Building new links in Budapest

On 16 March, the second EPBM on Phase 1 of Budapest's Metro Line 4 reached Szent Gellért station, the halfway point on the new link. Eszter Kalman, geotechnical engineer with DBR Metro Project Directory, provides an overview of the line and station construction

Budapest is currently embarking upon its largest transport infrastructure scheme in decades. The US$2.3bn Metro Line 4 (M4) project will play a vital role in the development of the Hungarian capital's transportation network, linking new terminals in the southwest and northeast via a number of key metro and suburban rail interchanges (figure 1). It is hoped that these new terminals, which are located on the outskirts of the city centre adjacent to commuter motorways, will ease Budapest's significant traffic congestion problems.

Line 4 is being built in two stages by DBR Metro Project Directory, a delivery entity that was established by the City's General Assembly in 2007. The first US$1.58bn phase of the project, which began in 2006 and is scheduled for completion in 2011, runs from Kelenföldi station on the Buda side of the city to Pest's central Keleti railway terminus. These Phase 1 works have been split into 11 main construction contracts and include 10 stations and 7.3km of twin 5.2m i.d. running tunnel. The second phase of the line, from Keleti to Bosnyak Ter (Square), will comprise a further 3.2km of twin bore tunnel and four stations. The entire line is scheduled for completion by 2013 and is being financed by the State (79%) and the Municipality of Budapest (21%), with additional support also currently being sought from the EU.

Preliminary design for Line 4 began in 1998 and was conducted by Hungarian firms Fömterv and Uvaterv in association with the UK's Mott MacDonald. By January 2006, the US$250M design-build contract for the 7.3km twin TBM driven running tunnels, crosspassages, TBM launch structure, and Gellert Ter station had been awarded to the Bamco consortium, which consists of Vinci Construction, Strabag and Hidépíró Zrt. Contracts for the remainder of the nine stations and associated structures are being built by several other consortiums.

The tunnels are being driven at depths of 15m to 20m through a densely built-up area with many historical buildings, requiring precise monitoring 24hrs a day. Between Gellert and Fovam stations the tunnels will also pass through widely varying soil layers under the River Danube, which is expected to be a major challenge.

Below: Works underway at Móricz Zsigmond Square Station following TBM passage

Geology

Budapest's geology comprises of Triassic dolomites overlain by tertiary sediments, primarily consisting of homogenous clayey sandstones and marls, followed by cohesionless quaternary deposits from the old Danube floodplains. The soil conditions along the tunnel alignment can be divided into three distinct zones:

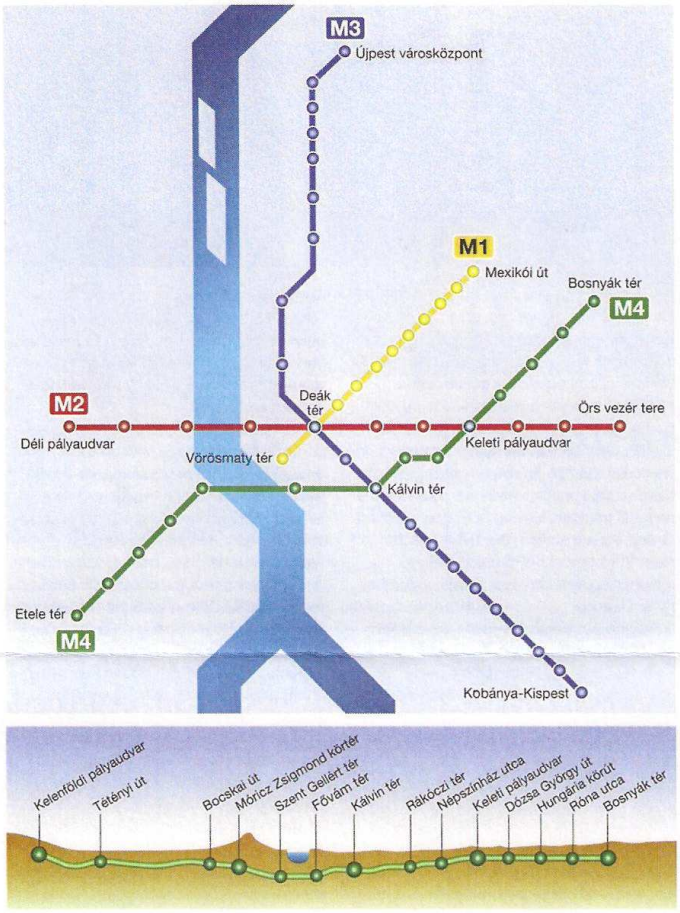
On the Buda side of the city, between the Kelenföldi Terminus and Gellert Square, the tunnel mainly lies in over-consolidated Kiscelli clay (Middle Oligocene), similar to London Clay. The depth of the Kiscelli clay varies, but it thins sharply towards Gellert Square, giving way to the Tardi clay formation (Lower Oligocene).

