SUSTAINABLE APPROACH TO DREDGING FOR THE BOSPHORUS IMMERSED TUBE TUNNEL CROSSING IN ISTANBUL

Vahan Tanal[1], Isikhan Guler[2], Jerald Ramsden[3]

ABSTRACT

This paper presents the sustainable dredging aspects of the Marmaray Bosphorus Immersed Tube Tunnel Crossing Project in Istanbul, Turkey. The Bosphorus, a narrow, navigable strait between Europe and Asia, is the only shipping access from the Mediterranean to the Black Sea. It features two opposing currents and provides a pathway for the annual migration of fish between the two bodies of water. The project features a 1.8-kilometer-long tunnel in 50 meters of water—making it the deepest immersed tube crossing in the world, below one of the busiest and most narrow waterways in the region.

Tunnel construction involves dredging over one million cubic meters of soil and rock. Subsurface investigations revealed that a certain amount of sediment was contaminated and therefore not suitable for open water disposal. The contaminated sediments will be dredged by closed environmental buckets and transported to a permitted confined disposal facility (CDF). The CDF will be permanently capped and reclaimed upon completion of disposal operations. This project will feature one of the first large scale beneficial uses of dredged sediments in Turkey as well as the first CDF ever constructed in the country. Construction operations, especially dredging and disposal processes, will be sensitive to fish migration (dredging will be stopped during periods of fish migration). Precautions will also be taken to minimize turbidity. Sustainable design features of this project include restoring the channel bottom by burying the tunnel and backfilling it to restore the original bathymetry, in order to prevent any long term impact to currents, salinity and aquatic habitats.

Keywords: Sustainable, Currents, Salinity, Dredging, Confined Disposal Facility

INTRODUCTION

The world has seen extraordinary developments in state-of-the-art engineering practices in recent years. Innovative engineering techniques are emerging in a host of practice areas, from traditional civil engineering to high tech telecommunications, renewable energy development, intelligent building design, and high tech instrumentation. High performance materials are being researched and utilized in virtually every type of major construction project. Even project planning, finance and delivery methods are evolving, providing engineers and contractors with more options than at any time in engineering history. At the same time, the needs of the modern world have become ever more complex and challenging. When these needs and our profession's capabilities intersect, tremendously dynamic engineering projects often result. This paper presents the case study of a major new immersed tube tunnel in Istanbul.

HYDRODYNAMICS OF THE BOSPHORUS

The Bosphorus Strait is a pathway between Marmara and the Black Sea (Figure 1). Its width varies between 0.7 and 3.5 kilometers with an average surface width of 1.3 kilometers. The width gradually decreases towards the bottom

[1]Senior Vice President, Parsons Brinckerhoff Quade & Douglas, Inc., One Penn Plaza, New York, NY 10119, USA, T: 212-465-5208, Fax: 212-465-5096, Email: Tanal@pbworld.com.
[2]Marine Works Division Manager, Yuksel Proje International, Ankara, Turkey, T: 312-495-7000, Fax: 312-495-7024, Email: Iguler@yukselproje.com.tr.
[3]Lead Coastal Engineer, Parsons Brinckerhoff Quade & Douglas, Inc., One Penn Plaza, New York, NY 10119, USA, T: 503-274-1337, Fax: 503-274-1412, Email: Ramsden@pbworld.com.

of the channel to a typical average of 500 meters at a depth of 50 meters. The depth of the waterway varies between 30 and 100 meters. Water flow in the Bosphorus features a strong, stratified two-layer system, including:

- An upper-level current that flows south from the Black Sea to the Sea of Marmara
- A lower-level current that flows north from the Sea of Marmara to the Black Sea

