Eurasia Tunnel Project: The Geotechnical Challenges of the Asian Transition Box

Alexis ROSE*

WSP | Parsons Brinckerhoff, Cardiff, UK

ABSTRACT

The Asian Transition Box (ATB) is part of the Eurasia Tunnel Project and was constructed in 2013. It is 168m in length, up to 40m deep and was the launch pit for the tunnel boring machine. The design of the excavation support system posed some significant challenges and it proved necessary to redesign the system once excavation had begun following unexpected ground movements and the trigger of amber alert levels. The redefined parameters were an extension to the traditional guidance for the locally well-known Trakya Formation and required new descriptions and parameters to those that are usually used. The new approach required robust justification to allow variation from conventional practice. This paper gives an overview of the Eurasia Tunnel Project, with a detailed focus on the ATB construction and the redesign work undertaken.

Keywords: Deep excavations, Plaxis 2D, geotechnical parameters

1. INTRODUCTION

The Istanbul Strait Road Tube Crossing Project, also known as the 'Eurasia Tunnel Project' is under construction between the Asian and European sides of Istanbul. The project is being constructed along a 14.6km route, comprising 5.4km of twin-deck tunnels and 9.2km of approach roads. The principal aim of the project is to relieve Istanbul's transcontinental traffic pressure, but the project is also driven by economic and environmental benefits.

The Build-Operate-Transfer contract for the project was awarded to the Turkish-Korean JV, ATAŞ, formed through the partnership of Yapı Merkezi and SK Engineering and Construction.

This paper focuses on a specific aspect of the project, the Asian Transition Box (ATB), which is where the 13.7m diameter tunnel boring machine (TBM) was launched from and also where the tunnel form transitions from TBM to mined tunnel (NATM). Parsons Brinckerhoff were the Designers for the ATB and IGT Muhendislik, based in Istanbul, were their Sub-designers.

The ATB is located less than 70m from the edge of the Bosphorus; its approximate location is shown in Figure 1.

* presenting author

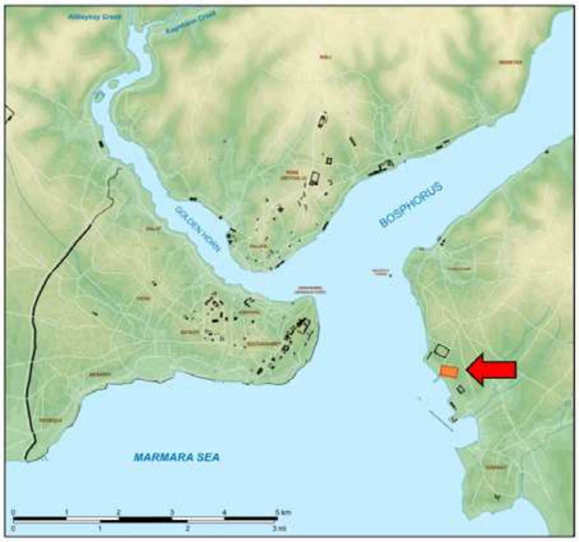

Figure 1. Site location

2. DESIGN ELEMENTS

The main elements for the 14.6km route are shown in Figure 2. The approximate lengths of the alignment components are as follows:

- 5.4km European approach roads
- 3.8km Asian approach roads
- 3.4km TBM tunnel
- 1.0km NATM tunnel
- 1.0km cut and cover tunnel

The maximum depth of the TBM tunnel is 106.4m below the Bosphorus surface water level, meaning that the TBM will be exposed to pressures in excess of 11bar, the highest ever for TBM construction.

The TBM tunnel is a twin-deck arrangement with traffic on the upper deck travelling towards Asia and traffic on the lower deck travelling towards Europe.

3. GEOLOGY

The geological setting is within a large scale fault system called the North Anatolian Fault Zone. The Marmara Fault System is the part of this fault zone that runs beneath Istanbul and many strong earthquakes occur along these fault lines. The fault map is shown in Figure 3.

The geology within the region comprises Carboniferous and Devonian sandstones, claystones, limestones and greywacke. The greywacke is the principal rock type at the location of the ATB and is locally known as the Trakya Formation.

The Trakya is a weathered argillaceous sandstone; deposition of these sediments together occurs from turbidity currents or submarine avalanches. Close to the Bosphorus the rock is even more intensely folded, faulted and fractured and as a result it has highly variable strength and stability properties.

