International Journal of the Physical Sciences Vol. 6(9), pp. 2303-2307, 4 May, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.559
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Istanbul (Bosphorus) immersed tube tunnel and survey works

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Accepted 03 May, 2011

The railway lines in both sides of Istanbul have been connected to each other by an underwater tunnel passing through the Bosphorus. This type of tunnel is known as immersed tube tunnel. Immersed tube tunnel is a part of MARMARAY project that is continued nowadays. MARMARAY is a rail transport project in Istanbul. It consists of the construction of an undersea rail tunnel under the Bosphorus strait. Suburban rail lines along the Sea of Marmara from Halkali on the European side to Gebze on the Asian side will be modernized with this project. An immersed tunnel consists of several prefabricated steel shell or concrete tubes. These tubes are constructed on land. They are floated and moved to the immersion site. They are installed one by one. They are lowered and connected to one another underwater. Then, the water is pumped out and the segments are covered with the backfill materials. An immersed tunnel is generally installed in a trench that has been dredged previously in the bottom of a waterway between structures constructed in the dry. All spaces between the trench bottom and the soffit of the tunnel can be a previously prepared gravel bed, or sand bedding pumped or jetted underneath the tunnel. Piled foundations are sometimes used, where soil conditions require them. As construction proceeds, the tunnel is backfilled. The completed tunnel is usually covered with a protective layer over the roof. Survey works requires high precision in every construction project such as dam, bridge, tunnel etc. Horizontal and vertical control of tunnels are performed by using geodetic control points. Survey works should be performed precisely.

Key words: Tunnel, immersed tube, immersed tube tunnels, geodetic control, MARMARAY.

INTRODUCTION

The immersed tunnel under the Istanbul Strait is 1387 m long, including the connections between the immersed and adjacent tunnels. The tunnel has been provided a vital link in the two-track rail crossing beneath the Istanbul strait, and has been located between the Districts of Eminönü on the European side and Üsküdar on the Asian side of Istanbul. Both rail tracks will run in the same binocular tunnel elements, separated by a central dividing wall (Marmaray Project, accessed March 30, 2011). Immersed tube tunnel was aligned in a pre-dredged trench in Istanbul project.

In order to embed the immersed tube tunnel in the seabed of the Bosphorus strait, a trench was prepared in the seabed big enough to accommodate the elements and allow for a cover and protection layer to be placed on top of the Tunnel. There are a minimum of 2 m of protection layer on the tubes. The cross section of the immersed tunnel is approximately 9 m deep. Bosphorus immersed tunnel have two bores, one for train traffic in each direction. The elements were totally embedded in the seabed. The seabed profile has been the same as it was before the construction began.

In order to determine the alignment of the Istanbul strait trench, bathymetric measurements were made. Digital map of the sea bottom (approximately 500 m width on both sides of the tunnel alignment) along the project alignment were gotten by using sonar.

The dredging of this trench has been done from the surface by heavy dredging equipment. The Clamshell Dredger and the Trailer Suction Hopper Dredger were used on the job. The Clamshell Dredger is a very heavy device mounted on a barge. Since the Clamshell Dredger is a very heavy device, it penetrates the sea bed. The shell closes automatically when lifted from the seabed, so the material is lifted to the surface where the Clamshell can off-load on barges. The dredger was operated at a depth of approximately 58 m, gravel and rock. It has been calculated that the total amount that was taken out was more than 1,000,000 m^3 of soft soil, sand.

In order to dredge and penetrate of the trench and to position immersed tubes on the project line, high precision was necessary during the survey works. The dredging and penetrating of the trench were controlled using a control unit equipped on the survey vessel. These equipments were a computer, sonar and sensor systems connected to the computer by a cable.

