Tema 4 / Topic 4:

Gradnja, sanacija in vzdrževanje podzemnih objektov

Construction, Renewal and Maintenance of the Underground Structures

New Metro Line Construction in Budapest

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One of the difficulties being encountered in the construction of Budapest Metro Line 4 is that the tunnel passes and will pass through different kinds of soil. Geologically and tectonically, there are 3 different sites: the **Buda side of the River Danube,** which is homogeneous, a special, over-consolidated clay marl, much like London clay; **the section under the Danube,** which is the highest risk zone of the metro construction, it being the highest tectonic zone in Hungary with numerous fault zones; and, third, the **Pest side,** where geological conditions are younger and younger as we move from Southwest to Northeast, and where the soil environment is very changeable.

There are significant differences between the soil structures of the Buda and the Pest sides. The TBMs will therefore have to be re-set. On the Buda side, the TBMs ran in so-called "Kiscelli" clay, a hard over-consolidated clay marl; while on the Pest side, in more varying strata of softer clays, sand, fine sand and locally sandy gravel.

The stations the line are being built with 3 different methods: open-pit, Milanese or mixed.

The two most interesting station constructions are the **Gellért tér (square) station** and the **Fővám tér station.** These two stations are next to the Danube. Gellért station posed a most sensitive task for both the designers and contractors of the project: they had to ensure the protection of the thermal springs in the area and their unbroken supply to Gellért Spa nearby, and that works would not disturb the life on the Budapest University of Technology, the guests of one of the most prestigious hotels in Budapest and residents living in the houses around. Fővám station is the first station on the Pest side, right at the other side of river. This station causes the greatest difficulties because the platforms reach 20 metres under the river, and are being built by NATM with freezing technology. Mining under the river has had the highest risk factor all along the line. The geological condition are highly changeable at Fővám tér. One of the highest risk tectonic zones in Hungary is along the west side of the station under the Danube, so there are a lot of fault zones making excavation very difficult.
The new metro line in Budapest will be a state-of-the-art, 100%-accessibility, green means of transport, indeed very useful for the city. It will decrease surface traffic, air and noise pollution. It will be a fully automatic, driverless system.

Key words: geological environment, station construction, mining technology, mining technology under river, freezing technology

Budapest is currently embarking upon its largest 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. 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.

1. Figure: Budapest Metro Line 4

Line 4 is being built in two phases by DBR Metro Project Directorate, a delivery entity that was established by the City's General Assembly in 2007. The first US$1.58 bn phase of the project, which began in 2006 and is scheduled for completion in 2011, runs from Kelenföld 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 Bosnyák tér, will comprise a further 3.2km of twin bore tunnel and four stations. The entire line is scheduled to be completed by 2013, and is financed by the state (79%) and the Municipality of Budapest (21%), with additional support also currently being sought from the EU.

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 Gellért and Fővám stations the tunnels will also pass through widely varying soil layers under the River Danube, which is a major challenge.