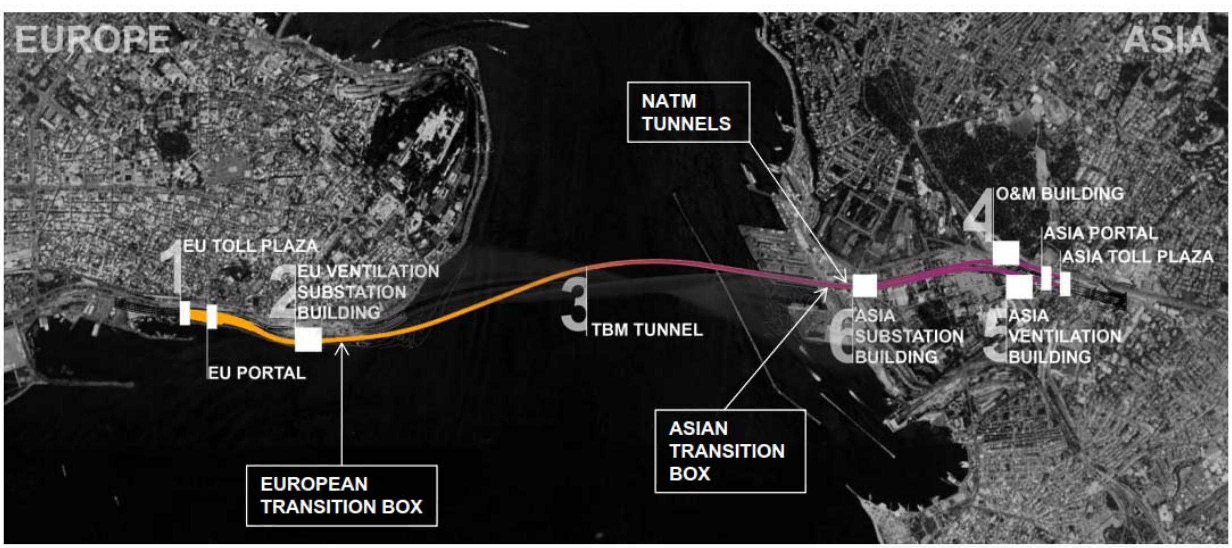

Figure 2. Eurasia Tunnel design elements

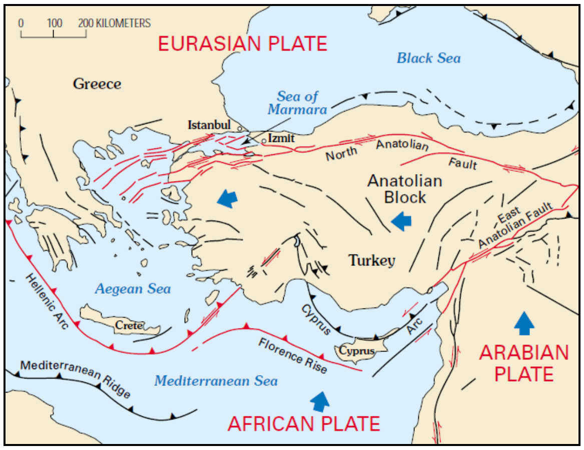

Figure 3. Fault map

4. GROUND INVESTIGATION

Three main phases of ground investigation were completed for the project, between 2010 and 2012.

A total of 12 boreholes were installed for the ATB, with an average depth of 36m. The majority of rock core was logged as sandstone, with thick zones of mudstone and thin zones of fault breccia, as well as diabase (dolerite) intrusions (a subvolcanic mafic rock).

Rock mass classification highlighted that the rock was poor quality, but this was not fully reflected in the derived geotechnical parameters. There were numerous iterations of the geotechnical parameter table put forward for design; a clear indication that it was challenging to confidently assign parameters to the materials.

The final version showed the rock divided into four zones; fair, poor, very poor and extremely poor, with effective friction angle (ϕ') ranging between 20^o and 35^o and the effective cohesion (c') ranging between 60kPa and 160kPa.

5. ATB DESIGN

The ATB is 168m in length and up to 40m deep. Various options were considered for the support of excavation design, although all centred on the use of piled walls with prestressed ground anchor tiebacks, which was considered to be the preferred construction method of local contractors. The option taken forward to final design involved an upper secant piled wall and a lower contiguous piled wall, as shown in Figures 4 and 5. The secant piles were up to 21m in length and the contiguous piles were up to 25m in length, all reinforced to full depth.