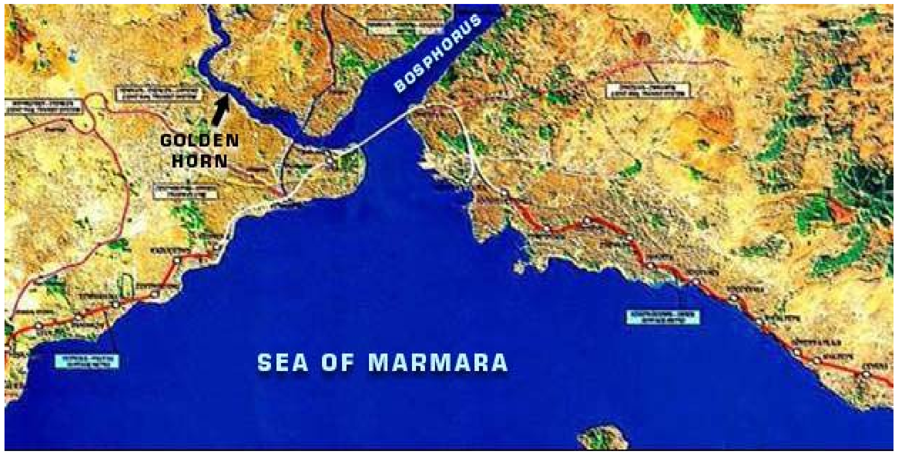


Figure 1. Map of project area.

This stratified current is primarily caused by two factors: differences in density and water levels. The water level of the Black Sea is higher than the Sea of Marmara, thereby generating currents on the upper level. Additional contributing factors to this upper flow include an influx of fresh water from rivers to the Black Sea, barometric pressure, wind, evaporation and precipitation. The lower-level flow, on the other hand, is generated by differences in salinity between the Sea of Marmara and the Black Sea. A turbulent interface layer separates the upper and lower currents. The interface thickness varies from about 10 meters at the Sea of Marmara to approximately 2 meters at the Black Sea. Further complicating flow characteristics of the Bosphorus are the presence of sills located near both entrances and a lateral contraction coupled with sharp curves near the center of the strait.

A detailed analysis of the Bosphorus' two-layer flow regime was undertaken during a hydrographic survey prepared by Istanbul Rail/Tunnel Consultants (IRTC) as part of feasibility studies and preliminary design for the Bosphorus Railroad Tunnel (1987). The hydrographic survey found that previous analyses of the Bosphorus were based only on limited sets of measurements. Therefore, an intensive effort was made to collect additional flow measurements and related data. Hydraulic measurements of the two-layer flow system were collected in 1985 and early 1986. Observations confirmed the two-level flow regime and long term monitoring was performed to determine current velocities and direction at the location selected for the tunnel crossing. These current measurement are summarized in Table 1.

Table 1. Current Measurements (IRTC, 1987).

Period	Locations	Water Depth	Current Meter Depth	Average Velocity	Current Stratum
10/06/85-20/07/85	Sarayburnu	41 m	28.5 m	0.644 m/sec	Lower
10/06/85-14/06/85	Sarayburnu	41 m	37.0 m	0.350 m/sec	Lower
04/08/85-09/08/85	Sarayburnu	41 m	28.5 m	0.760 m/sec	Lower
04/08/85-09/08/85	Sarayburnu	41 m	37.0 m	0.410 m/sec	Lower
26/01/86-31/01/86	Kızkulesi	7 m	5.0 m	0.886 m/sec	Upper

The Istanbul Water and Sewage Authority (İSKİ) performs water quality measurements along the Bosphorus and at both entrances (Figure 2). These measurements include flow measurements at the B2A-B2B section as well as point measurements. Results of flow measurements in June 2000 and June 2001are displayed as an example in Figure 3.