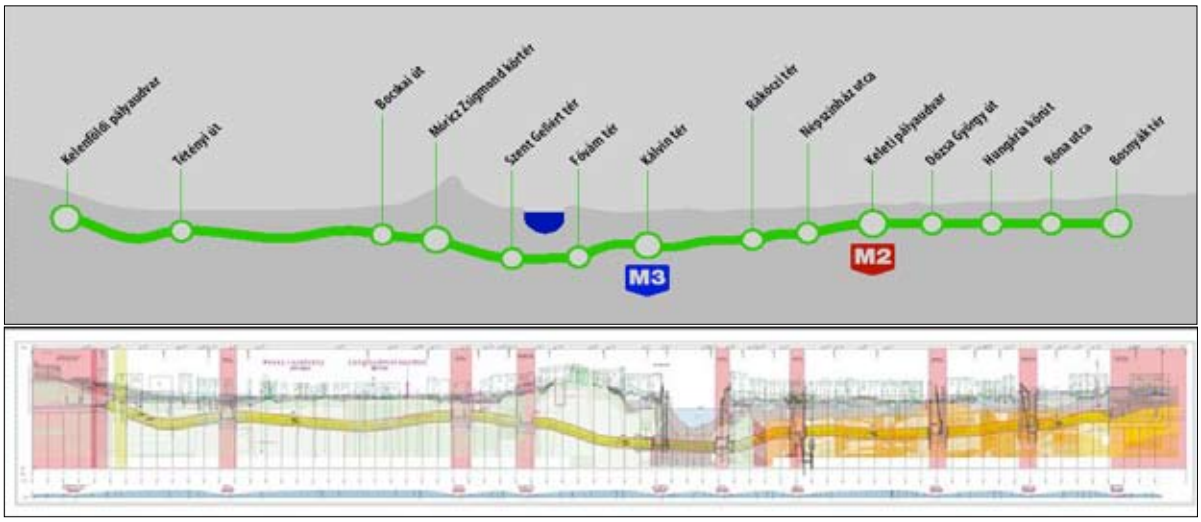
Geology

Budapest's geology is comprised 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 Kelenföld Terminus and Gellért tér, 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 Gellért tér, giving way to the Tardi Clay formation (Lower Oligocene). The Kiscelli Clay has three different layers; the upper zone of the clay stratum in a thickness of 1 to 3 m is expanded, heavily fractured and weathered, due to the geological erosion. Below this an expanded, fissured zone is found. This clay is very good environment for a tunnel construction.

The section between Gellért and Fővám stations is the most challenging zone of the alignment, with major fault zones under the Danube River, where ground is expected to be very poor.

On the Pest side, between Fővám tér and Keleti Railway Terminus, the geology becomes increasingly younger (from Middle to Upper Miocene) 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.



2. Figure: Geological longitudinal section of Metro Line 4 in Budapest

TBM tunnelling

Due to the major differences between the ground conditions on Buda and Pest sides of the city, two hydraulic 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, the south shield has reached Fővám station, and the North shield is expected to break in the beginning of August. 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 success of the drives.

Stations

The stations are being built with open-pit, top-down and mixed construction methods. Móricz Zsigmond tér 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 27-m deep and 1-m wide diaphragm walls. The main structure of the Móricz Zsigmond station has now been built and both TBMs have already passed through the station.

3. Figure: Móricz Zsigmond station

The stations built by top-down or 'Milanese' method are the Tétényi út (road), Bocskai út, Népszínház utca (street) and Keleti Railway Terminus stations. In the latter case, the roof slab is constructed first, then excavation is continued underneath the slab. An interesting feature of this the stations is that a glass ceilings will be built on the tops to let sunlight in down to platform level. The Tétényi 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 út 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 to facilitate future branch-lines towards Budafok. Tunnelling on the Buda side having been completed, construction of these two stations is now well underway.

On the Pest side of the city, Népszínház utca station and the Keleti Railway Terminus are being built with the cut-and-cover method. Népszínház station is 108m long and 19.6m deep. The Keleti Railway Terminus station will be the final station on the first section of the M4 line. It is one of the largest stations with a length of 86m and a turn-out structure of 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 Kelenföld 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 cut-and-cover walling, 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 120m2. Constant monitoring is essential during the excavation.

4. Figure NATM Tunnelling- Kelenföld railway station

Gellért tér station is possibly the most difficult of the tasks that had to be solved by designers and constructors. In addition to the thermal springs, which supply the city's famous Gellért Spa, the Budapest University of Technology and a prestigious hotel are also nearby.

