DESIGN CONCEPT OF A LARGE TBM TUNNEL HAVING EXTENSIVE DIAMETER WITH PIONEERING THREE DECK ORIENTATION UNDER EXTREME WATER PRESSURE CONDITIONS

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The 3-Deck Great Istanbul Tunnel Project is a combined highway and metro system connecting two continents under Istanbul Strait (the Bosporus) in Istanbul, Turkey.

1-INTRODUCTION

Figure 1 - 3-Deck Great Istanbul Tunnel Project both highway (orange line) and metro (yellow line) sections including combined Bosporus crossing (green line)

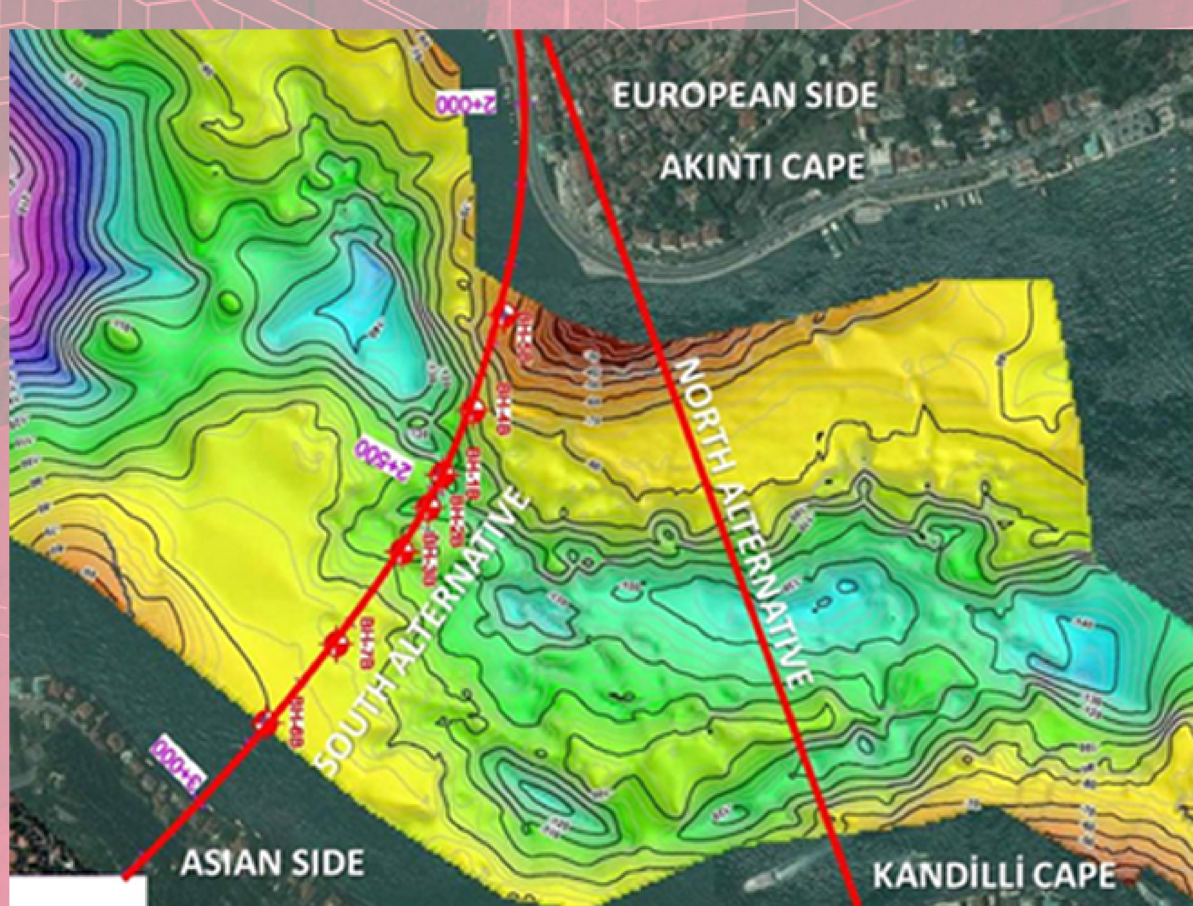

Figure 3 - Geophysical survey map

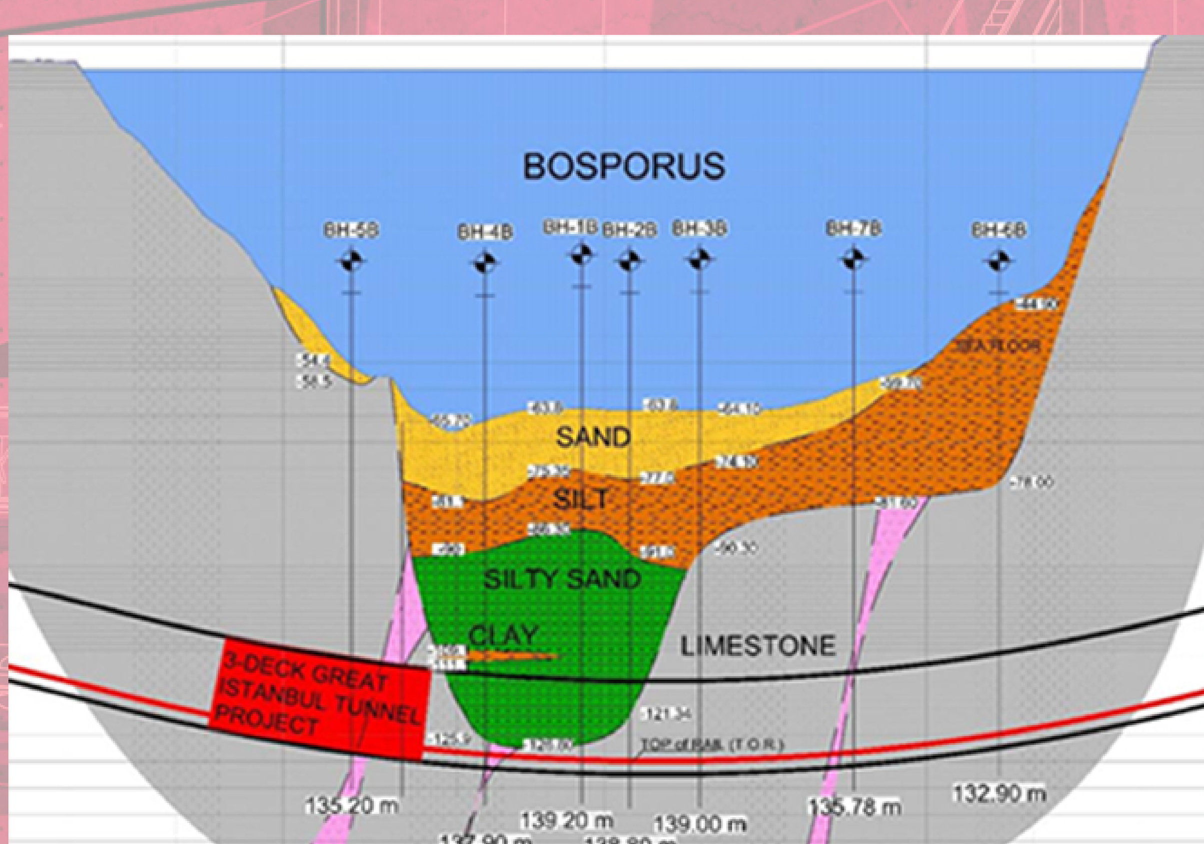

Figure 4 - Soil profile of the Bosporus crossing

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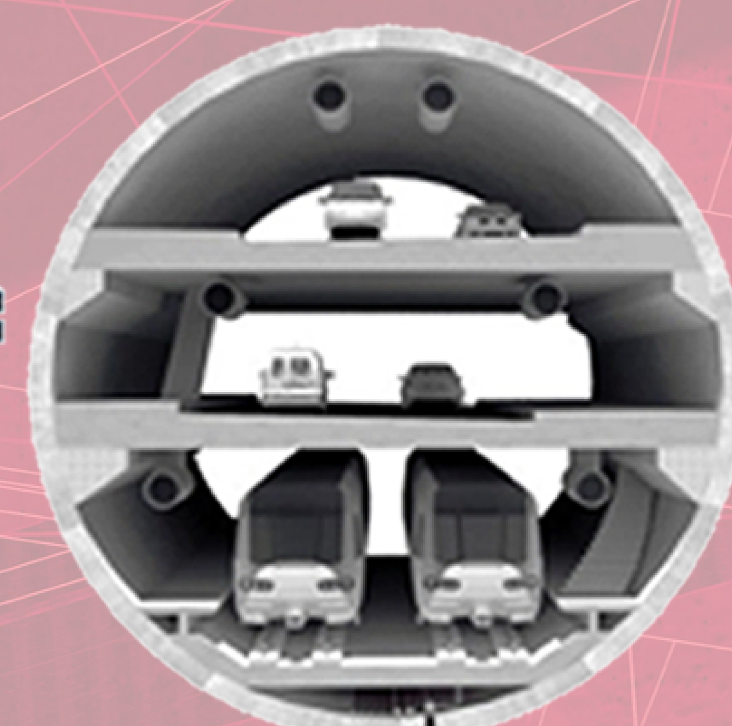

Figure 2 – Unique design of TBM tunnel for combined transport systems

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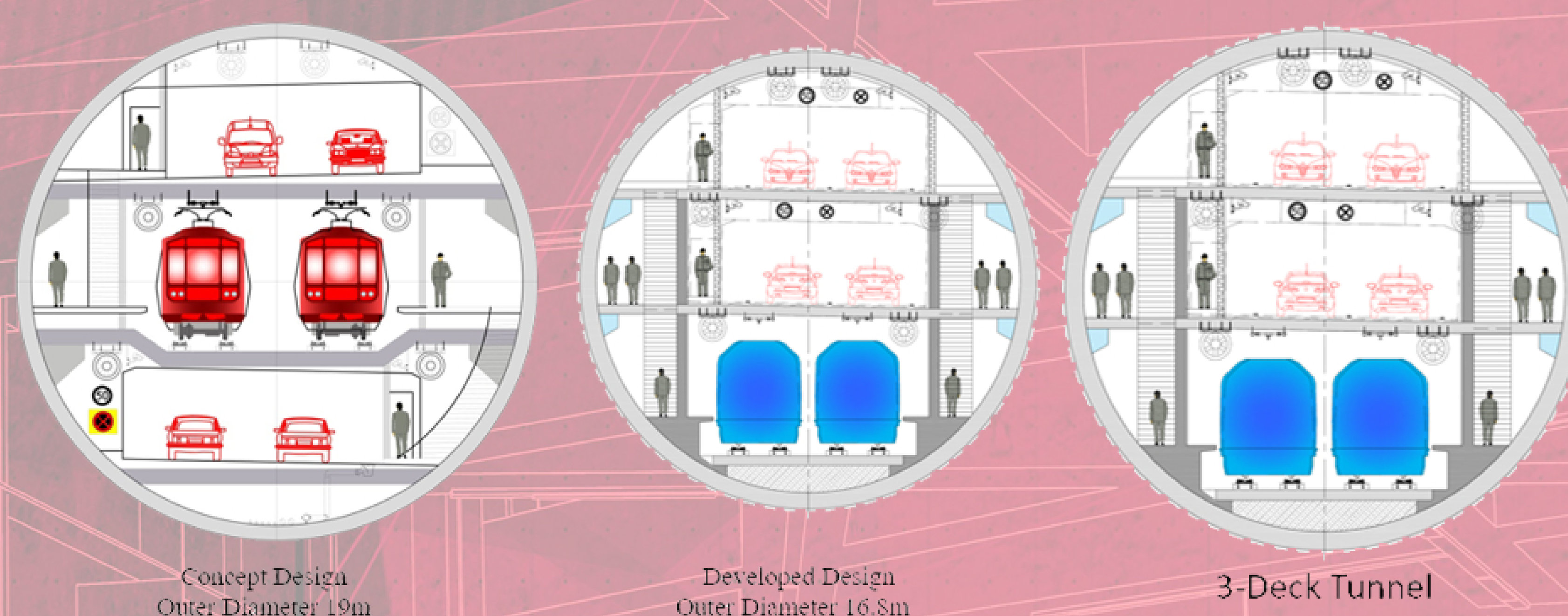