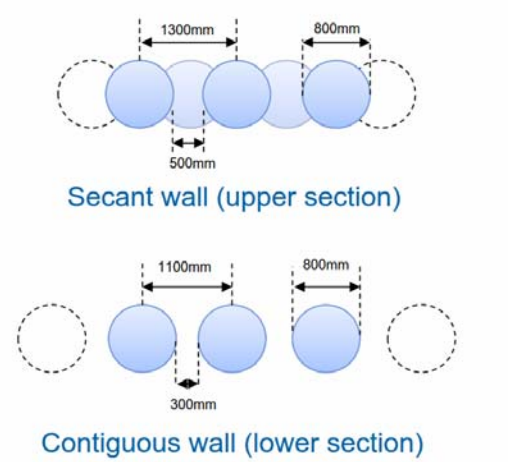

Figure 4. Pile dimensions

The ground anchors were up to 38m in length. They were double corrosion protection (DCP) anchors and were pre-stressed to 60 tonnes.

It was preferred to construct the wall in a two-phase approach because there were concerns over buildability and the installation of ~50m long piles into rock. This solution would provide a stiff ground control system and allow for flexibility in adapting the design if necessary, via the observational approach.

The secant piled wall was required for the top half of the excavation, where ground conditions and water seepage was considered more likely to be a problem. Accordingly, the design included inclined drain holes within the lower part of the secant piled wall to prevent build-up of water pressures. A contiguous piled wall was considered appropriate for the lower level, where the ground conditions were believed to be more favourable.

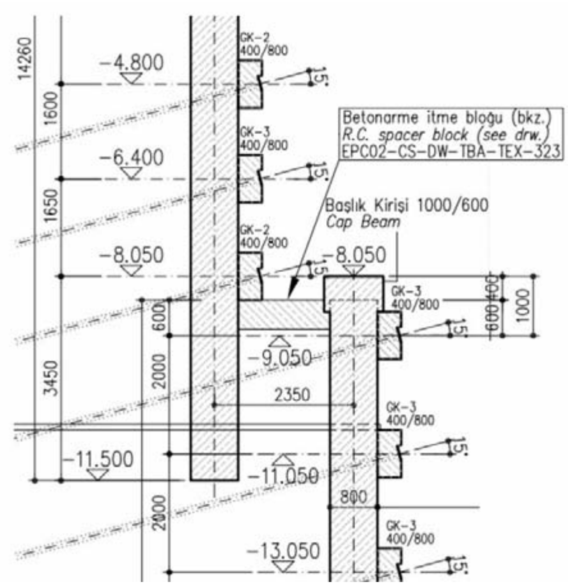

Figure 5. Interface between piled walls

The design was undertaken using Eurocodes Design Approach 2 and Design Approach 3. Finite Element analysis was used to design the support of excavation system, to allow scrutiny of the ground stresses and deflections and the forces in the piles and anchors. Limit Equilibrium analysis was used to check the overall stability.

The contract requirements set out that the deflection tolerances should follow the guidance from Clough & O'Rourke. From this, it was considered that the horizontal deflections should be limited to 0.1-0.2% (approx.) of the excavation depth.

6. EXCAVATION

Excavation began in April 2013. Examples of the ground conditions revealed during excavation are shown Figures 6 and 7. As indicated in Figure 7, the material at some locations was extremely weak and clayey and coud be excavated by hand. It was clear that in these instances, the material did not accord with the geotechnical design parameters. Also, groundwater was a problem and was observed flowing from the excavation walls and collecting in the base of the excavation.

Figure 6. Fault breccia

Figure 7. Fault gouge

In the first week of June 2013, monitoring data was beginning to indicate a potential problem with the support of excavation. On the 13th June, unexpected lateral displacements were measured from the inclinometers in the western section of the south wall, where excavation was at a depth of 12m. Corresponding increases in anchor loads were also recorded and an amber alert level was reached in one instance. This raised concern over the adequacy of design and the amber alert triggered the temporary suspension of excavation operations. The excavation was partially re-filled as a safety measure.

7. REDESIGN (PARAMETERS)

The redesign considered the live monitoring data in parallel with revisiting the original geotechnical parameter reports and also the core boxes obtained during the ground investigation.

