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Marmaray project: Marine operations, the Bosphorus Crossing

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Abstract

This paper describes the most important factors influencing the marine regime of the Bosphorus, and present and explain the measurements taken up till now in the Bosphorus. It also describes the other constraining factors influencing the immersion processes in the area, and discusses the background for the final requirements to the Contractor related to how to control and predict the marine conditions. It also describes in broad terms the results of the initial investigations performed by the Contractor regarding the immersion process as of the time of writing this paper.

Keywords: Bosphorus crossing; Marmaray project; The current regime; TKGN Joint Venture

1. Introduction

The Bosphorus Strait is one of the busiest sea lanes in the world. All commercial traffic to and from the Black Sea has to pass the Bosphorus, and therefore a large number of commercial ships traverse the length of the Bosphorus every year. On top of that a vast number of smaller commercial ferries carrying passengers and cars across the Bosphorus find their way in between the bigger ships in the area near Uskudar and where the immersed tunnel will be constructed.

The current in the strait varies dramatically and is of a complex nature. The current is stratified. Non-saline water from the rivers leading to the Black Sea and general surface water is normally flowing in the upper layers of the Bosphorus from the Black Sea towards the Marmaray Sea, and saline water is normally flowing in the lower layers in the opposite direction from the Marmaray Sea towards the Black Sea.

However, major variations due to many different factors in this regime occur during the seasons, and a further complicating factor is that water from the Golden Horn – a side stream to the Bosphorus – is flowing into the Bosphorus exactly in the area where the deepest immersed tube tunnel of the world will be constructed – the Bosphorus Crossing Immersed Tunnel.

2. Forecasting of the current and related risks

At the time of planning the requirements that would be incorporated in the Contract and defining the risk sharing between the Contractor and the Employer regarding the control of the immersion process, not much factual information about the actual current in the Bosphorus could be found. Sporadic measurements had been done by different organizations and companies, but no measurement campaign over longer periods where the "quality" of the measurements had been documented could be made available to the engineers.

To ensure safety and to minimize risks have been very important considerations for the management in everything that has been done on the project up till now, and it is generally accepted that accidents and uncontrolled processes related to the immersion process of the elements constitutes high risks. Therefore more comprehensive studies had to be established.

The sporadic measurements available indicated that the current in the Bosphorus can vary quite dramatically and the surface current velocity can be as high as 3–4 m/s in extreme situations. The bottom current is generally low and

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does normally not exceed 1 m/s. It was therefore decided that a simple measuring campaign would be performed by the Employer in the period before the bid was initiated and as long into the bid period as was reasonably possible in order for the bidders to be able to utilize the results. Such a campaign could not and was not designed to give a solid basis for the bidders planning in details but served only the purpose of giving the bidders a better basis for limiting the costs for the risk they had to allocate in their bids related to the immersion process.

It was also decided that a requirement for the Contractor to establish a comprehensive data base of the current regime in the entire immersion area would be included in the bid documents. The purpose of this campaign would be twofold. First, to enable the Contractor to develop a reliable forecasting model that would be sufficient to avoid major surprises and unnecessary risks during the last critical phases of the immersion processes, and secondly to ensure the establishment of a database that could be used to define a risk sharing mechanism between the Employer and the Contractor of "unforeseen current conditions".

The mechanism to establish "reference conditions for the current regime in the Bosphorus for the purpose of risk sharing related to immersion processes" becomes complicated because the current will vary substantially from place to place of each elements position on the alignment. Therefore, it would be almost impossible to establish continuous monitoring (baseline conditions) of the current in each immersion position, and later on during construction it would be impossible to monitor the actual current in the same positions due to dredging and construction activities taking place in the alignment. It was therefore decided that the "reference condition in each immersion position" would not be direct monitoring of the current in that position, but the reference condition would be defined as the output of a calibrated computer model (a micro-environment model) using input from three monitoring stations placed strategically in the water column near the alignment. Continuous monitoring at these three points can be done during the whole period, and therefore the risk sharing mechanism will also be effective over the whole period. The monitoring in these three positions is continuing and the monitoring is done from seabed to water surface. Important information will not only be the current profile itself, but also other factors such as salinity, the transition layer between the upper and lower current and the temperatures.

The mechanism and the requirements to establish reliable forecasts of the current in the immersion position for the needed critical window was based on experience from similar situations, for example the Oeresund Immersed Tunnel established between Denmark and Sweden where quite similar physical conditions like stratified current exist. The forecast mechanism was furthermore combined with the monitoring we would have to do anyway in three positions as described above for the purpose of establishing the reference conditions for current. The input to a current forecasting model is known to be all relevant meteorological and hydrologic data, and the forecast of such weather data, as they change in the regions surrounding the Bosphorus Strait. The area we talk about here can be quite large, but how large it is and which input data are required can only be decided later, after the calibration and optimization of this "macro model" has been done. However, most likely the regions have to cover the Black Sea and the surrounding land areas, the Marmaray Sea and the surrounding land areas and major land areas east and west of Istanbul in general. The most important weather systems and hydrological systems are expected to be low and high atmospheric pressure in the region, wind systems, temperatures in the air as well as in the water, salinity profiles, precipitation and fresh water inflow to the Black Sea. The output of this forecasting model should then be the current in the three fixed points, and because the current will be monitored continuously in these points these data can be used to calibrate the "macro model". The development, calibration and verification of the reliability criteria is progressing.