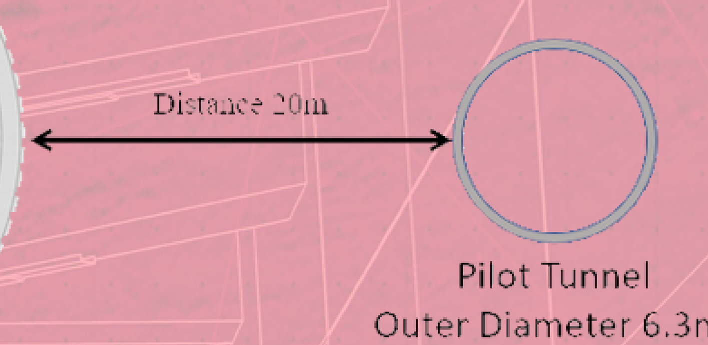


Figure 5- Optimization of tunnel cross section

Figure 6 - Pilot Tunnel

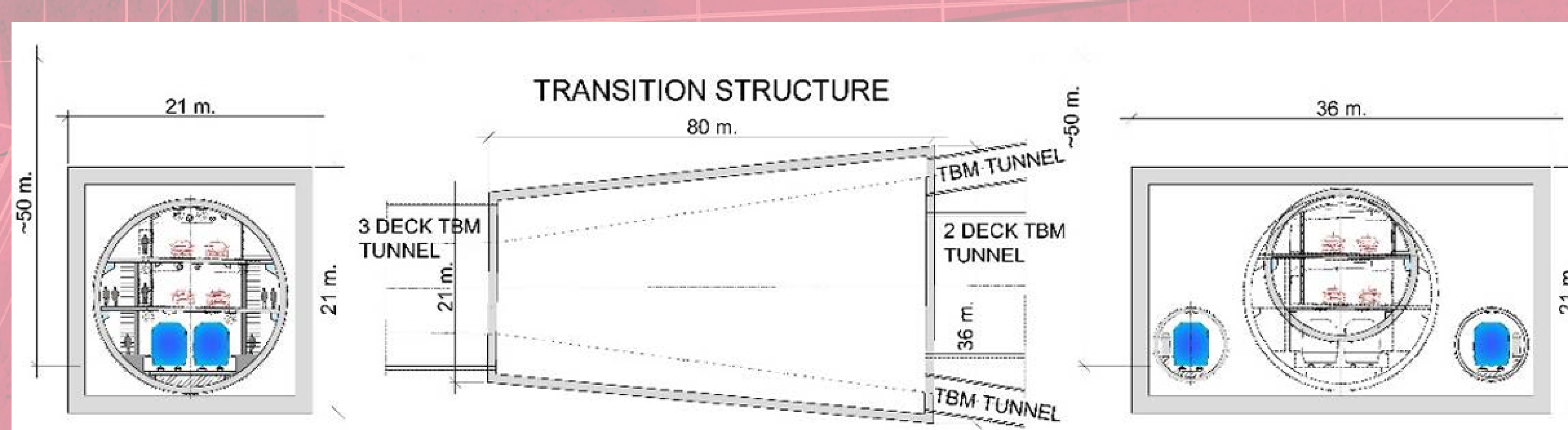
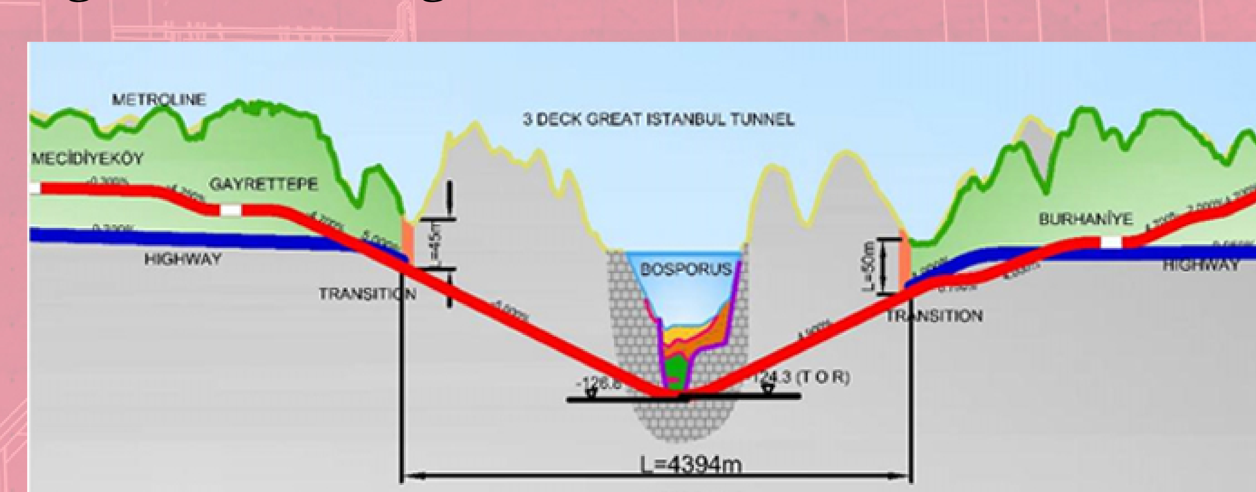


Figure 7 - Transition and TBM Launching and Receiving Structure

Figure 9 - Alignment Plan of the Bosporus Crossing



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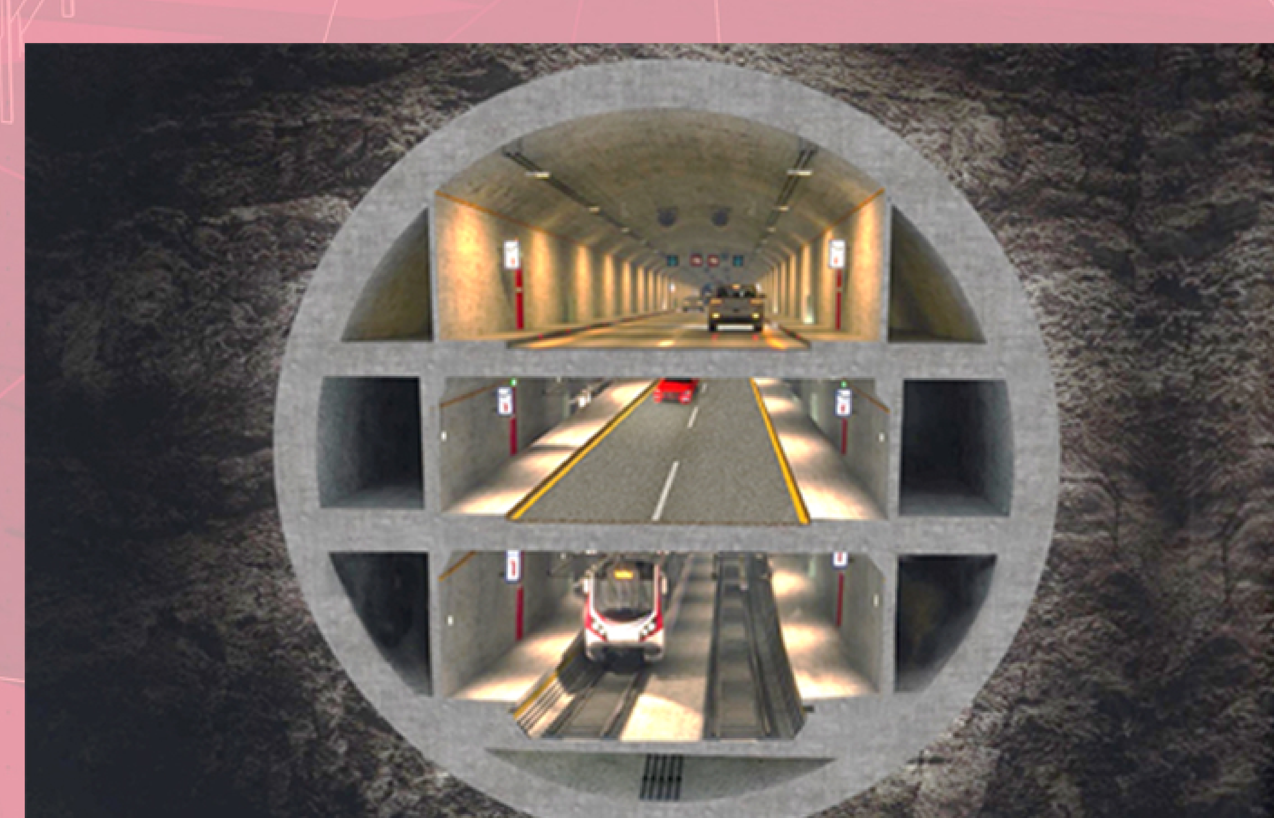

