TECHNICAL ARTICLE – 2
Railway Crossing the Bosphorus Strait
— Realizing the 150-Year Turkish Dream of Connecting Asia and Europe —

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1. Introduction

Istanbul, the largest city in the Republic of Turkey, is a historic strategic point connecting Asia and Europe, and it is divided east-west by the Bosphorus Strait. The Railway Project to cross the Bosphorus Strait (Marmaray Project) constructed a railway connecting Europe and Asia, with the objectives of relieving traffic congestion in the Greater Istanbul area that has a population of 14 million, and reducing the atmospheric pollution caused by this traffic. This project was a 150-year dream of the Turkish people, and in this article the design and construction of the 13.6-km underground railway project including the tunnel across the Strait are described. In August, 2004, construction by the Taisei Gama Nurol Joint Venture commenced, and in October 2013 the opening ceremony for the underground railway was held. The clients were the Ministry of Transport, Maritime Affairs and Communications of the Republic of Turkey and the Railway, Ports and Airports Construction Bureau, while the client's representative was AVR which was a joint venture of the Oriental Consultants, Japan International Consultants for Transportation Co., Ltd., and YükselProjeUluslarası A.Ş.

2. Outline of the Project

Fig. 2-1 shows the location of the Bosphorus Strait, and Fig. 2-2 illustrates the route plan. From the civil and geotechnical engineering points of view, this project was a large project simultaneously using 3 tunneling methods; immersed, shield and mountain tunneling methods. Also, the project included the operation of the world's deepest immersed tunnel, the world's first direct submarine connection of immersed tunnels and the shield tunneling without a vertical shaft, so the degree of technical difficulty of the construction work was significant. As demonstrated in Fig. 2-3, out of the total length of 13.6 km of twin parallel tunnels, 1.4 km under the sea was an immersed tunnel, the remaining portion on land was shield tunnel, whereas the portion around Sirkeci Station was constructed mainly by the mountain tunneling method.