HISTORY AND SPECIAL FEATURES OF THE IMMERSED TUBE TUNNELS

There were 108 immersed tube tunnels in the world until 1997. 48 of them in Europe, 27 of them in North America, 20 of them in Japan, 9 of them in South Asia and 4 of them in other countries (Marmaray Project, accessed March 30, 2011). Some of them are listed below:

(i) Detroit River immersed tube tunnel between USA and constructed in 1910 in Canada.
(ii) Railway, single steel shell tunnel, the tunnel consists of eleven tubes, 24.4 m below the water level, eleven pieces of tubes, tube length is 80 m, height is 9.4 m, width is 17 m, total length of the tunnel is 800 m.
(iii) Freidrichehafen, Berlin, Germany; 1927.
(iv) Pedestrian, reinforced concrete tunnel. The tunnel consists of two tubes, 10.8 m below the water level, one tube, tube length is 52.8 m, height is 6.67 m, width is 7.65 m, total length of the tunnel is 105.8 m.
(v) Mass transit immersed tube tunnel for highway constructed in 1941 in Netherland.
(vi) Vehicles, cyclists, pedestrians, concrete-box elements. The tunnel consists of nine concrete box tubes, tube length 61.35 m, height is 8.39 m, width is 24.77 m. The total length of this highway tunnel is 584 m.
(vii) Immersed tube tunnel for highway constructed in 1958 in Cuba.
(viii) Vehicular tunnel, prestressed concrete box elements. The tunnel consists of five concrete box tubes, 23 m under the sea level. The tunnel consists of five prestressed concrete box tubes. The lengths of the tubes vary between 90 and 107.5 m, height is 7.10 m, width is 21.85 m. The total length of this highway tunnel is 520 m.
(ix) The Dees immersed tube tunnel in 1959 in Canada.
(x) Vehicular tunnel; reinforced concrete box elements, 22 m under the sea level. It was the first project considering the earthquake loads. The tunnel consists of six concrete tubes. The length of the tubes is 104.9 m. The height of the tubes is 7.16 m. The width of the tubes is 23.80 m. The total length of this tunnel is 629 m.
(xi) The Scheldt E3 (JFK) immersed tunnel, constructed in 1969 in Belgium.
(xii) Vehicular and railroad; prestressed concrete box elements, 25 m under the sea level. The lengths of the tubes vary between 99 and 115 m, height is 10.1 m, width of the tubes is 47.85 m. The total length of this tunnel is 510 m. The weight of each tube was nearly 47000 tons.
(xiii) The bay area rapid transit (BART) tunnel constructed in 1970 in USA.
(xiv) Railway; single shell steel binocular section. The tunnel is the longest existing immersed tube tunnel in the world. It is in use in San Francisco California. It is one of the deepest vehicular tubes in service today, it is 40.5 m under the sea level. The tunnel consists of 58 tubes. The tunnel consists of six concrete tubes. The length of the tubes is 111 m. The height of the tubes is 6.50 m. The width of the tubes is 14.60 m. The total length of this tunnel is 5825 m.
(xv) The Oresund tunnel constructed between Denmark and Sweden in 2000.
(xvi) Railroad (railway) tunnel, road tunnel. Reinforced concrete box elements. It is 22 m under the sea level. The tunnel consists of 20 tubes. It is the world's largest immersed tunnel in terms of volume. The length of the tubes is 176 m. The height of the tubes is 8.55 m. The width of the tubes is 38.65 m. The total length of this tunnel is 3750 m.
(xvii) The immersed tunnel under the Istanbul (Bosphorus) strait constructed in 2011 in Turkey.
(xviii) Railway tunnel. It is earthquake-proofed immersed tube. The sections have been placed down to 60 m below sea level (55 m of water and 4.6 m of earth). The length of the tubes is 130 m. The width of the tubes is 15.5 m. The height of the tubes is 8.75 m. The tunnel consists of 11 tubes. The weight of each tube was nearly 18,000 tons

IMMERSED TUBE TUNNEL CONSTRUCTION

The advantages of the immersed tube tunnel technique against a conventional driven tunnel can be summarised as (Seced Newsletter - December 2001).
(i) Improved vertical alignment since the immersed tube element need only be 1 to 2 m below the navigation envelope, whereas a driven tunnel must have a minimum cover for structural integrity (typically one tunnel diameter).
(ii) Less dependence on ground conditions.
(iii) Ability to tailor the cross section to fit precisely to the project requirements. A circular or near circular driven tunnel may require additional bores to accommodate multi-lane or multi-track requirements.

The immersed tube method for underwater crossing involves the following basic construction steps:

(i) Prefabricating long tunnel units in a dry-dock or shipyard.
(ii) Ground improvement along the tunnel alignment.

