface. Any remedial measures will be simple, cost-effective solutions.

Hampton Pump Out Shaft

Thames Water Utilities required an upgrade to its existing system with the Hampton Pump Out Shaft. This shaft has 15m i.d. and is approximately 40m deep. The shaft pumping station is to replicate the duty of an existing shaft and associated connections to the supply network. The shaft connects to two tunnels for the supply of water and lies almost entirely in London Clay. The external water pressure can be attributed to leakage from the gravels above and/or infiltration through any London Clay fissures.

The design of the shaft follows the approach of a hybrid sprayed concrete lining (SCL)/segmental shaft - increasingly used for permanent works in London.

The top of the shaft is formed of pre-cast concrete segments with a SCL below. The advantage of this SCL method over segments is that the junction with the tunnel is simpler and quicker to form. Due to the depth of the shaft it would also be necessary to thicken the segments, to accommodate the increased ground loading, which presents its own difficulties, particularly in the transition between segments of different thicknesses. Also, forming low-level openings in the shaft lining would be time-consuming with pre-cast segments necessitating large steel sections if using jamb-and-lintel frames.

The construction of the lower section of the shaft, the low level portals and soft-eye was therefore constructed using SCL instead of pre-cast concrete segments. This was felt by Costain Ltd. (Contractor) and Mott MacDonald (Designer) to offer a simpler, safer and more durable solution in terms of ease of construction and performance in the long-term with savings in cost and programme.

For an efficient design a varied profile consisting of a thinner section at top, at the interface with the PCC lining, and a thicker section at the bottom, at the connection with the base slab, was considered. The thickness of SCL is 425mm at the segment interface and 625mm at the shaft bottom.

Crack limitation and improved flexural capacity was achieved using polypropelene fibres rather than steel fibres or steel mesh as they removed concerns over durability. Strux structural polypropelene fibres from Grace were used in the sprayed concrete.

To waterproof the shaft, Masterseal 345 was sprayed between primary and secondary sprayed concrete layers. The membrane could be applied to the primary lining using the same equipment (Meyco Oruga) as for the sprayed concrete. Standard waterproofing detailing, typically consisting of re-injectable grout tubes, hydrotites and waterstops were adopted at the joint with the PCC lining and the junction with the connecting tunnel and also where differential movement could occur and in areas of geotechnical concern such as areas of silt pockets within the London clay.

A smoothing layer was applied to rougher areas of the primary lining profile arising from joints and the inherent roughness of the 10mm aggregate. Shotpatch 12 was sprayed for this "regulating" process achieving considerable cost savings on Masterseal 345. A finishing coat was applied to the secondary sprayed concrete lining in areas where access is required.

Meyco's innovative ground support and waterproofing system proved very efficient, safe and economical for this deep shaft with multiple openings. The use of sprayed concrete as part of the permanent works has improved the cost-effectiveness of constructing underground structures.

The integration of a fully bonded membrane into the lining to establish a thinner monolithic waterproof structure ensured considerable savings both in terms of cost as well as to the programme.

A permanent composite SCL lining combined with a fully bonded waterproof membrane proved very successful and is recommended for future projects where it is deemed an appropriate solution. T&T

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Contacts

HEAD OFFICE
Progressive Media Markets
Progressive House
2 Maidstone Road
Sidcup, Kent
DA14 5HZ
United Kingdom

WEB
www.tunnelsonline.info

TEL
+44 20 8269 7789

FAX
+44 20 8269 7840

HOW TO CONTACT US

EDITORIAL


Tris Thomas

EDITOR
Tristan Thomas BSc (Hons)
Tel: +44 20 8269 7893 Fax: +44 20 8269 7840
Email: tthomas@tunnelsonline.info


Amanda Foley

DEPUTY EDITOR
Amanda Foley
Tel: +44 20 8269 7789 Fax: +44 20 8269 7840
Email: afoley@tunnelsonline.info

CONTRIBUTING EDITOR
Patrick Reynolds MEng
Tel: +44 20 8269 7748 Fax: +44 20 8269 7840
Email: patrickjreynolds@hotmail.com

DESIGN
Natalie Kyne

TECHNICAL ILLUSTRATOR
Nick Stenning

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

ADVERTISING


Gary Tween

GROUP ADVERTISEMENT MANAGER
Gary Tween
Tel: +44 20 8269 7849 Fax: +44 20 8269 7840
Email: gtween@tunnelsonline.info

NORTH AMERICAN MANAGER
Steven Caming - Granite Media Services
Tel: +1 603 447 1187 Fax: +1 603 447 6166
Email: granitemediaservices@yahoo.com

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

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

PUBLISHING


David Wildman

PUBLISHING DIRECTOR
David Wildman
Tel: +44 20 8269 7778 Fax: +44 20 8269 7840
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Tunnels & Tunnelling International is printed at Stephens & George Print Group, Merthyr Tydfil.

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Tunnels & Tunnelling International ISSN number 0041-414X is published monthly for US$226 a year by Progressive Media Markets Ltd, Progressive House, 2 Maidstone Road, Sidcup DA14 5HZ, UK. Periodicals postage paid at Rahway, NJ.

POSTMASTER: send address corrections to Tunnels & Tunnelling International c/o BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001. US agent: BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001.

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