Between Gellert and Fovam stations is the most challenging zone of the alignment, a major fault zone under the Danube river, where ground is expected to be very poor.

On the Pest side, between Fovam Square and Keleti Railway Terminus, the geology becomes increasingly younger (from Middle to Upper Moicene) and highly changeable - varying locally from soft clays to sand, fine sand and sandy gravel. Throughout the route the groundwater level is located above the tunnel in the quaternary deposits.

TBM tunnelling

Due to the major differences between the ground conditions on Buda and Pest sides of the city, two hydraulic Herrenknecht EPBMs with monoblock cutterheads were selected to drive the running tunnels. These machines have been operating in open and compressed air modes through the Kiscelli clay on the Buda side. Each have been progressing at an average rate of about 12 rings (18m) per day, working 24hrs a day, six days per week, and both have now reached Gellert Station where maintenance works are being undertaken before



Left: Fig 1 - Map of Budapest's Metro network and long section of Line 4

relaunch under the Danube. From here they will run in closed mode for the majority of the remaining distance to Keleti. In this poorer geology careful control of the machines will be key to the success of the drives.

Just-in-time delivery of the five segment plus key pre-cast concrete lining rings for the project is being provided by Slovakian-based manufacturer ZIPP. The rings are lowered into the tunnels by two heavy-duty cranes and transported, along with mortar, via railbound trains. Each train also includes four muck wagons, which are also lifted by crane and unloaded into a dedicated spoil area. With both TBMs working, around 135 trucks are required daily to transport the waste to its final discharge site 20km away.

From an environmental point of view, one of the most sensitive aspects of the M4 works is the tunnel section under the Danube and Szent Gellért square station. Prior to construction this area was subject to thorough geological and hydrological testing in order to develop a construction methodology that would preserve the city's famous underground thermal springs. During construction, a continuous groundwater monitoring system was established at Szent Gellért square, which comprised 20 wells to measure the quality, temperature, composition and rates of discharge into the springs.

Stations

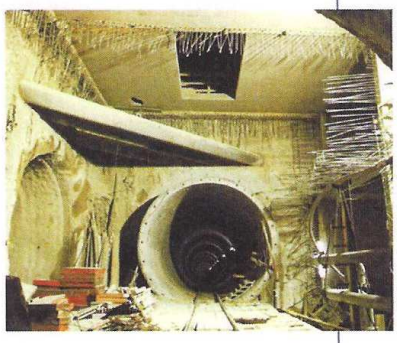
The stations are being built by numerous open pit, top-down and mixed construction methods. Móricz Zsigmond Square Station is an open-pit station. Support of the pit is constructed in two stages, from surface level to a depth of 5-7m a secant pile wall is installed, followed by 27m deep x 1m wide diaphragm wall. Following excavation, a 3m thick reinforced concrete base slab is formed. The main structure of the Móricz Zsigmond square station has now been built and both TBMs have already passed through the station.

The stations built by the top-down or 'Milanese' method are the Tetenyi road, Bocskai road, Nepszinhaz and Keleti Railway Terminus stations. Here the top slab is constructed first, then mining is continued underneath the slab.

During construction of Tetenyi road station engineers paid special attention to the preservation of "Bikás Park". Once the work is finished the area will be reinstated. An interesting feature of this particular station is a glass dome that will be built over the station, through which sunlight will reach platform level. The Tetenyi station shaft, diaphragm walls, base slab and also the floor slab over the passenger area are all now completed.

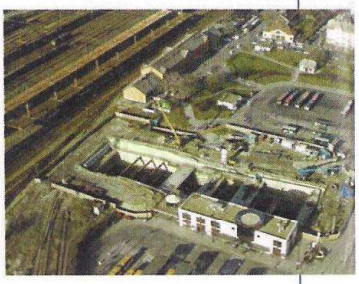
The commercial and administrative centre of Bocskai road is a shopping precinct, which will greatly benefit from the addition of the metro. One of the most important aspects of the station design here was the need to facilitate the need for future branch-lines towards Budafok. The ventilation shaft, the mining ventilation tunnel, the diaphragm walls and the floors have all been completed. Both TBMs have now passed these two stations and as a consequence construction of the internal walls is now well underway.