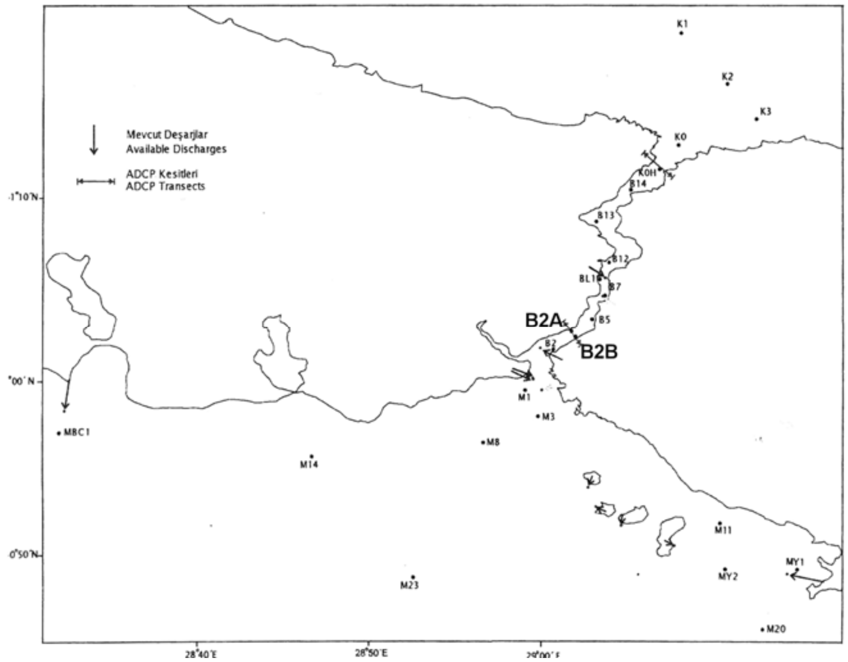
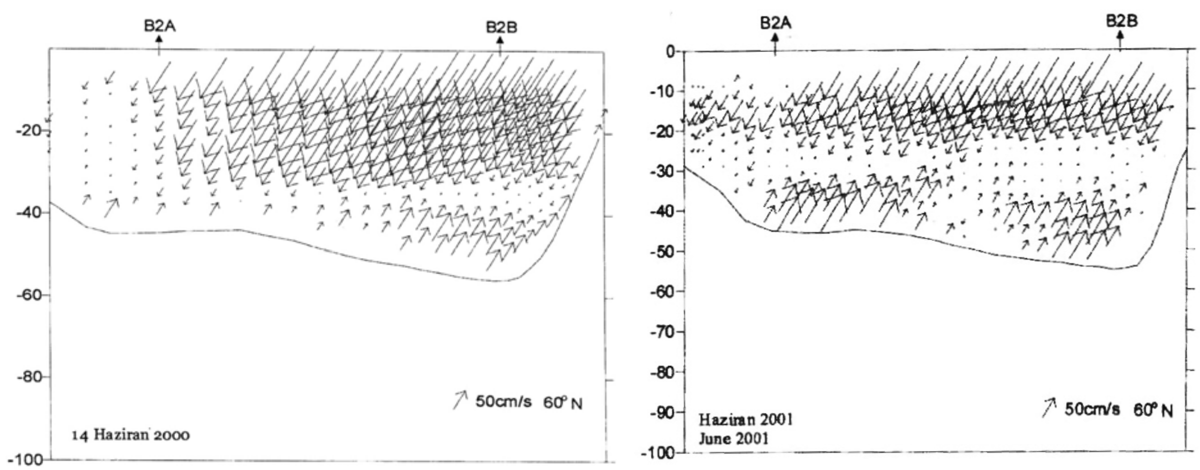


Figure 2. Current measurement stations in the vicinity of the Bosphorus (İSKİ, 2000 and 2001).



June 2000 **June 2001**

Figure 3. Current velocities at section B2A-B2B (İSKİ, 2001).

The direction of the upper currents from the Black Sea to the Sea of Marmara as well as the lower layer currents from the Sea of Marmara back to the Black Sea can be seen in Figure 3. The upper and lower stratum thicknesses change depending on short and long term hydrologic and weather variations.

During the project's tender period, 2,952 sets of current data were collected over a 123-day period from 9 May to 2 September, 2003, and evaluated. As shown in Figure 4, the current meter was set at Station 1 (Dolmabahçe), where the current pattern is the most complex. Three-minute records were taken hourly and averages of the recorded values computed. Figure 5 provides an example of current velocity measurements.