Design concept of a large TBM tunnel having extensive diameter with pioneering three deck orientation under extreme water pressure conditions

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ABSTRACT: 3 Deck Great Istanbul Tunnel Project aims to connect Europe and Asia under the Bosporus via Metro and Highway systems in a single tunnel. The constructability plays a vital role. In the Bosporus crossing section of the project there are many engineering challenges such as; extreme hydrostatic pressure, variable soil conditions, extensive diameter of the tunnel, limitation of the tunnel construction time, design of transition structures and TBM launching and receiving structures including logistic area requirements under dense urban patterns, setting out a common alignment for two different means of transport systems having discrete origins and destinations and a limited time frame for the overall design. This paper will present its readers the encountered problems and developed solutions during the design process.

1 INTRODUCTION

The 3-Deck Great Istanbul Tunnel Project is a combined highway and metro system connecting two continents under Istanbul Strait (the Bosporus) in Istanbul, Turkey. The project consists of 16.5 km highway and 31 km metro line with 14 stations. The Bosporus crossing section of the project is 4.3 km long and through a single TBM tunnel with 16.8 m outside diameter. The tunnel contains 2×2 lane highway and double track metro.

Marmaray commuter rail system immersed tube tunnel under the Bosporus was holding the record of the deepest tunnel in İstanbul below sea level with a depth of 60 m until Eurasia Highway system TBM tunnel constructed at 106 m below sea level. The 3-Deck Great Istanbul Tunnel Project Bosporus crossing tunnel designed at 130 m below the sea level is expected to break the record not only in Istanbul but also many in the world.

The metro section of the project will be located between İncirli (European side) and Söğütlüçeşme (Asian side). In addition, metro line will provide connection to the Istanbul New Airport at the European Side and Sabiha Gökçen Airport at the Asian Side. The highway section of the project will be located between Hasdal (European side) and Çamlık (Asian side). With the realization of the project, travel time between the European Side and the Asian Side will be 14 minutes by using the highway and 6 minutes by using the metro system.

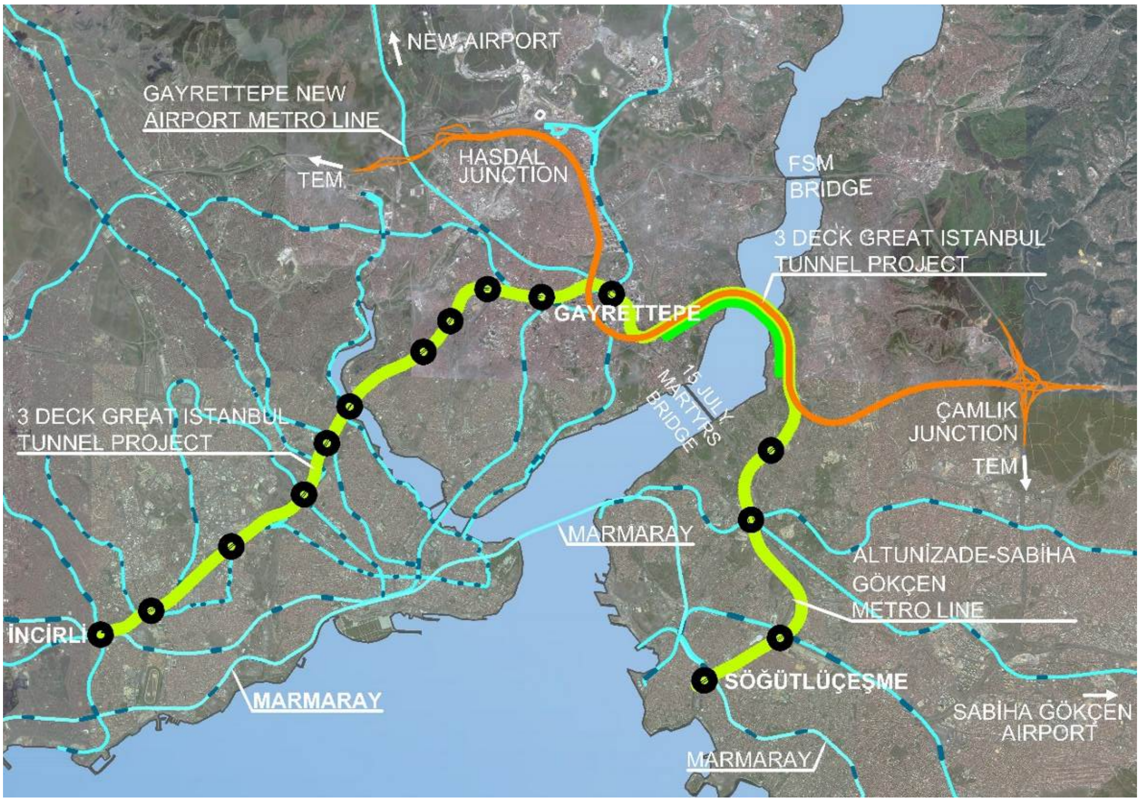

Figure 1 - 3-Deck Great Istanbul Tunnel Project both highway (orange line) and metro (yellow line) sections including combined Bosporus crossing (green line) (author)

This paper will present its readers the encountered problems and developed solutions for the Bosporus crossing section of the project during the design process to achieve a robust design under challenging conditions.

2 AIM OF THE PROJECT

The Ministry of Transport and Infrastructure General Directorate of Infrastructure Investments (UAB-AYGM) conducted a study to improve transportation capacity between two continents in Istanbul and developed a mega transport project with combined metro and highway systems. This study was announced to the public in February 2015 (Republic of Turkey Ministry of Transport and Infrastructure 2015). In this study, existing and future transportation demand between the two continents was assessed. According to the transportation survey, demand for the crossing, which was 1.3 million in 2015, was estimated to reach 3.8 million in 2023. Total capacity provided by the existing bridges and tunnels will be insufficient in 2020. As a result, it was realized that a new high-capacity transportation system is required.

Table 1. Population of Istanbul and daily transportation demand for intercontinental crossing (author)

	2000	2014	2023
Population*	10	14	17
Daily crossing demand*	0.8	1.3	3.8

*millions.

Table 2. Existing daily capacity for intercontinental crossing (author)

	2014	2023
15th July Martyrs Bridge	355,000	355,000
Fatih Sultan Mehmet Bridge	475,000	475,000
Yavuz Sultan Selim Bridge	-	475,000
Eurasia Tunnel	-	235,000
Marmaray	125,000	900,000
Metrobus	160,000	200,000
Maritime	235,000	250,000
Total	1,350,000	2,890,000

A new high capacity transportation system was developed by the Ministry of Transport and Infrastructure consisting of 16 km long 2x2 lane highway system with a daily capacity of 120,000 vehicles and 31 km long double track metro system having 15 stations with a daily capacity of 1,5 million passengers.