Fig. 2-1 Location of Bosphorus Strait

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Fig. 2-2 Route plan

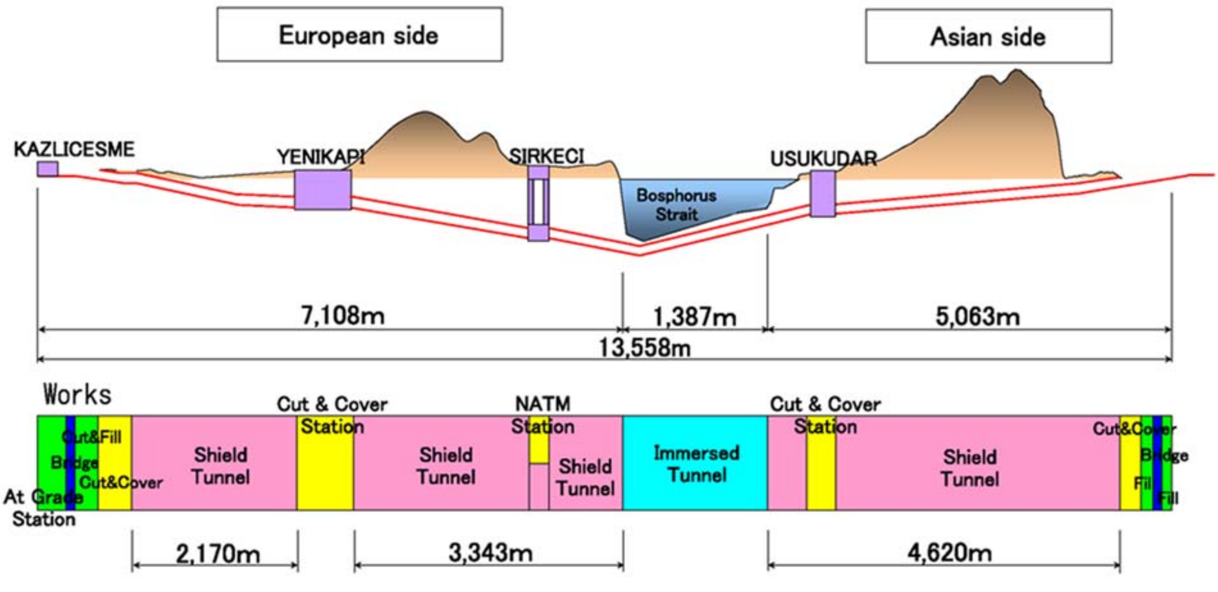

Fig. 2-3 Overall longitudinal section of the project including the tunnel across the Strait

3. Construction of Immersed Tunnel at the World's Greatest Water Depth under Rapid Tidal Flows

In the immersed section of the tunnel under the Bosphorus Strait, 11 segments were placed on the bottom of the sea at the maximum depth of 60 m, as shown in Fig. 3-1. As demonstrated in Fig. 3-2, the construction depth of the immersed tunnel was 60 m in the sea which is the deepest in the world.

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Because the maximum tidal flow is 3 m/s on the surface layer and -1 m/s in the lower layers (negative velocity means the opposite direction of water flow), the placement of tunnel segments in the Bosphorus Strait required tidal flows to be predicted 36 hours in advance. Therefore, a tidal flow analysis and prediction system were developed based on various local measurement data including long term local weather data. Moreover, the tidal flows for 36 hours after start of towing were predicted using various data prior to the initiation of tunnel installation, and the predicted flow velocity was sent through internet to engineers in both Turkey and Japan so that the information would be shared (Fig. 3-3). The specification for the immersion operation vessel and the operating procedures for the immersion operations were determined by repeated hydraulic model tests at the Taisei Technology Center (Fig. 3-4). Furthermore, when immersing the segments, the foundation mat was constructed using a newly developed underwater leveling robot (Fig. 3-5). The joint between the immersed tunnel and the shield tunnel, which is described later, was constructed by providing a sleeve pipe at the end of the segment; see Fig. 3-6.