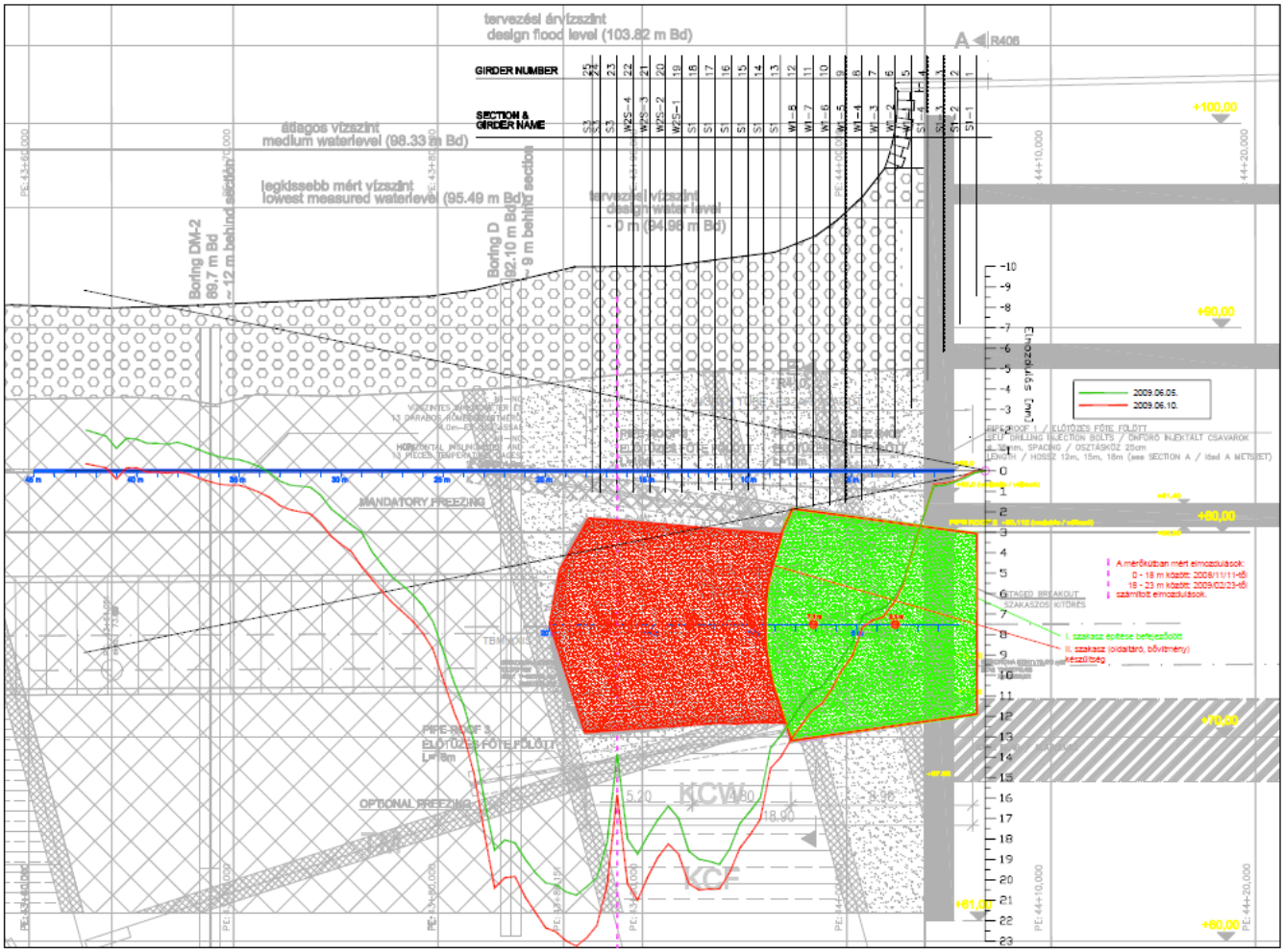
Following construction of the 41m deep diaphragm walls, an open construction pit was built at the end on 2007 for the upper station box. NATM works for the remainder of the station, including platform tunnels, then advanced from a 31m deep shaft next to one of the University buildings.

Fővám tér station is the first station on the Pest side of the river. The exit of 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. The mining work here carried the highest risk factor on the whole line. The geological conditions are highly changeable at Fővám tér. 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 Geotechnical Site Investigator (GEOVIL Ltd.) of the contractor uses 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.



5. Figure: Curve of the results of Horizontal Inclinometer by GEOVIL Ltd

6. Figure: Ground freezing pipes under the Danube on the Fővám station

At Fővám station on the upper station level, grouting works will be finished by the middle of this year. The platform tunnels under the Danube and under Corvinus University have been complete. The first TBM arrived at the station in June, and the second TBM is scheduled to arrive early August.

Rákóczi tér 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 (by GEOVIL Ltd.), 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.

7. FigureNATM Tunnelling- Kálvin tér station

Kalvin tér station will be the main interchange between Metro Line 4 and Metro Line 3. The excavation of the interchange tunnel is under continuous geotechnical supervisor by Geovil Ltd, this excavation is very difficult and highly risk because of the nearly buildings and the 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.

All in all, one of the biggest challenges at present is the management of contractor claims, a team of international advisors currently assists the Project Directorate and Constructors to resolve disputes.