The minimum requirement for the accuracy of this forecasting model is that the confidence level of the maximum velocity of the current not exceeding the threshold level of 1.5 m/s in the critical period shall be not less than 90%.

3. Other constraints for immersion

As described, the Bosphorus Strait is one of the world's busiest straits when it comes to commercial shipping. The statistics tell us that approximately 50,000 major commercial ships pass through the navigation channel of the strait every year. This channel changes direction several times along the length of the Strait and especially in the alignment area of the tunnel heavy navigation is required by the ships. The channel is also narrow, of the order of 800 m. The set-up of the immersion equipment will require a working area free of ship traffic of approximately 600 m in the cross-direction of the channel, and therefore it will most likely be necessary to close the channel down completely for traffic when the 3–4 center placed tunnel elements will have to be immersed. Such a close down can, in such situations, be arranged, but international notices will be needed.

The specific requirements of such notices do not go well in hand with the uncertainty of natural events, and this only emphasizes the importance of the need for reliable forecasting systems.

4. The immersion process, model tests

The Contractor on the Bosphorus Crossing contract (the TKGN Joint Venture) performed tests of the immersion process in detail as early as in the bid period. These tests have been repeated and improved on a running basis as more information has become available during the process. The following information is based on the status of these tests as of October 2004.

The Basic Design of the IMT indicates that there will be 11 elements differing in length between 98 and 140 m with a typical length of 130 m. The model tests were performed in Taisei Corporation's advanced testing facilities available in the Technology Center in Japan. The model scale used was 1:120. The flow condition simulated was one directional uniform flow of 2, 3 and 4 knots similar to 1.0, 1.5 and 2.0 m/s.

The complete immersion procedure consists of three different and sequential processes; the towing process, the mooring process and the lowering process. The purpose of the model tests is:

- to determine the maximum forces during all phases to enable the Contractor to design the mooring equipment;
- to check the behavior and the handling of the immersion barge and the element during lowering, and
- to confirm the preliminary procedures regarding the handling of winches.

The elements will be produced and fitted out in the construction yard in Tuzla Harbor. When the forecasting system indicates that the weather window needed will be there, the towing of the elements will be initiated. It is expected that the traditional set-up of towing boats with one boat connected to each of the four corners of the immersion pontoon will be used. The route will be to the south of the Princess Islands. An alternative route north of the Princess Islands between these islands and the main land of Turkey has been discussed but two arguments do not favour this route. One is an area of relatively shallow water that has to be passed, and another is the more frequent traffic of passenger boats and other boats that exists in this area. The southern route will have a last check-point where an update of the weather forecast and the model output will be performed. If the forecast has changed in such a way that the required window is no longer available, this point will be the area where the element is temporarily moored and secured in waiting for the next window to emerge. If the forecast has not changed for the worse, the towing will continue to the last "go/no-go point" which will be the immersion position in the Bosphorus Strait before the first mooring line is established.

Since the early days of the planning of this procedure was considered, it has been in the mind of engineers experienced in immersion techniques that the extreme forces on the element that would occur if the element was turned from a streamlined position where the element is parallel to the current to a position perpendicular to the current in the upper layer strong currents should be avoided. This idea has been further developed and adopted by the Contractor, so the first step of the mooring process is to moor the immersion pontoon carrying the element in a streamlined position parallel to the current. Only one mooring line (number 5) is used for this purpose together with some of the tug-boats to maintain full control. From this position, the element will be lowered until it is in the relatively calm zone between the upper and the lower current and further upstream mooring lines will be activated to control the immersion pontoon (numbers 3, 6, 7 and 8). Tug boats are not required anymore, but will be on stand by. In this position the immersion pontoon and the element will be turned in the horizontal plan into the correct position in order to be lowered further down into the trench. Before the final lowering is initiated, the remaining four downstream mooring lines (numbers 1, 2, 3 and 9) connected to the pontoon are activated to ensure full control of the immersion pontoon.

The element will in this position only be kept in place by the down force on the 4 "sling lines" (numbers 10, 11, 12 and 13) carrying the element. This total down force is temporarily being designed for approximately 800 ton. However, before the final positioning of the element in the trench takes place the four adjusting wires (numbers 14, 15, 16 and 17) connected directly to the four corners of the element are activated for detailed control of the element.

Many different tests with this set-up have now been carried out, and the preliminary design of the mooring equipment has been done. The designed winch capacity (brake force) of the mooring wires (1–9), the sling wires (10–13) carrying the element down force and the adjusting wires (14–17) are as follows:

Wire nos.	Brake force (tons)
1	60
2	60
3	60
4	80
5	140
6	100
7	100
8	80
9	60
10	250
11	250
12	250
13	250
14	50
15	50
16	50
17	50