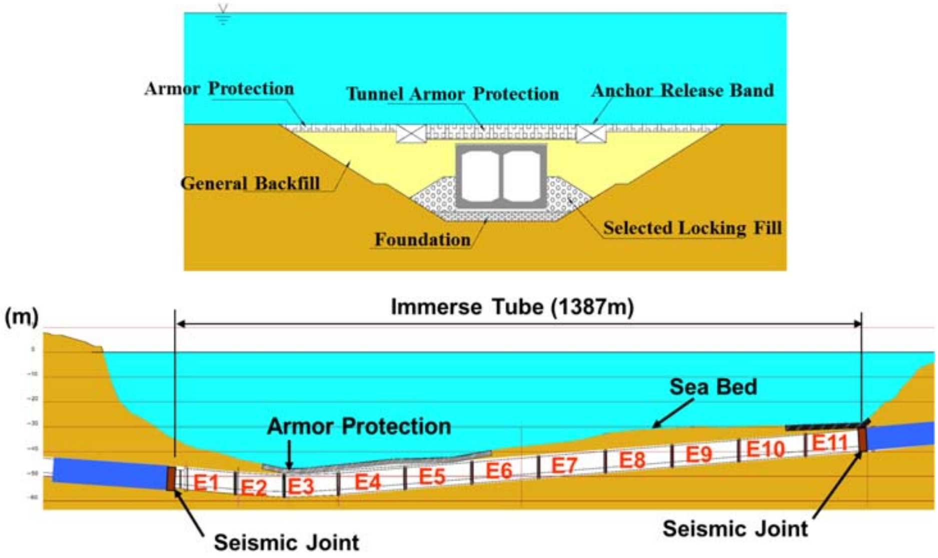

Fig. 3-1 Longitudinal and transverse sections of the immersed tunnel

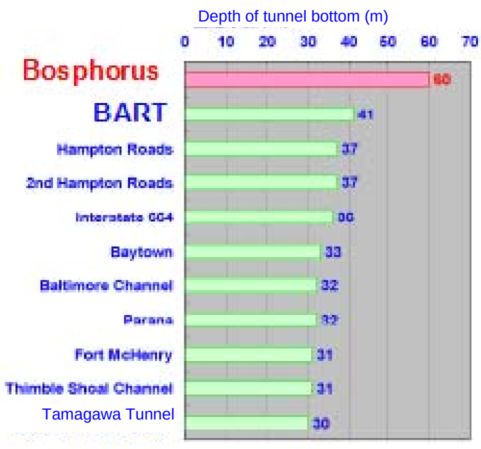

Fig. 3-2 Water depth of Immersed tunnel constructions (as of 2004)

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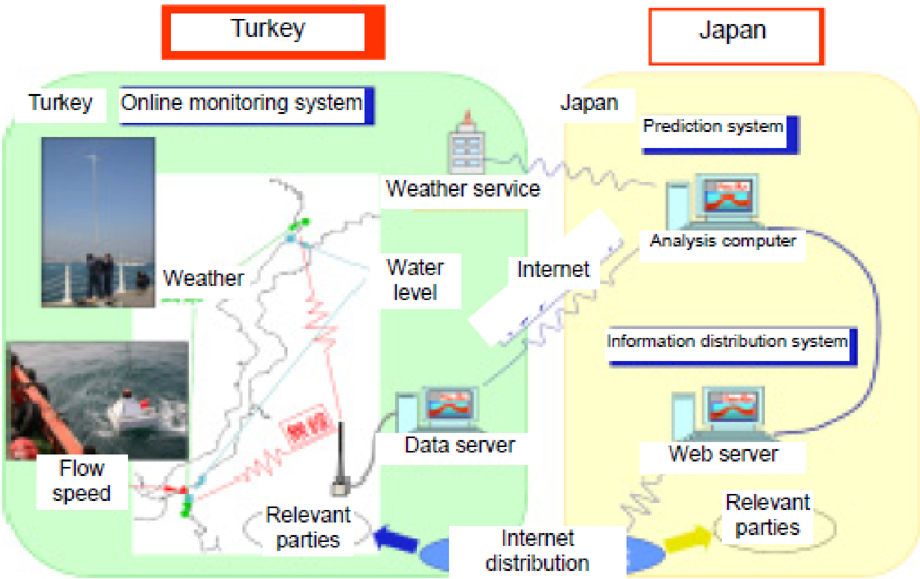

Fig. 3-3 Outline of the tidal flow prediction system

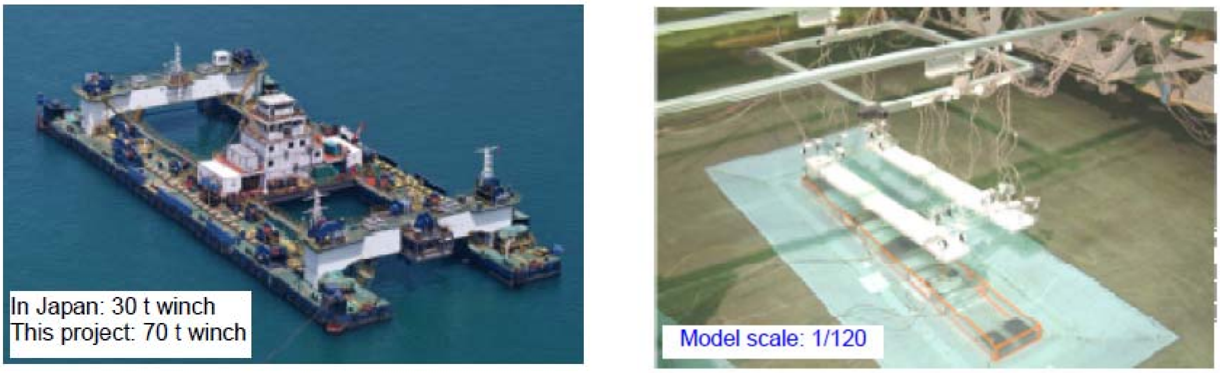

Fig. 3-4 Immersion operation vessel and hydraulic model tests to confirm the immersion procedures (Taisei Technology Center)

