Design and construction of shoring at Uskudar station, Marmaray project

Wolfram Groh
*Bauer Lebanon Foundation Specialists s.a.r.l.*

Erdogdu Savaskan
*Bauer Lebanon Foundation Specialists s.a.r.l. - Turkey, Istanbul Branch*

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ABSTRACT: The realization of the old imagination of a railway link across the Bosphorus is in the making. The contract BC01 of the Marmaray Railway Project comprises the construction of about 14 km of railway between the Istanbul city districts of Kazlicesme in Europe and Ayrilikcesme in Asia. The main works consist of drilling and construction of 10 km twin tunnels, immersion into the Bosphorus seabed of 1.4 km prefabricated twin tunnel tubes, and the construction of 4 stations, with cut-and-cover method being used for construction of the underground stations in Yenikapi, Uskudar and Sirkeci (N-entrance). The shoring works in Uskudar, which were executed by Bauer Lebanon Foundation Specialists s.a.r.l. and completed in July 2007, comprised of about 27,300 m² of 1500 mm thick reinforced concrete diaphragm wall having a depth of max. 58 m, for shoring and groundwater cut off, and about 34,700 m³ of jet grouting with columns of 3.4 m diameter, for internal lateral support.

1 INTRODUCTION

After The realization of the old imagination of a railway link through the Bosphorus Straits is in the making.

The contract BC01 of the Marmaray Railway Project comprises the construction of about 14 km of railway between the Istanbul city districts of Kazlicesme in Europe and Ayrilikcesme in Asia (see Figure 1). The main works consist in the boring and construction of 10 km continental twin tunnel, the immersion into the Bosphorus seabed of 1.4 km prefabricated twin tunnel tubes, and the construction of 4 stations, with cut and cover method being applied for construction of the underground stations in Yenikapi, Uskudar and Sirkeci (N-entrance). The tunnel stations of Uskudar (in Asia) and Sirkeci (in Europe) are located near the Bosphorus shore and, owing to the gradient of the immersed tunnel, their construction required the excavation of 30m deep pits, under water pressure of up to 28m. The Turkish partnership of Gama and Nurol, who were awarded the Marmaray Contract BC01 in joint venture with the Japanese firm Taisei, subcontracted the design and construction of the shoring works of both stations to Bauer Lebanon Foundation Specialists, a regional foundation contractor affiliated to Bauer Spezialtiefbau GmbH of Germany.
Before starting of works in Üsküdar the site area had to be reclaimed through major traffic diversions, and shoring works could only be started after archeological excavations and investigations were completed. In June 2006 a major part of the site area could at last be handed over to the contractor and shoring works could be commenced. The shoring works in Uskudar, which were completed in July 2007, comprised of about 27,300 m² of 1500 mm thick reinforced concrete diaphragm wall with a depth of max. 58 m, and about 34,700 m³ of jet grouting using 3.4 m diameter columns, which required about 32,700 m of boring to a max. depth of 50 m.

Figure 1. Layout Plan of the Marmaray Railway Project, Contract BC01

2 SOIL CONDITIONS

In Uskudar, a 5 m thick layer of filled ground was encountered below the asphalted road surface, which consists in clayey sand with remains of old building foundations and sewer network, and is contaminated with organics. This upper layer is followed by medium dense to dense alluvial silty sands, with lenses of clay and layers of marine shells, which reach down to the bedrock. The fines content of the alluvium varies between 10 and 30 per cent. The bedrock consists of sandstone (including graywacke), siltstone, claystone and diabase (in the form of volcanic intrusions), with RQD of 30 to 90 per cent and UCS of 50 to 120 MPa. Within the upper 3 to 5 m, however, the rock is in general highly weathered and highly fractured. The bedrock surface showed highly variable gradients (see Figures 3 and 4), which in consequence led to a major revision of the shoring design, as the predictions of rock level contours, which were based on the investigation bores available for tender, had to be substantially revised during construction, thus increasing the quantities of diaphragm wall and jet grouting.