Bosporus crossing section of this project was anticipated as a three-deck TBM tunnel to combine both transport systems in a single structure, which is unique for many aspects in the world.

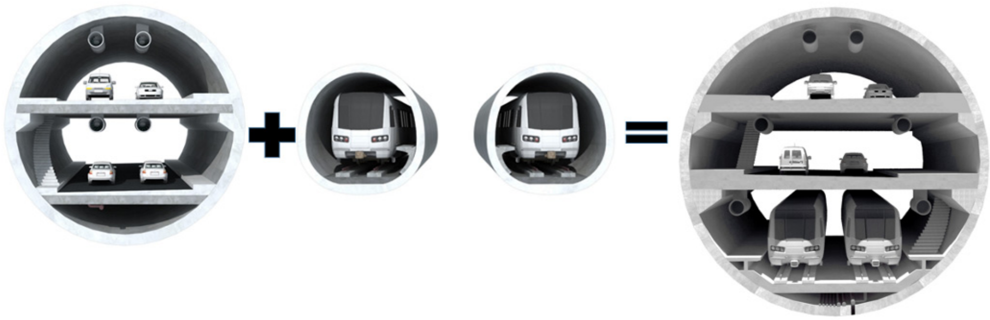

Figure 2 – Unique design of TBM tunnel for combined transport systems (author)

3 DESIGN DEVELOPMENT PHASE, CHALLENGES AND SOLUTIONS

In the Bosporus crossing section of the project there are many engineering challenges such as; extreme hydrostatic pressure, variable soil conditions, extensive tunnel diameter, limited tunnel construction time, design of transition structures and TBM launching and receiving structures including logistic area requirements under dense urban patterns, setting out a common alignment for two different means of transport systems having discrete origins and destinations and a limited time frame for the overall design.

3.1 *Geophysical survey and soil investigations*

Due to limited design time frame of ten months, all design activities were scheduled as fast track. Site survey and soil investigations on the Bosporus were the critical activities of the schedule. Obtaining working permits, mobilization, performing survey and investigations, and evaluation of results was occupying a major part of the time frame. Therefore, these activities should be performed once on the most suitable alignment corridor.

Based on former studies of three existing tunnel projects under the Bosporus (Marmaray Commuter Railway Project, Eurasia Highway Tunnel Project and Melen Water Tunnel Project), there are mainly two types of soil encountered as Holosen sequence consisting of sand, silt and clay deposits on top underlined by Trakya formation consisting of sandstone, siltstone, mudstone and shale alternation with rare conglomerates. TBM tunnel need to be excavated in the Trakya formation because of its large diameter. Therefore, optimum alignment should pass through higher rock levels to keep the depth as low as possible.

Geophysical study to investigate the seafloor morphology of the Strait of Istanbul carried out by Hacettepe University (Gökaşan *et al.*, 2006) contributed significantly to estimate the location of higher rock levels. For the verification of rock levels, geophysical site survey was conducted in the area determined based on that study. 1.5 km2 bathymetrical measurements and 54.22 km of high-resolution geophysical measurements were made and the results were compared. It was realized that rock levels along concept design corridor are deeper than 250 m below sea level which is also consistent with the previous geophysical study. As a result, significant rerouting for the corridor became necessary. Two new corridor alternatives were developed where the maximum rock levels are around 130 m.

Rock levels are observed at 135-140 m below the sea level at the north alternative and 120-130 m below the sea level in the south alternative. Borehole locations for soil investigations were identified on the south alternative, which is advantageous due to its shorter length and lowest depth for rock level.

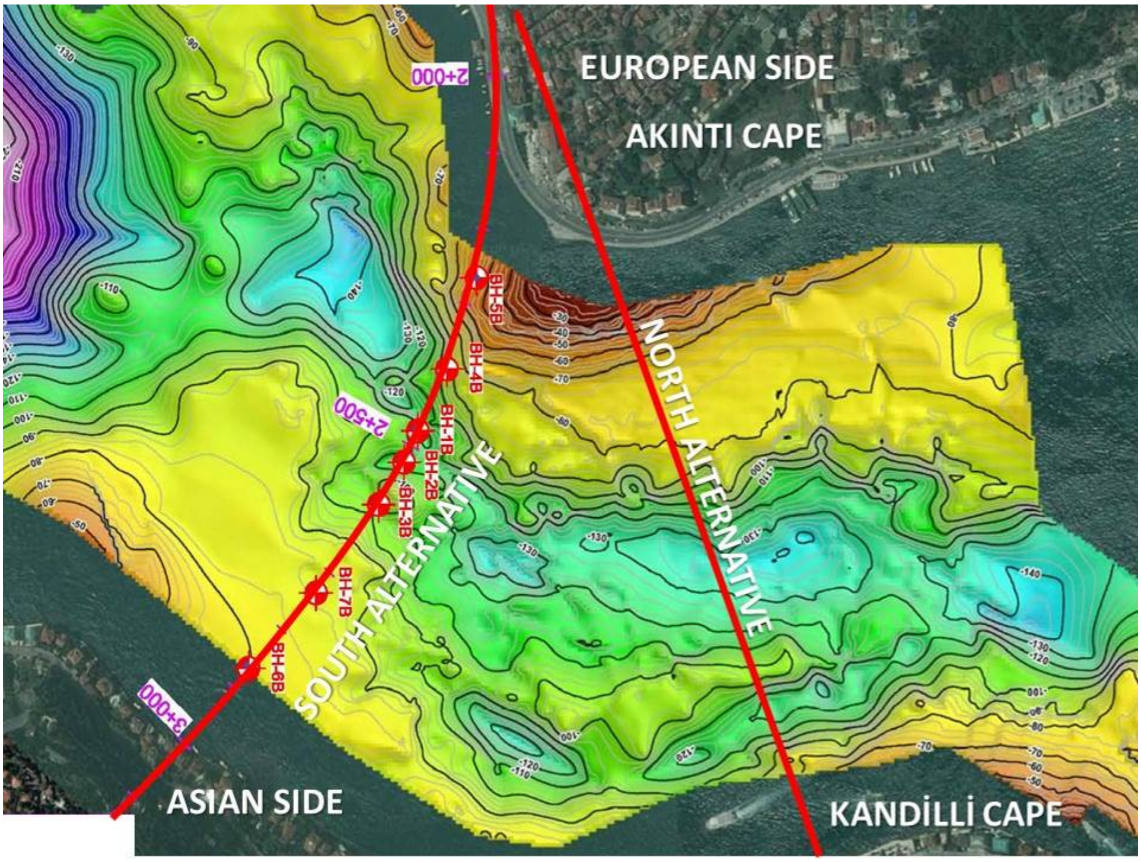

Figure 3 - Geophysical survey map (author)

The RV Fugro Scout, research and survey vessel, started soil survey works in Bosporus on 28 July 2017 to investigate the soil characteristics and rock levels. In the scope of this investigation, seven borehole drillings around 80 m below the sea floor were conducted. As a result, the deepest rock level on the alignment was determined as 126.80 m below the sea level and the correlated and idealized geological profile was revealed.