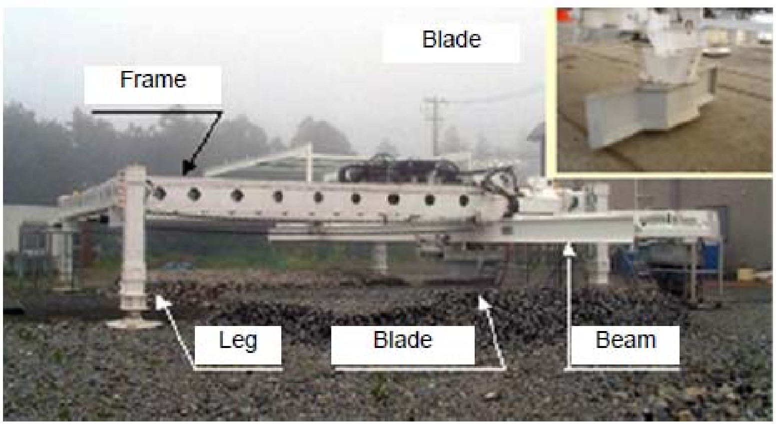

Fig. 3-5 Underwater leveling robot used in the construction

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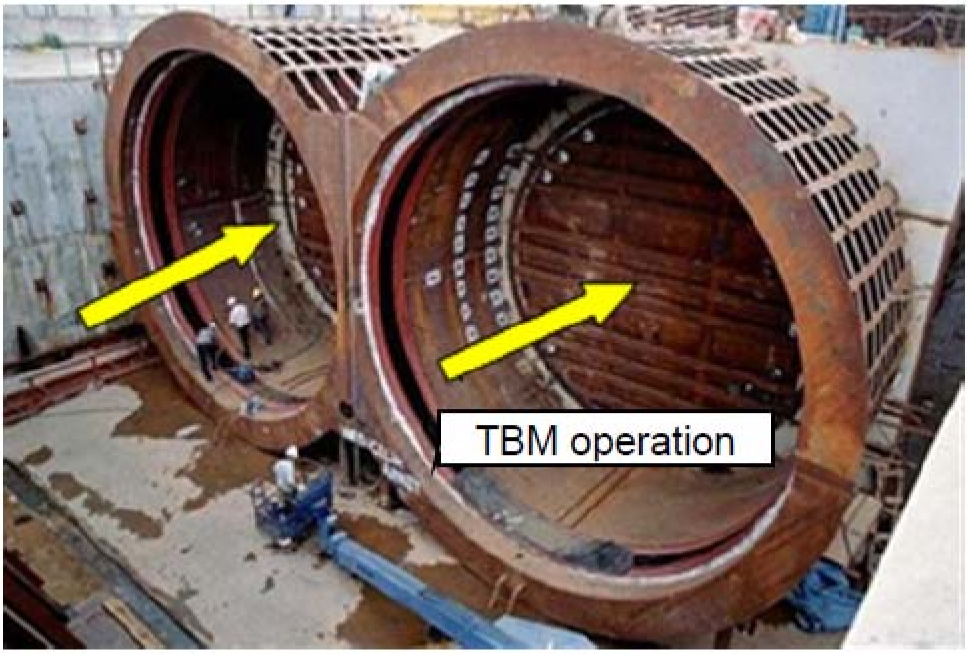