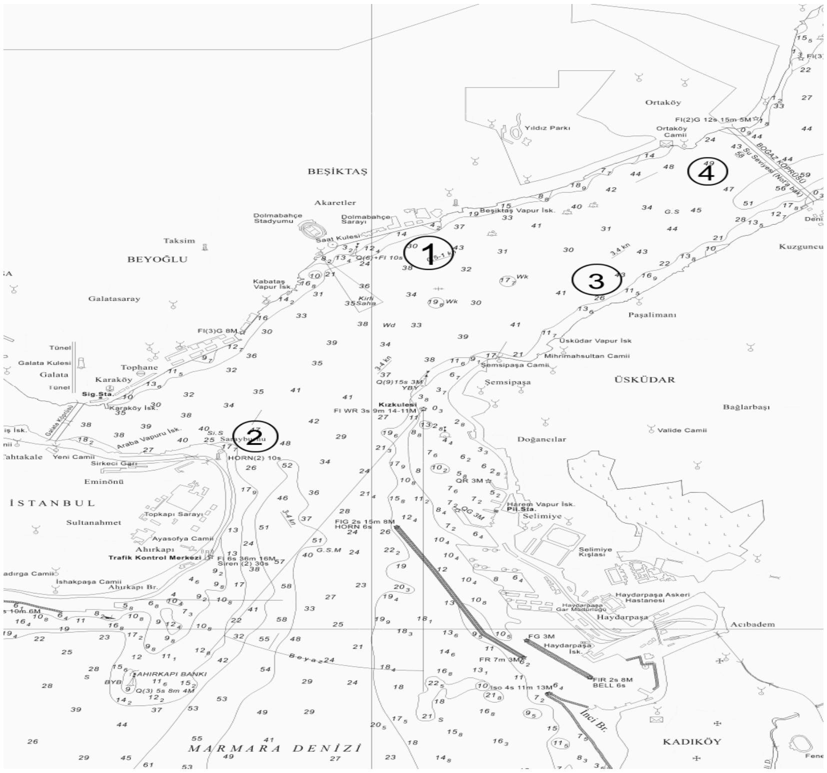


Figure 4. Measurement stations in the southern Bosphorus.

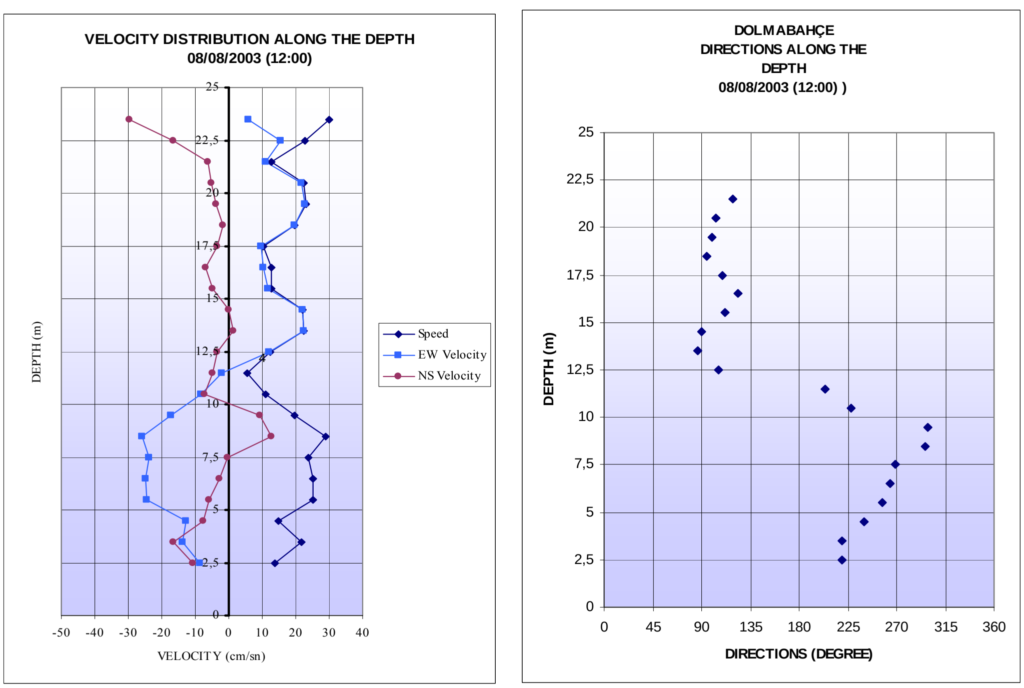


Figure 5. Continuous measurements at Dolmabahçe Station on 08/08/2003 at 12:00.

Figure 5 shows that in spite of the upper layer flow being North to South, the current flowed predominantly in a South to North direction at the upper layer. Examination of the component in the North to South direction shows that the current actually changes direction with depth. As a result of current measurements, the clockwise secondary eddy circulation of currents between Stations 1 and 2 was confirmed, although it was not uniform with depth and the pattern was very sensitive to meteorological conditions.

CONSTRUCTION AND ENVIRONMENTAL EFFECTS

The immersed tube tunnel under the Bosphorus to connect the Asian and European sides of Istanbul will be constructed in the next 5 years. The immersed tunnel length will total approximately 1.8 kilometers. Each tube tunnel section will measure approximately 130 meters in length and 16 meters in width. They will be constructed at a dockyard floated to the tunnel site and sunk into a dredged trench along the sea bottom. The tubes will be completely buried and covered with earthen fill without affecting the bathymetry of the sea bed.