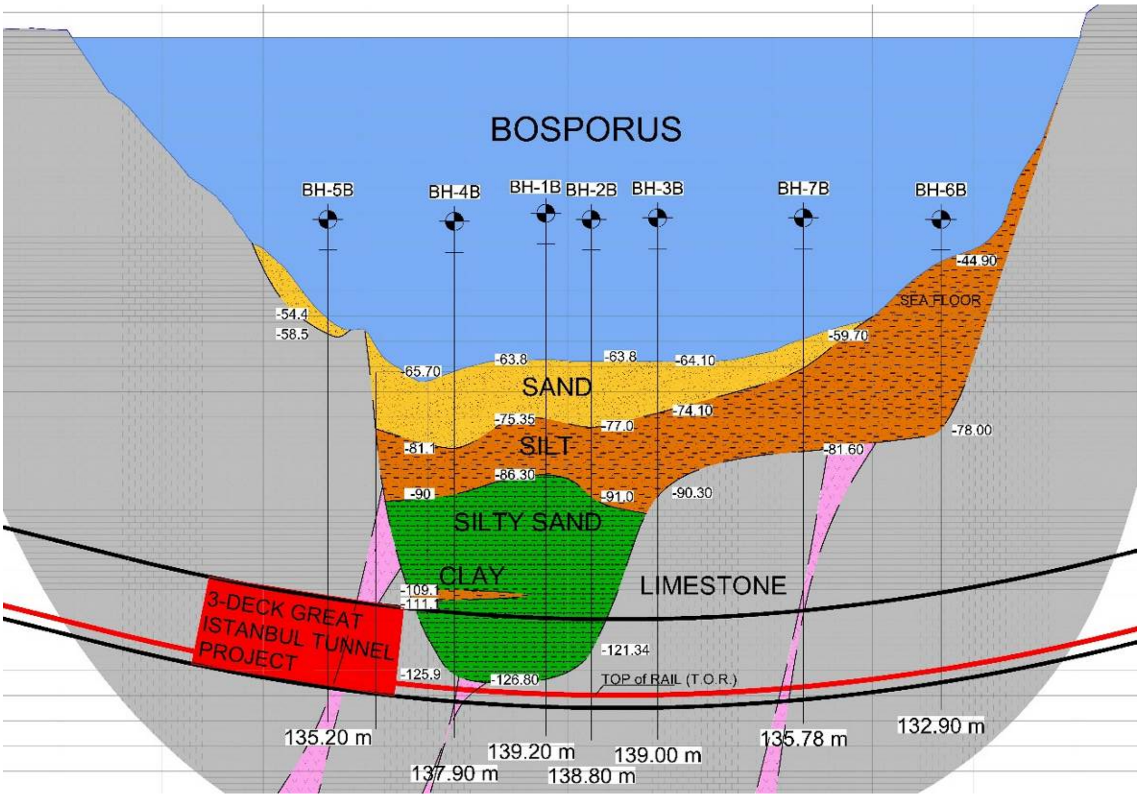

Figure 4 - Soil profile of the Bosporus crossing (author)

3.2 *TBM tunnel design and optimization of cross section*

Under consultancy of Tunnelconsult Engineering Ltd., manufacturers of large TBM machines all over the world were identified as the potential manufacturers. In this context, Herrenknecht from Germany, Hitachi Zosen and JIMT from Japan were consulted. Immediately after the soil investigation results were obtained the data was shared with these potential TBM manufacturers to allow them to investigate the possibility of manufacturing the largest TBM machine in the world and constructability of the tunnel under these soil conditions and hydrostatic pressure of 13 bars. Results of their investigations were discussed in a series of meetings and their comments and confirmations were obtained to take into the consideration in the design. Based on manufacturers' recommendations and geological investigation results, tunnel alignment was located mainly in Trakya formation except for 300 m long section at the sag point in impervious sandy clay formation.

At the same time, structural analysis was conducted by Tunnelconsult Engineering Ltd. to determine segment thickness and orientation. According to that study, segment thickness was determined as 65 cm and segment orientation determined as 10+1 segment including key.

In the concept design, metro tracks were in the middle deck and highway lanes were at the top and the bottom decks of the tunnel. With this orientation, since the provision of vertical structural elements was not possible, required middle deck thickness increased due to heavy metro system loads. Vehicle clearance requirements with this orientation and increased deck thickness resulted in a tunnel diameter of 19 m which may exceed the constructability limits of the existing technology.

A new orientation was developed to decrease the tunnel diameter by locating the metro system at the bottom deck. With this new orientation, vertical structural elements were provided to decrease the span length and the thicknesses of intermediate decks. As a result, the outer diameter of the tunnel was decreased to 16.8 m.

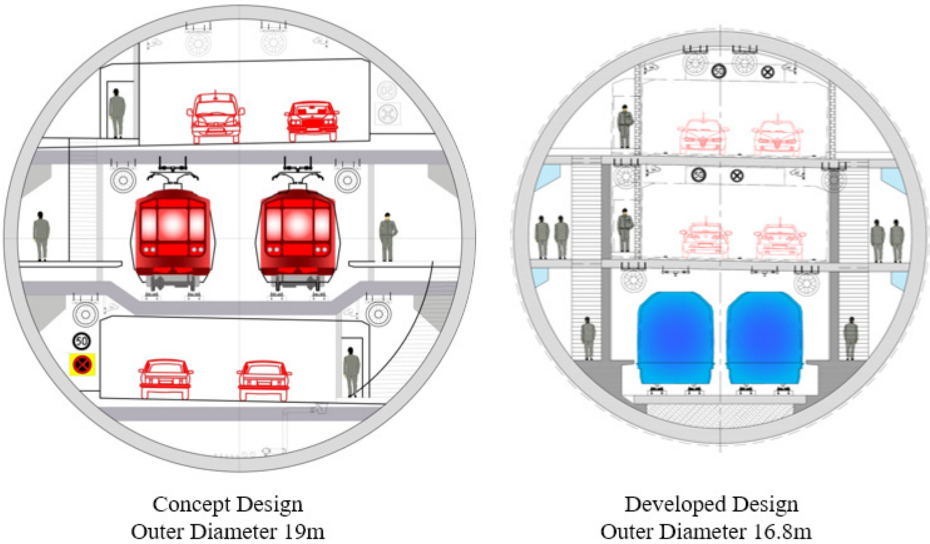

Figure 5- Optimization of tunnel cross section (author)

In this project, a pilot tunnel was introduced. It was anticipated to run in parallel to 3 Deck Tunnel. This concept was proposed to identify the risks such as; unexpected soil conditions, inactive faults crossings etc. that might be encountered during the TBM drive of the three-deck tunnel. Manufacturing period of the required conventional TBM and construction period of a pilot tunnel would be much shorter than the three-deck tunnel due to its small dimensions. By this way, it would be possible to construct the pilot tunnel onsite prior to the commencement of three-deck tunnel construction. The pilot tunnel would contribute significantly to identification of exact soil conditions to be faced on the alignment, determination of soil improvement measures and implementation of soil treatments from pilot tunnel prior to the main TBM operations. In the future, this pilot tunnel would be used for relocation of overhead energy transmission lines, which cause visual pollution on the Bosporus.