Fig. 3-6 Sleeve pipes at the end of immersion segment

4. Construction of Sirkeci Station and the Mountain Tunneling Method

Sirkeci Station is located in a historical tourist and commercial district near to Topkapi Palace. Fig. 4-1 demonstrates the land use above ground at the planned location of Sirkeci Station. Excavation directly under many densely-built commercial buildings, hotels, etc. was carried out from vertical shafts that were made in a small construction space. In other words, it was a construction environment that required great attention to the local traffic situation and the neighboring environment. Fig. 4-2 shows a perspective view of the underground part of Sirkeci Station. Because this complex underground structure was mainly constructed by the mountain tunneling method, the construction procedures and the construction schedule were extremely complex. Also, the lining concrete was required to be water tight, so it was necessary to investigate the lining structure in detail using a 3-dimensional structural analysis model that precisely reproduced the real structure; see Fig. 4-3.

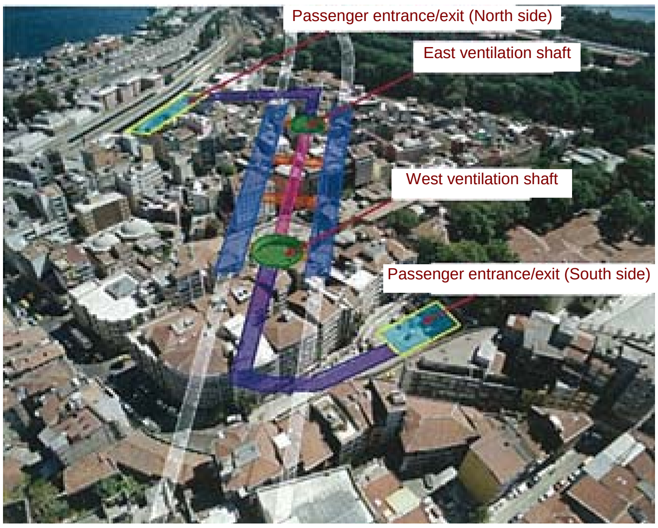

Fig. 4-1 Land use directly above Sirkeci Station

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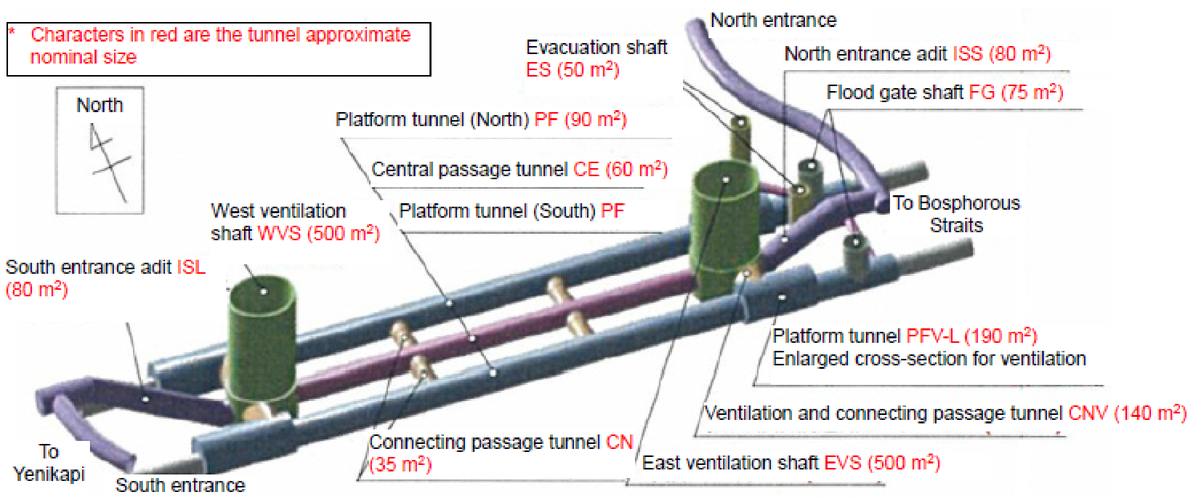