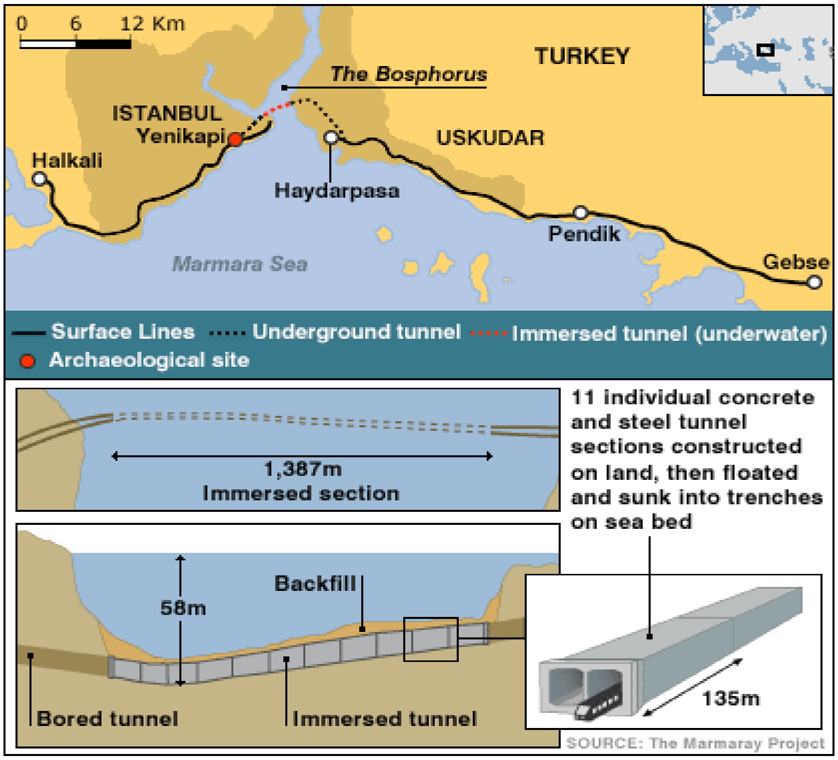

Figure 1. Bosphorus immersed tube tunnel project.

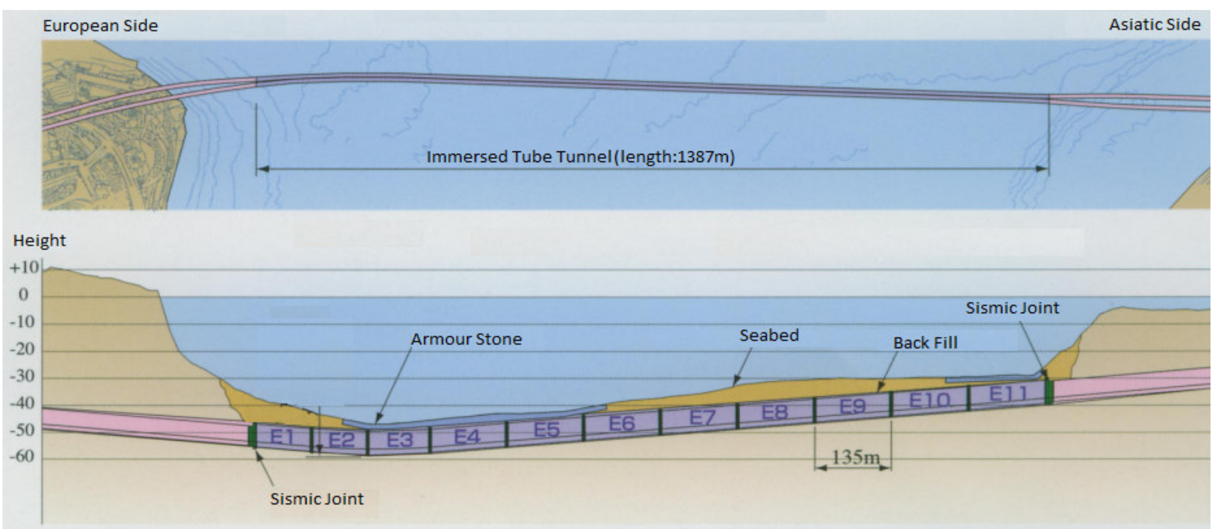

Figure 2. Immersed tube tunnel alignment and the placement of prefab tubes (Ünlütepe, 2005).