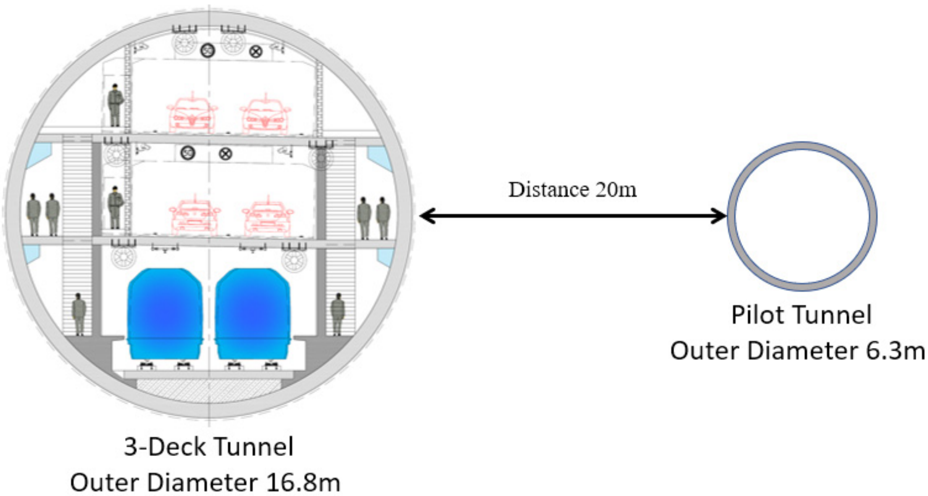

Figure 6 - Pilot Tunnel (author)

3.3 *TBM launching-receiving structures and transition structures.*

Among the many challenges of the project, limitation of tunnel construction time of the main TBM, design of transition and TBM launching-receiving structures including logistic area requirements under dense urban patterns were three important ones to overcome in the design.

In the concept design, the main TBM tunnel length was 6.5 km. Tunnel length was decreased to 4.3 km by positioning launching-receiving structures close to the Bosporus as much as possible. TBM advance rate was estimated as 4 m per day. Reduction of 2.2 km in length resulted in a decrease in construction time by 1.5 years and considerable savings in the total cost of the tunnel consequently.

Due to extensive space requirement which was not possible to construct by tunnelling method, a cut & cover structure was required to provide the transition between three-deck tunnel section and tunnels of metro system and two-deck tunnel of highway system. Transition length required in the concept design was around 300 m. With the new orientation of the cross-section, transition length was decreased to 80 m, which resulted in less land requirements. The depth of the transition structures was maintained at around 50 m, which allowed sufficient soil cover on top of the main tunnel.

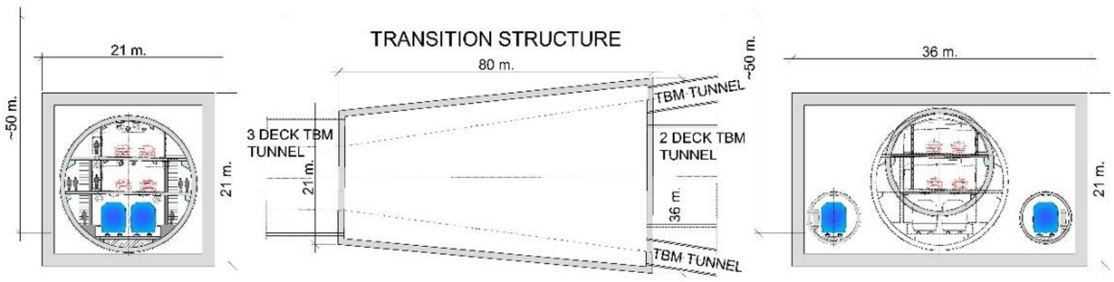

Figure 7 - Transition and TBM Launching and Receiving Structure (author)

It was decided that transition structure could also be used for launching-receiving operations of TBM during construction stage. Having the advantage of a single structure for launching-receiving operations of TBM and transition with reduced length, it became possible to locate these structures within the municipal areas along the route without any need for land acquisition.

Transition and TBM Receiving Structure
European Side

Transition and TBM Launching Structure
Asian Side

Figure 8 - Layout of Transition and TBM Launching and Receiving Structures (author)

3.4 *Alignment design*

Great effort was spent to set out a common alignment by using the most critical geometrical design requirements for two different means of transport systems having discrete origins and destinations in compliance with structural, geotechnical and tunnelling requirements such as sea crossing corridor at high rock levels, suitable locations for transition structures and nearby metro stations to be integrated to existing metro lines on each side at desired elevations.