Fig. 4-2 Isometric view of the underground part of Sirkeci Station

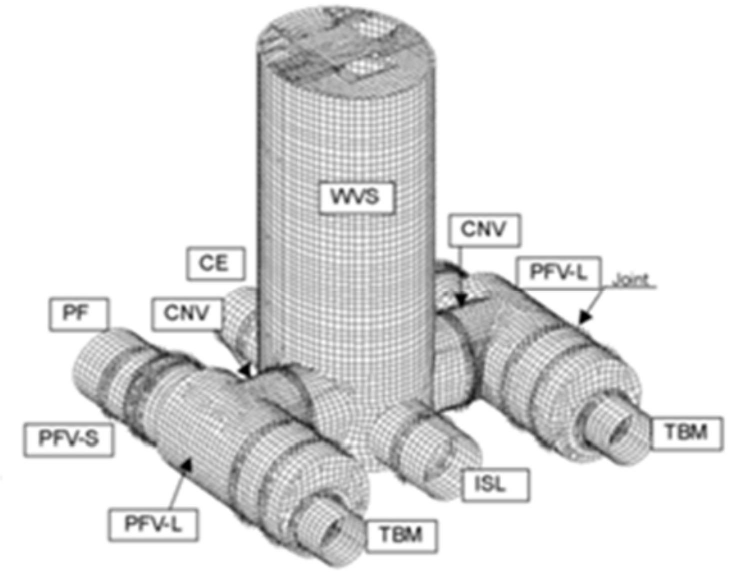

Fig. 4-3 Structural model for analysis of the ventilation shafts

5. TBM Tunneling Method of Slurry Type

The shield tunneling method was adopted for 10.1 km (in each direction) out of the total of 13.6 km of the Bosphorus Strait crossing railway construction project (Fig. 2-3). Under thin soil cover, construction in sandy soil was carried out by the mud pressure method, and under large depths construction in rock was carried out by the muddy water method. Outside Japan there is no differentiation made between the TBM and shield methods, so in this paper the muddy water shield method is referred to as the slurry-type TBM method. Fig. 5-1 shows a slurry-type TBM. As shown in Fig. 5-2, this excavation method was used mainly in urban areas, and technical efforts were made to minimize the effects on houses etc.

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Fig. 5-1 Slurry-type TBM

Fig. 5-2 Excavation in an urban area

6. Conclusions

The Bosphorus Strait Construction Project was started in August 2004. Because Istanbul is a famous World Heritage and during construction many archeological relics were found. As a result the construction was substantially delayed. The opening ceremony was held on 29th of October 2013 which was the 90th anniversary of the founding of the Republic of Turkey. This ceremony was attended by Prime Minister Erdogan (Turkey) and Prime Minister Abe (Japan), as shown in Fig. 6-1.

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This project was realized through the great understanding and cooperation of not only Taisei Corporation, Gamma, Nurol, who carried out the design and construction, but also the Client's Representative, AVR, the Turkish Ministry of Transport and the Turkish Government, JICA, and the Japanese Government. Above all, the greatest satisfaction for all those involved in the construction was the heartfelt celebration remark of the residents of Istanbul and the Turkish people that the project, which they had longed for, was completed. Details of the construction including the geotechnical aspects will be presented during the Asian Regional Conference on Soil Mechanics and Geotechnical Engineering in November 2015, Fukuoka, Japan. (http//www.15arc.org/)

Fig. 6-1 Opening ceremony of the submarine railway attended by Prime Minister Erdogan (Turkey), Prime Minister Abe (Japan), and other dignitaries

Last but not least, the authors express their sincere thanks to the great assistance from Professor Ikuo Towhata (VP of ISSMGE for Asia), University of Tokyo, and Mr. Nobuhiro Akisato, Dr. Kenichi Horikoshi, Mr. Hiroyasu Ishii of Taisei Corporation during the preparation of this article.