The groundwater in Uskudar is encountered at 2 m below road level and is of moderate salinity. The Marmaray Project is located in the southern part of Istanbul, and being close to a branch of the North Anatolian Fault Zone in the Marmara Sea, bears high seismic risk. The alluvial silty sands are considered to be liquefiable under seismic impact.
3 SHORING MEASURES

3.1 Design

Based on the design requirements given by the tender documents BAUER proposed the following shoring measures (see Figures 2 to 7):

Retaining of sides of excavation and vertical groundwater cut off is provided by means of reinforced concrete diaphragm wall, 1500 mm thick, with lateral support system based on five layers of reinforced concrete strut beams. For the purpose of groundwater cutoff, and to provide a reaction system against buoyancy of the middle section of the station structure, the diaphragm wall is anchored by a minimum of 7 m into bedrock. Steel columns installed in 1500 mm diameter bored piles are positioned in the center line of the station to reduce the free span of the strut beams for economical reasons. In view of the substantial earth- and water pressure acting on the shoring system the design calculations had to be run with finite element method (FEM). These calculations showed excessive horizontal deflections of the diaphragm wall at station foundation level, in wall sections with low bedrock level.

Therefore a soil improvement system was required to provide lateral support below foundation level, and Bauer proposed to treat the soil in block volumes by means of jet grout columns, which are laid out in the shape of horizontal strut beams (see Figure 7). It was further proposed to install a grid of jet grouting columns within the alluvium layer to provide stabilization of the alluvium soil against liquefaction in case of seismic impact. This grid was incorporated in the layout of soil improvement, however in areas with deep rock level respective jet grout columns needed to be extended to reach rock. Deep wells were proposed in a grid of 300 m² per well to allow the lowering of the groundwater level in the station area during excavation and to maintain it below foundation level during construction of the station structure.

![Figure 2. Plan View of Uskudar Station Excavation Area (seen from North)](image-url)
Figure 3. Longitudinal Section of Üsküdar Station (seen from South)

Figure 4. Longitudinal Section of Diaphragm Wall and Jet Grouting (seen from South)

Figure 5. Construction Step 11 at Final Excavation Stage (Middle Section)
3.2 Construction of Diaphragm Wall

Deep trench excavation was carried out by means of a Bauer Slurry Trench Cutter BC40 (see Figure 8). The primary panels were excavated in lengths ranging from 6 to 7 m, and were reinforced with two rebar cages each, which were spliced for installation (see Figure 9). The secondary panels were constructed with a designed overcut of 200 mm at every joint with primary panels. The important concrete volumes of up to 250 m³ per tremie pipe required a perfectly controlled concrete mix with fine tuned composition of chemical admixtures. Gama-Nurol, in close cooperation with the ready mix supplier, managed to supply a concrete with a retardation of 7 hrs, without compromising the slump value, air content and compressive strength.
3.3 Soil Improvement by means of Jet Grouting

The jet grouting was executed based on the two-phase method as shown in Figure 10. The individual columns were constructed in direct sequence (wet in wet) where possible, thus homogenizing the treated soil volume, which was designed to act as a strut slab.
In view of the required levels of the lateral support, between 30 and 40 m below working platform, the verticality tolerance of the bore and the achievable column diameter were the most critical parameters. The design grid size for jet grout columns of 5 m² per column was based on the achievement of column diameter of 3400 mm. Under consideration of a maximum bore verticality tolerance of 1/100, the design column diameter was 2800 mm in this case. If the target diameter of 3400 mm would not have been achieved, and based on the same verticality tolerance of 1/100, a reduction of, say, 25% in column diameter would have resulted in a reduction of the grid size of columns of more than 50%, i.e. the construction time would have been twice as long. Figure 11 illustrates the effect of verticality tolerance on the required column diameter, under consideration of a homogeneous jet grout block without gaps between columns. Therefore pre-construction grouting trials and quality control were treated with high priority.

Before start of soil improvement works, groups of columns were constructed as trials, and, the size, location and compressive strength of individual columns verified by means of coring (see Figure 12). The construction parameters of jet grouting were adjusted and fine tuned during these trials until the column diameter required by design was achieved. The quality control system during construction included inclinometer survey of each and every column and frequent verification cores, which were tested in the laboratory. The boring and jetting works were carried out by means
of a modified Bauer BG28, with an extended mast of 50m height, and equipped with the Bauer B-Tronic computerized controls (see Figure 13).

**Trial/Testing Phase**

![Trial column 4 diagram](image)

**Figure 12. Jet Grout Trial Column with Test Cores**

**Figure 13. Jet Grouting Plant and Rig**

**REFERENCES**

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