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Survey of the design of back anchors for tunnel boring machines (TBM), used in the excavation of metro tunnels in Sofia

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Abstract

In the year 1974 the Municipality of Sofia approved the city plan containing the intention to build a metro system in Sofia. The construction works commenced in the year 1982. The route for Sofia metro Line- 1 Extension Project from Sveta Nedelya Square to Vassil Levski Stadium was financed with a loan from Japan International Cooperation Agency (JICA) and was carried out by the Japanese Contractor Taisei Corporation, under contract with the Sofia Municipality. For this route, with length of 2.4 km, two metro stations, two ventilations shafts and one start shaft, for strengthening of this deep excavations was design and used more than 610 tons temporary steel structures to keep the R.C. wall and pilot in vertically position. Contemporary machine methods of the tunnel excavation in the soft ground in Sofia was used for this route. The machine excavation is executed as a full-face excavation, employing tunnel-boring machines (TBM), with diameter 5820 mm.

The paper provides a review of the design approach for three types of temporary steel-frame structures, called “back anchors”, used to support the TBM in the beginning of the drilling process, before the TMB enters the tunnel. The paper begins with the choice of structural configuration of the back anchors, used in the excavation of metro tunnels in Sofia. The construction process, the materials used, the static analysis methods and, the monitoring of the structure during the TBM start are also described.

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1. Introduction

The tunnels of Sofia metro in the city central area are excavated by tunnel boring machines (TBM). A TBM requires a temporary support called back anchor to initiate the drilling before it enters the tunnel. As conditions at each metro station where boring typically starts vary, as do TMBs themselves, the design of each back anchor is done individually and locally.

The design brief submitted by Taisei Co. included two principle requirements to be met by the structure, namely, the design values of the forces acting on the back anchor and their application points, the type of hot rolled section to be used and an outline of the geometry of the structure commensurate with the dimensions of the TMB and the available space on site.

A structural configuration consistent with the requirements, which produces as direct transfer of the applied forces to the foundations as possible was proposed. It consists of two vertical frames parallel to the TMB axis which transfer the forces mainly by truss action. The overall 3-D stability of the structure is achieved by designing all the member-to-member connections as rigid. Bracing is avoided as much as possible to facilitate construction of the back anchor and operation of the TBM.

2. Description of the structure

2.1. Back anchor used in the start shaft

The structure of the back anchor used in the start shaft can be described as a combination of 2-D frames making together a 3-D frame. The 3-D frame is supported by the concrete wall behind it. The frames are developed along a rectangular figure with bases 5,37/5,37 m with axial distance (altitude) between them 4,40 m (Fig.1). The 5,67 m wide front vertical frame, perpendicular to the TBM axis, takes the loads from the TBM at four levels (Fig.2). There are 16 forces, 850 kN each along the perimeter of the front frame. Between the points of application of the TMB forces, the vertical front frame is stiffened by diagonal braces made of coupled HEB 300 segments (Fig.1). The rest of the structure is made of HEB 400, except where indicated. A view of the back anchor together with the TBM is shown in Fig. 3.

Fig.1. View of Back Anchor using in start shaft
2.2. Back anchor used in metro – station 8

The structure of the back anchor can be described as a 3-D frame (Fig.4). The 3-D frame is supported by slanted members at four levels. The frames are developed along a rectangular figure with bases 5.37/5.37 m, with axial distance (altitude) between them 4.40 m (Fig. 5). The 5.67 m wide front vertical frame perpendicular to the TBM axis takes the loads from the TBM at four levels. There are two forces, 750 kN each at the top level, and pairs of forces of 2250 kN each at the levels below. Between the points of application of the TMB forces, the vertical front frame is stiffened by diagonal braces made of coupled HEB 300 segments. The rest of the structure is made of HEB 400 except where indicated. A view of the back anchor together with the TBM is shown in Fig. 6 and Fig. 7.
2.3. Back anchor used in metro – station 7

The structure of the back anchor can be described as a combination of 2-D frames making together a 3-D frame. The 3-D frame is supported by slanted members at four levels. The frames are developed along a trapezoidal figure with bases 5.67 m and 4.60 m, with axial distance (altitude) between them 2.9 m (Fig. 8). The 5.67 m wide front vertical frame, perpendicular to the TBM axis, takes the loads from the TBM at four levels. There are two forces, 750 kN each at the top level and pairs of forces of 2250 kN each at the levels below. Between the points of application of the TMB forces, the vertical front frame is stiffened by diagonal braces made of coupled HEB 300 segments. The rest of the structure is made of HEB 400 except where indicated. A view of the back anchor together with the TBM is shown in Fig. 9, and a close-up view of the back anchor only, in Fig. 10.
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The design of all the members made sure that the strength and stability requirements of the Bulgarian standard for design of steel structures, [1] and the respective Eurocode, [2] are adequately met. Theoretical solutions for buckling [3] were also used for extra verification.

3. Structural analysis

The structural analysis was followed by a 3-D frame FE analysis, [4] by the programs SAP2000, [5] and Tower 5.5. The design values of the forces used in the member design were obtained assuming linear elastic material behaviour, absence of geometrical imperfections and lack of geometrical nonlinearities. In addition both versions were solved assuming second order effects such as P-Δ effect, misalignment of the TMB axis and the back anchor axis by 10 mm in plan, modelling of rigid offsets at the member intersection. The principle
features of the SAP2000 computational model are shown in Fig. 11 and Fig. 12. A numerical solution of the beam on elastic foundation problem, [6] was used to compute the contact stress between the foundation slab, and the horizontal HEB section on which the diagonal braces step.

Fig. 11. The model - loads and supports  
Fig. 12. The model – cross section orientation

4. Conclusion

The back anchors used in the start shaft 9, metro-station 8 and metro-station 7, described in this paper were used and removed by the time of writing. To the delight of the authors and indeed the clients – Taisei Co., all three TBMs started without complications, meaning the back anchors successfully served their mission. Although the structures were designed to withstand the specified forces, they were not reached during the TBM start; this meant a larger overall safety factor. It is fare to say that one can never be too safe, and any opportunity to add extra safety must be happily embraced. In our particular case it was not necessary to apply the full forces in order to bore through the RC wall, where the boring process started.

References