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THE PORTO METRO – AN OVERVIEW OF THE UNDERGROUND CONSTRUCTION

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INTRODUCTION

The upgrading of the existing railway network of the city of Porto, by means of a light metropolitan system, with about 70km of tracks, was decided in 1998 and has been carried out by the public company Metro do Porto SA.

The crossing of the crowded area of the city center, part of it being an UNESCO world heritage, has required about 7 kilometers of double track tunnels and 10 large underground stations.

TUNNEL CONSTRUCTION

The tunnels were excavated by two Earth Pressure Balance (EPB) Tunnel Boring Machines (TBM), about 8.7m in diameter. Line C tunnel, linking Campanhã to Trindade station (E-W), had a length of 2350m and three underground stations, with a maximum overburden of 32m and a minimum one of 3m, before reaching Trindade station. Line S tunnel, with a total length of 3950m, linking Salgueiros to São Bento station and ending near the north abutment of the D. Luiz I bridge, had a maximum cover of 21m.

In the network two more tunnels were included: an ancient completely refurbished railway tunnel for the West exit from Trindade station (Lapa tunnel), of about 400m long, and also a service tunnel about 270m long (J tunnel) linking the yellow and blue lines and allowing the transfer of unoccupied vehicles between both lines. This tunnel was excavated by blasting and using NATM.

The TBM tunnel excavation started in Campanhã towards Trindade in the year 2000, and stability problems were encountered, consisting in overexcavation and three collapses until the surface. The last of these collapses, on 12 January 2001, caused the death of one person in a small house over the tunnel, swallowed by a crater underneath. LNEC has presided to the Accident Inquiry Commission appointed by the Government.

Tunnel and station excavations were carried out in the Porto granites, with a random and heterogeneous weathering pattern ranging from sound granite (W1) to a residual cohesionless granular soil (W5), with unpredictable and sudden changes of fracturing and weathering degrees, both in the vertical and horizontal directions.

Large weathered zones could be found following zones of sound granite, the changes being neither progressive nor transitional, what made it difficult for the TBM EPB to differentiate between zones where the chamber could be operated in open mode (no pressure) and the weathered ground, where a support pressure was required on the face (close mode).

A more effective solution for TBM Tunnel driving was found with the introduction of an active support system, which involved the injection of pressurized bentonite slurry to compensate for deficiencies in the face support pressure when driving in mixed face conditions. In association with ground improvement solutions and detailed monitoring plans including on line interpretation of data, it was possible to pass under very old houses with a minimum cover, with minimum surface settlements and building disturbance.

UNDERGROUND STATIONS

The same geotechnical conditions shown by the Porto granites, as well as the variability of construction type and risk conditions of the neighbour existent buildings had to be faced also in the excavation of the 10 large underground

stations of the blue and yellow lines, where mixed cut and cover and underground excavation methods were used to meet the very different shapes and sizes of the stations:

Heroísmo station – recent embankment formations overlying a complex pattern of weathered granite formations did not prevent the excavation of a large access and ventilation shaft of about 1000m2 cross section, in the base of which 4 tunnels were excavated in several steps, using NATM: the railway tunnel (platforms) with a cross section of 232m2, the 180m2 access tunnel, crossing and overlying the former, and two 24m2 ventilation tunnels. No significant damage was induced to neighbour buildings during construction.

24 de Agosto station – a very large station over 20m in depth required, due to the variability of the boundary geotechnical conditions, different solutions for the retaining walls (diafragm anchored walls, piles, props) and a careful monitoring risk assessment and even reinforcement of some surrounding buildings.

Bolhão station – located under important streets (Santa Catarina and Fernandes Tomás) in a densely built up area of historic value with classified monuments (Bolhão market, Souls Chapel), about half of the station was a cut and cover and the rest excavated by underground techniques (enlargement of the TBM tunnel for the platforms, and mechanical and blasting excavation of the cross gallery and Camélias access shaft). The monitoring of the building settlements and of blast induced vibrations and the definition of the primary support (shotcrete, wire mesh and fiber reinforced shotcrete, steel ribs, bolting, supporting beams) were major issues during the construction.

Trindade station – in this station, where converged the new tunnels of the yellow and blue lines and the Lapa and J tunnels, significant excavations and slope stabilization were carried out.

Salgueiros station – an eight shaped 24m deep large shaft, made of two uncomplete elipses with total maximum length and width of about 80m and 40m respectively, excavated either in soft ground or in medium to hard granitic rock.

Combatentes (Lima) station – a large access and ventilation shaft around 30m in depth allowed the multistep construction of two large section orthogonal tunnels, one for the railway platform and the other as the access and technical facilities tunnel.

Marquês station – a large elliptical shaft, 27m deep, with 48m and 40m long axes, excavated following the NATM methodology, is the core of the station, having at the bottom the railway platforms. A sub-vertical fault, slightly oblique to the longer axis of the ellipse, determined about half of the excavation in residual granite soil, with kaolin content, and the other half in a moderately to slightly weathered granite, thus requiring the appropriate construction and monitoring techniques.

Faria Guimarães – initially designed as a cut and cover station, it became a totally underground station with three major ventilation and access shafts, and two oblique large section tunnels (platforms and technical facilities) excavated by NATM. Due to the complexity of the station, several 2D and 3D analyses of the structural behaviour, considering the constructive sequence, for the prediction of the ground settlements (warning and alarm levels) and for the risk assessment of the various surrounding buildings were carried out. A careful monitoring plan was followed in order to ensure the safety of the construction.

Aliados station – in front of Porto City Hall, a huge cut and cover excavation with several levels of anchored trussed beams, was carried out with no damage caused to surrounding structures.

S. Bento station – Connecting the metro to the historical central railway station of Porto, this underground construction, was carried out, based on an accurate monitoring plan and careful design.

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