On closer inspection of the core boxes and the borehole logs, it was noted that there was likely to have been mis-interpretation of the strength of the rock. For example, a description of “moderately strong, slightly weathered rock” was noted in one case; the sections of rock that were recovered were indeed moderately strong, but, were accompanied by a TCR (total core recovery) of 25% and an RQD (rock quality designation) of 7%.

In this example, the strength of the ground will be governed by the unrecovered material, likely to be a heavily fractured fault breccia material or a soft clayey fault gouge material, both of which would probably have been washed out with the borehole flush fluid.

The site of the ATB is very close to the Bosphorus and potentially closer to fault zones, which demanded a change from common practice and the introduction of a completely weathered rock, which may not be commonly observed.

8. REDESIGN (ANALYSIS)

Site observations showed that in places the material had properties more akin to a soil, and consequently the stronger sandstone layers could not be relied upon. The ground model and parameters were amended accordingly, with the most fundamental change being the introduction of a cohesionless material.

The back analysis was undertaken using Plaxis 2D software (Figure 8) and aimed to replicate the observed deflections. The Mohr-Coulomb soil model was unable to reproduce the observed deflections and it was proposed to use the Hardening Soil model.

The Hardening Soil model allows stress dependency of soil stiffness, where different stiffnesses can be applied to primary and unloading moduli. It was not originally considered appropriate to use this soil model for the initial design because the added degree of complexity could not be supported by the available data. However, with the addition of the monitoring data to allow model calibration, this approach was now regarded as the preferred solution. The analysis revealed a failure surface behind the wall within the free anchor length zone.

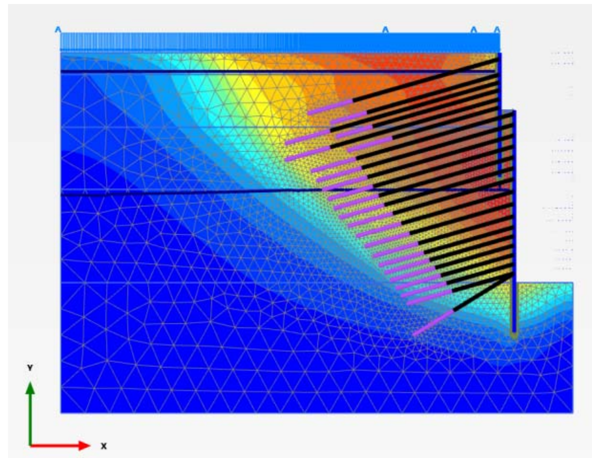

Figure 8. Plaxis model example

The design was completed in stages and on completion of each stage the construction drawings were detailed and issued progressively so as to minimise delay and standing time on site.

9. COMPLETION

Following the successful reanalysis and revised design of the ATB, the excavation recommenced. Work was only halted for two weeks before the new design started to be implemented on site. The stages of progress are shown in Figures 9 to 11. Final excavation depth was reached in January 2014.

The 13.7m diameter, 120m long TBM was launched from the Asian side of the city in April 2014 and broke through on the European side in August 2015.

10. CONCLUSIONS

Ground conditions encountered during construction can often differ to those anticipated from ground investigations or existing knowledge. The experiences of the ATB illustrate the real consequences of this problem.

A far greater importance must be placed on comprehensive GI and understanding of complexities in data interpretation. Similarly, communication between engineering geologists and geotechnical engineers, both locally and in remote design teams, is essential whilst formulating design parameters.

Figure 9. Progress 1st July 2013

Figure 10. Progress 4th October 2013

Figure 11. ATB completion January 2014

Effective implementation and management of the observational approach, along with proactive use of monitoring data to reappraise ground conditions and allow dynamic redesign, was key to the success of the project.

ACKNOWLEDGMENTS

The Author would like to thank the following people for their invaluable assistance: Adrian Dolecki and Mark Glendinning from Parsons Brinckerhoff Cardiff, Tolga Toğan and Ray Castelli from Parsons Brinckerhoff New York, and Anıl Kurban from IGT Muhendislik.

REFERENCES

Clough, G. W. and O'Rourke, T. D. (1990). Construction induced movements of insitu walls. ASCE Special Publication 25.

Keskin, H. B. (2008). Analysis of the performance of retaining systems in deep excavations in greywackes. PhD Thesis, Boğaziçi University.