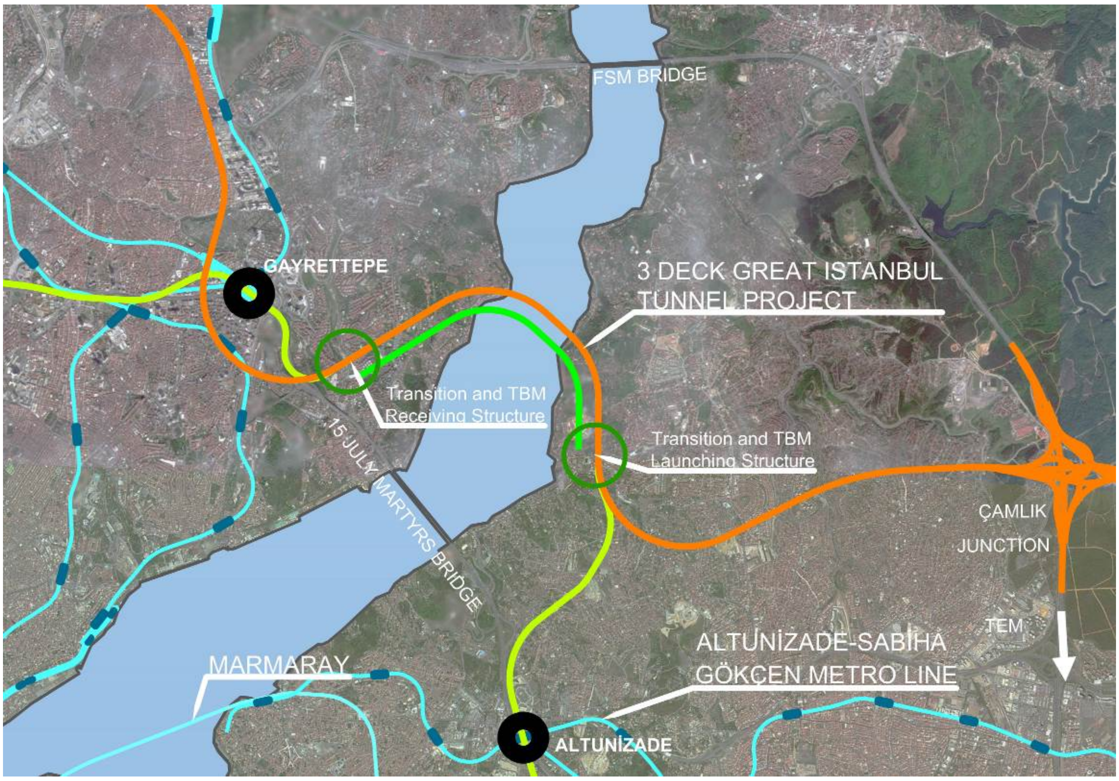

Figure 9 - Alignment Plan of the Bosporus Crossing (author)

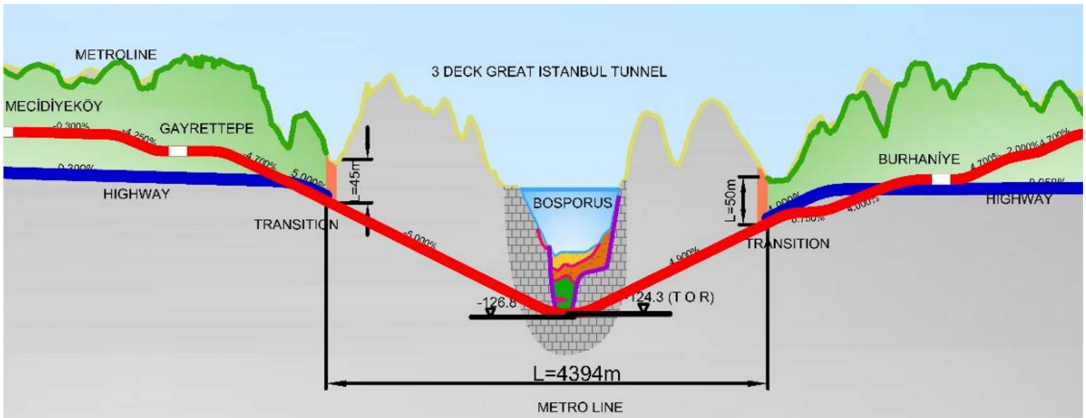

Figure 10 - Alignment Profile of the Bosporus Crossing (author)

4 CONCLUSION

3 Deck Great Istanbul Tunnel Project aims to connect Europe and Asia under the Bosporus via Metro and Highway in a single tunnel. In the Bosporus crossing section of the project there are many engineering challenges such as; extreme hydrostatic pressure, variable soil conditions, extensive tunnel diameter, limited tunnel construction time, design of transition structures and TBM launching-receiving structures including logistic area requirements under dense urban patterns, setting out a common alignment for two different means of transport systems having discrete origins and destinations and a limited time frame for the overall design. Due to limited design time frame, all design activities were scheduled as fast track. TBM tunnel diameter was minimized by reorientation of metro and highway decks and inner structural elements. Potential

TBM manufacturers investigated constructability of the largest TBM tunnel under extreme hydrostatic pressure. To eliminate the effects of hydrostatic pressure around 13 bars to be faced during construction, tunnel alignment was positioned in low permeable rocks and impervious soil layers. Tunnel length was minimized by locating transition and TBM launching-receiving structures close to the Bosporus as much as possible. TBM Launching-receiving area and transition length requirements for transport systems were optimized. A single structure was designed to reduce construction area within municipal properties to avoid land acquisition.

As a result, the 3-Deck Great Istanbul Tunnel Project stands out as an exceptional state-of-the-art engineering design project with its unique characteristics.

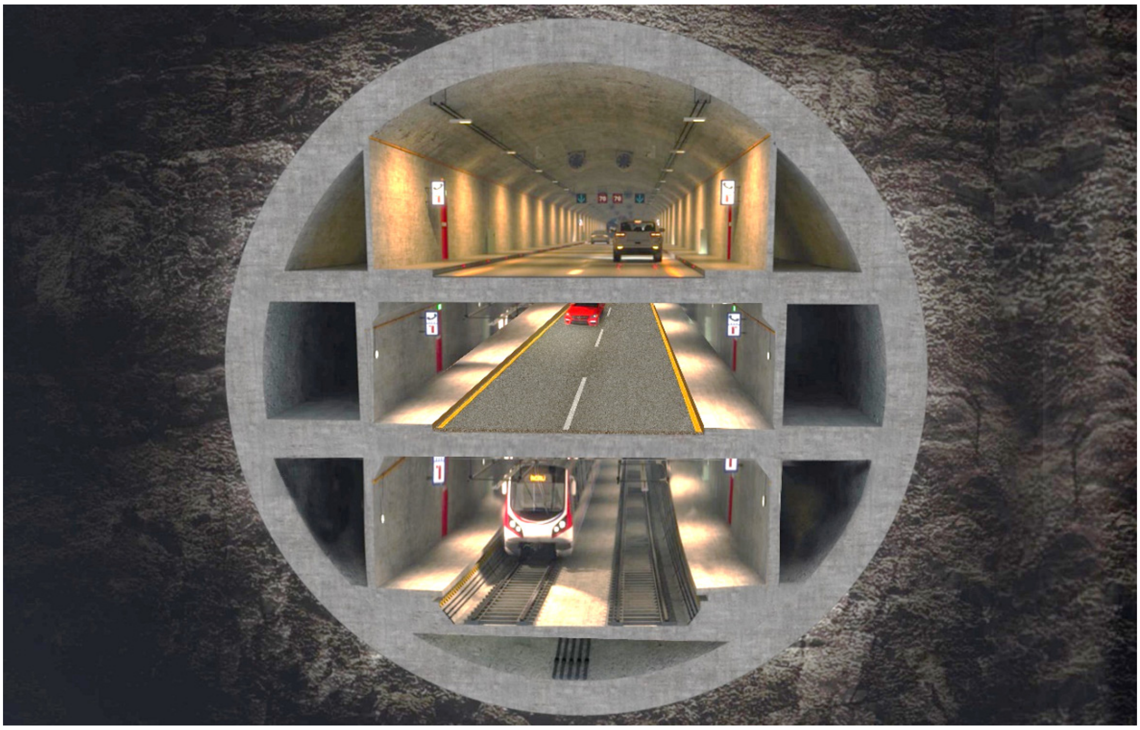

Figure 11 - artistic rendering of the cross section of the tunnel (author)

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