(iii) Floating and towing the units with removable bulkhead to the site.
(iv) Immerse the units in a pre-dredged trench.
(v) Horizontal and vertical survey control of the units during immersion.
(vi) Connect the units one by one.
(vii) Covering the completed tunnel with backfill.

Below issues have been effective during the construction of Bosphorus immersed tube tunnel project (Figures 1 and 2).
(i) Control of the excavation in the deep waters of the

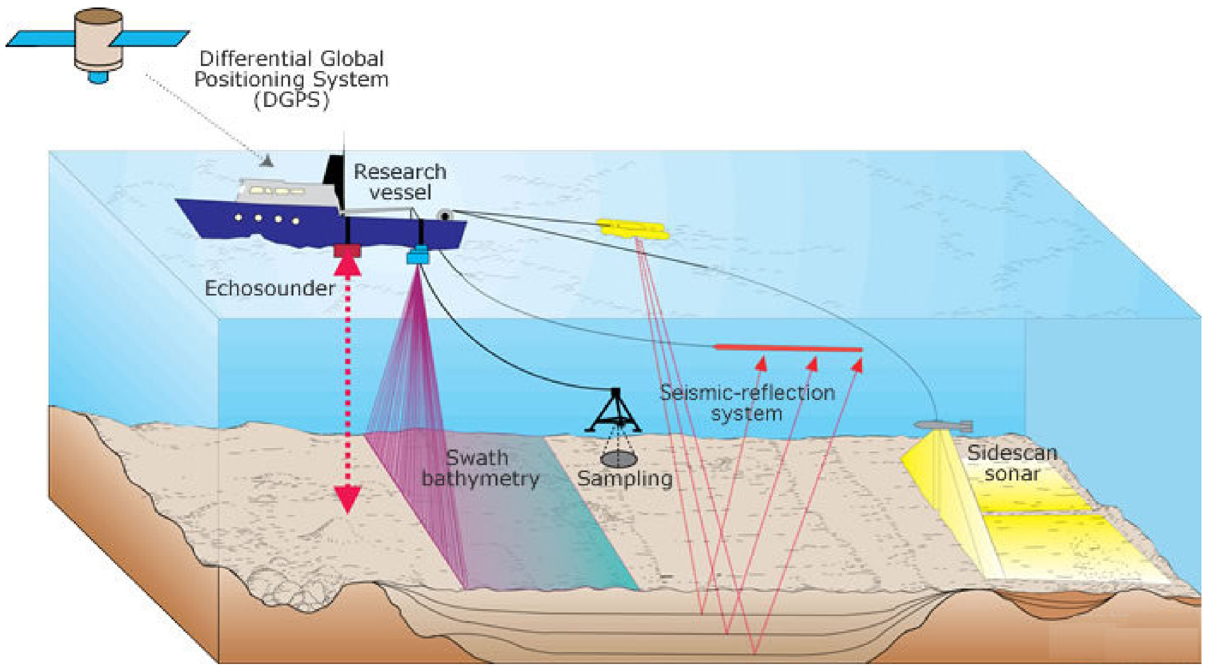

Figure 3. Example for bathymetric survey works (Gulfofmaine, 2011).

Bosphorus

(ii) Placement of the immersed tubes with difficult currents and ship navigation conditions.

(iii) Rock excavation at the end transitions.

(iv) Dredging and disposal of contaminated soils at the European side of the crossing.

(v) Excavation of trench and preparation of foundation in deep water.

(vi) Placing, geodetic positioning and linking the tube elements.

(vii) In spite of adverse underwater conditions, placement of the trench backfill materials protecting the marine environment.

SURVEY WORKS

Survey works performed in this project can be given step by step as below:

(i) Establishment of new control points (horizontal and vertical) near the work area.