Subsurface investigations, including bathymetric and geophysical surveys, soil borings and laboratory tests performed in 1985 and 2003 identified and characterized the subsoil and rock profile along the tunnel alignment. Soil characterization tests indicated that on the European side of the alignment, for approximately 600 meters, the upper 1 to 3 meter layer of underwater sediments were contaminated and therefore unsuitable for open water disposal. The limits of the contaminated sediments were subsequently delineated and the quantity of contaminated sediments to be dredged was established on the basis of dredged trench slopes of one vertical on three horizontal within those depths. The contaminated sediments will be dredged by closed environmental buckets and transported to a permitted CDF designed by the contractor. Dredging best management practices to be implemented include water quality monitoring during dredging and avoidance of dredging during high current events to minimize suspended sediment transport from the dredging site. The CDF will be permanently capped upon the completion of disposal operations. Clean dredged material, meanwhile, will be disposed in open water at a designated disposal site at Çınarcık Basin in the Marmara Sea. The design team developed a three-dimensional hydrodynamic model to simulate the stratified flows in the Bosphorus. Among other uses this hydrodynamic model was used to illustrate that the proposed dredging would comply with water quality criteria for the site.

Navigation in the Bosphorus is continuous with several oceangoing ship transits occurring each hour. Construction is being tailored through minimization of impacted areas to mitigate, to the extent practicable, impacts to navigation. Not only does this minimize economic impacts, but it also reduces air emissions related to idle vessels.

As might be expected, the two-level flow system in the Bosphorus provides a diverse marine habitat and supports a wide variety of marine life. The Bosphorus is situated in the transition zone between the highly saline environment of the Mediterranean and Marmara Seas, and the brackish surface water of the Black Sea. Therefore, species acclimated to both high and low saline environments are found in the area. Fish regularly migrate through the strait for food or spawning.

The ecological study conducted for the tunnel project presents a summary of the physical parameters of the Bosphorus and surrounding areas. It examined issues such as salinity, temperature and dissolved oxygen levels. The ecological study also identified short term impacts caused by project dredging. It was determined that dredging will release sediment into the water column. The sediment that remains in suspension will increase turbidity and will be carried by the currents from the project area. To mitigate these conditions, dredging and disposal operations will be sensitive to migrating fish and will be curtailed during key periods. Precautions will also be taken to prevent any adverse impacts to the natural water flow, to keep the water clean, to minimize turbidity, and to meet the requirements of the clean water act and related regulations.

When complete, this project will significantly alleviate road congestion and vehicle pollution in metropolitan Istanbul. Mass transportation facilities such as this tunnel are considered sustainable development, particularly in highly developed urban areas. The sustainable features of this project include the use of prefabricated tunnel elements, the confined disposal of contaminated dredged materials and the fact that the project will have no permanent impacts on the rich aquatic habitat of the Bosphorus, nor will it affect currents or salinity. Additionally, the project won't create negative visual impacts, preserving the spectacular view of the Bosphorus and the historic Istanbul skyline.

CONCLUSIONS

The Bosphorus Strait is not merely a waterway connection between two seas, but also provides a major route for maritime traffic and the migration of numerous marine species. A long term measurement program is progressing to determine any spatial and temporal changes in detail, while also providing valuable data on the waterway's noteworthy two-layer flow mechanism. The ecologically critical nature of this waterway is preserved by implementing sustainable planning and design principles on this world-class project.

Innovative engineering and construction techniques should no longer be isolated or exceptional. On the contrary, progressive practices are becoming commonplace to meet ever more stringent environmental and regularity criteria. The beneficial use of dredged materials, whether treated or naturally clean, is mandated as the only alternative to costly disposal alternatives, as open water disposal of dredged material is no longer an acceptable option. Engineers must be prepared to meet the ever-growing engineering challenges to deal with contaminated dredge sediments, lest the dramatic increases in disposal costs threaten the economic feasibility of future immersed tube tunnel construction.

The design and construction of immersed tunnels, including the Bosphorus Tunnel, can be successfully accomplished while adhering to sustainable engineering principles. To accomplish this goal it is necessary to achieve harmony among the engineers, public authorities and the communities affected by the construction. As civil engineers, we have chosen a profession that can both serve the public good and enhance the quality of life. Sustainable design provides a means to accomplish that mission.