On the Pest side of the city, Nepszinhaz road station and the Keleti Railway Terminus have been built by cut and cover. Nepszinhaz road station is 108m long and 19.6m deep. The station box has now been completed by the contractor, but the ventilation shaft and tunnel is yet to be constructed. Keleti Railway Terminus will be



Right: Construction of the internal walls at Bocskai Road Station





Above: Open cut station construction works underway at Bocskai road station and Keleti main railway terminus

the final station on the first section of the M4 line. It is one of the largest stations at 86m long and has a turn-out structure which is a further 100m in length. The construction methods are mixed, with an open cut station box and cut and cover turn-out structure.

The M4 Kelenföldi Terminus is located directly below the mainline railway station, providing easy access between rail, metro and local transport modes. Construction has therefore been required under the 28 tracks of the terminus above. Divided into five sections, in total the works will take two years to complete, with the last of the five sections currently underway. The method used is diaphragm walls with cut and cover but, as this station is the final station on the line, there will also be an 80m long NATM interchange tunnel, which has a cross section of more than 120m^2. Constant monitoring of instrumentation is essential during the excavation.

Gellert square station is possibly the most difficult of the tasks that had to be solved by designers and contractors. In addition to the thermal springs, which supply the city's famous Gellert Spa, the Budapest University of Technology and a prestigious hotel are also nearby. There are also numerous residential properties in, and adjacent to, the square. The station was designed to allow passengers to connect easily with surface transportation services as well as the neighbouring University.

Following construction of the 41m deep diaphragm walls, an open construction pit was built at the end of 2007 for the upper station box. NATM works for the remainder of the station, including platform tunnels, then advanced from a 31m deep shaft next to one of the University buildings. Currently, a sprayed concrete lined (SCL) crossover structure is also being built, by enlarging the segmentally lined TBM-bored running tunnels. As part of a design review for Bamco to confirm the feasibility of the crossover design in the over-consolidated Kiscelli clay, Mott MacDonald carried out extensive numerical modelling and ground movement analyses for the area affected by the tunnel and crossover construction. Building response assessments were also performed for the structures in the station vicinity identified at risk by the contractor. In particular, Bamco has taken great care with the thermal springs, which are considered a national treasure. Having both now reached Gellert square station, the TBMs will be reset from open to EPB mode before relaunching them on their drives under the River Danube.

Fovam square station is the first station on the Pest side of the river. The exit to the station is adjacent to the Corvinus University and links with the surface tram transportation network. This area will be fully rehabilitated parallel to the metro station construction.

This is one of the deepest stations located 46m underground. It is particularly challenging as half of the platforms will be located under the banks of the river. Therefore these are being built by NATM using ground freezing technology. This mining work carries the highest risk factor on the whole line. The geological conditions are very changeable at Fovam square. One of the highest risks results from the tectonic fault zone, which runs along the west side of the station under the Danube. By contrast, the eastern side of the station is located in sandy rock, sandy silt and sand.

The contractor is using a large array of geotechnical instruments to monitor the excavation and prevent against collapse. Piesometers, horizontal inclinometers, reverse head (RH) horizontal extensometers, convergence measuring points and vertical inclinometers are all being employed. In addition, a Gyro Smart borehole survey system for 3D analysis of the freezing pipes and temperature lances have been installed.

At Fovam square station on the upper station level, grouting works will be finished by the middle of this year. The platform tunnels under the Danube are due to be finished by April and under the University by May. Therefore the first TBM is scheduled to arrive at the station by early May and the second early June.

Rakoczi square station will have an exit on the surface that will take up the smallest amount of space as possible, additionally passengers can reach the market hall by large rapid elevators. With regard to the station works, the station box and ventilation shaft have been built by open-pit. Following this the contractor finished the ventilation tunnel and the platform tunnels by NATM. During platform tunnel construction the pore water pressure must be reduced, as the soil conditions here are possibly some of the poorest on the line. The soil consists of sand, sandy silt and silt; there are also two separate groundwater levels under the surface.

Kalvin square station will be the main interchange between Metro Line 4 and Metro Line 3. As part of the new works the station's existing underpass system will be completely rebuilt. As a result of this new interchange, a high-standard public transport link will develop between South-Buda and North-Pest as well as South-Pest. An interesting point of this station is that the M4 tunnels will run above the M3 tunnels. Another sensitive point of these works is the close vicinity of the surrounding buildings and that one of the busiest intersections in the city will have to be closed for months. The construction works here will be finished soon.

Overall on the project, one of the biggest challenges at present is the management of contractor claims, with a team of international advisors currently assisting the Project Directorate and Contractors to resolve disputes. Over the coming months however the biggest challenges will be the River Danube TBM crossing and completion of the ground freezing operations at Fovam square station.

Currently 40% of all the works on the first phase of the M4 have been constructed with completion expected in 2011. T&T