(ii) Bathymetric surveys (extended to a width of 500 m on both sides of the immersed tube tunnel alignment). In order to produce sea bottom map, a multi beam echo-sounder has been used. The position of the survey vessel has been controlled by using real time kinematic (RTK)-GPS survey method (Figure 3).

(iii) Alignment and level control of the trench by an automation system (RTK-GPS, multi beam echo-sounder and control units on the survey vessel) during excavation.

(iv) Controlled immersion of a tube was performed by combination of different survey equipments such as multi beam echo-sounder, GPS, a device that produce ultrasonic waves and used for determining the relative position of the tubes according to each other (Figure 4).

(v) The position of the immersion barge was determined by RTK-GPS survey method. There is a multibeam echo-sounder on immersion barge. The position of the immersed tube, sea bed topography and the position of the tube immersed before were controlled by using this echo-sounder. Distances between two tubes have been controlled by using ultrasonic and supersonic sensors (Ünlütepe, 2005).

In addition to these survey methods, the immersed tube was controlled horizontally by anchor and wiring systems and the winches on the immersion barges control the vertical position until the element was down and rests on the foundation. In other words, the vertical movement of the element will be controlled by ballast loading and the use of winches. Horizontal control will be achieved by the use of winches, dead weights or anchors and buoys. Once the tunnel element is lowered into its final position, it will be jacked against the preceding immersed element by means of hydraulic jacks.

CONCLUSION

Istanbul immersed tube tunnel project has been applied for Bosphorus passing. It is a part of MARMARAY project. European railway system has been connected to

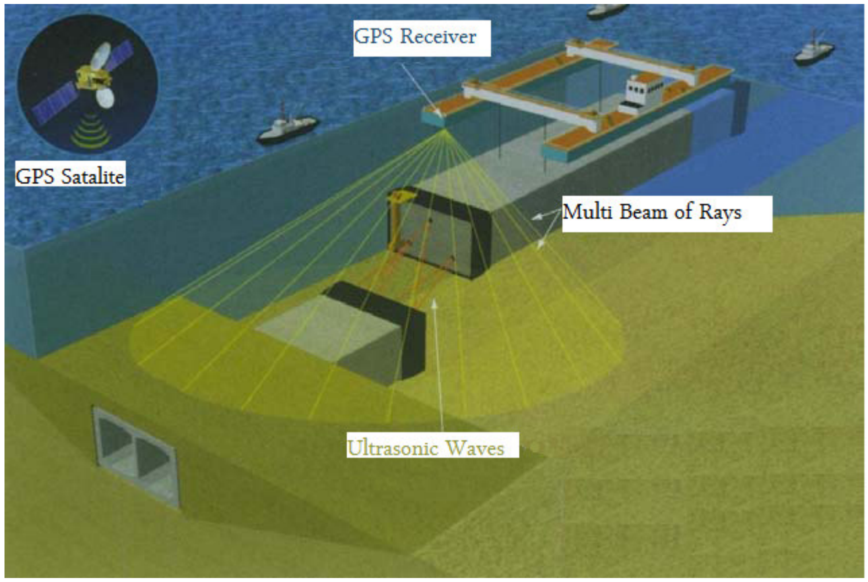

Figure 4. Survey works during immersion (Ünlütepe, 2005).

Asian railway system by immersed tube tunnel. Working on a boat and underwater is very hard. Especially working against stream is very hard in Bosphorus. An immersed tunnel is preferred if the water depth is not deeper than 60 m, the waterbed is suitable for dredging, such as soft sandy, silty or alluvial soils and if there are topographic restrictions such as inadequate soil thickness over tunnel segments to construct a bored tunnel beneath the water. Cost of a bored tunnel is higher than an immersed tube tunnel. Construction speed of an immersed tube tunnel is better than a bored tunnel. Because construction activities are simultaneously carried out for almost the entire length of the tunnel. There are a lot of safety aspects in a bored tunnel construction, like dealing with water and air pressure. These are not problems in immersed tube construction.

These works required more careful attention. Survey works performed in a tunnel such as immersed tube tunnel project differ from survey works performed on the land. For this reason, it requires more precision. There are survey works standards for all projects that will be performed on the land, but there is no any standard for the project that will be performed underwater in Turkey. This means survey standards related to hydrographic survey works should be constituted soon.

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