Marmaray Project: Marine Operations, the Bosphorus Crossing
Immersed Tunnel Construction:

• 1 Marine environment of the Bosphorus

• 2 Marine construction activities

• 3 Hydrological survey and modeling

• 4 Model tests for immersion operations
1 Marine Environment of the Bosphorus

- Intensive international and local navigation
- Unpredictable, sometimes fast currents
- An ecologically sensitive environment
2 Marine Construction Activities

• 2.1 Ground improvement works

• 2.2 Dredging and backfilling works

• 2.3 Tube immersion operations
2.1 Ground Improvement Works

Treated area: 471 x 20.5 m
Depth: 4 – 10 m under tunnel
## 2.1 Ground Improvement Works

<table>
<thead>
<tr>
<th>(1) Installation</th>
<th>(2) Grouting</th>
<th>(3) Step Up</th>
<th>(4) Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rig</td>
<td>Casing Guide</td>
<td>Grout</td>
<td>Middle Casing</td>
</tr>
<tr>
<td>Middle and Upper</td>
<td>Barge</td>
<td>Grout Pipe</td>
<td>Joint Grout Pipe</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower Casing</td>
</tr>
</tbody>
</table>

**Volume of treated soil:** 74.500 m³  
**Number of CPG columns:** 3,264  
**Volume of grout:** 11,000 m³  
**Replacement ratio:** 13.3 %
2.1 Ground Improvement Works

Compaction Grouting barge “SAR III”: 86 x 24 m
2.2 Dredging and Backfilling Works

Deepest point: 61 m under Mean Sea Level
2.2 Dredging and Backfilling Works

Contaminated soil: 120,000 m³  
Clean soil: 1,000,000 m³  
Stone backfill: 130,000 m³  
Soil backfill: 800,000 m³
2.2 Dredging and Backfilling Works

Grab dredger “Kanyu”: 4.000 hps  
Grab: 27 m³, 3.9 ton
2.2 Dredging and Backfilling Works

The project’s marine operations have a serious impact on navigation.
2.3 Tube Immersion Operations
2.3 Tube Immersion Operations

Duration to complete process:
- For all the immersion process, 24-48 hours required,
- For anchoring and lowering process, 12-24 hours required,
- In case of making ‘NoGo’ decision, a placing barge returns to the second decision point.
2.3 Tube Immersion Operations
2.3 Tube Immersion Operations
3 Hydrological Survey and Modeling

- Limited knowledge of the Bosphorus’ hydrology at tender stage
- Very little tidal movement (10-20 cm)
- Rapid changes in current velocity
- Surface currents up to 3.5 m/s (7 knots) South
- Stratification: bottom current in North direction
3 Hydrological Survey and Modeling

Current Profile - Column 1

Distance from instrument [m]

[Graph showing distance from instrument with North and South axes, and a line representing North cm/s]
3 Hydrological Survey and Modeling

Employer’s Requirement: a comprehensive hydrological monitoring and modeling program

With 2 objectives:

1. Develop a reliable forecasting model as a tool to avoid risks during the immersion operations

2. Establish data that can be used in a risk sharing mechanism for “unforeseen current conditions”
3 Hydrological Survey and Modeling

• 3 permanent Acoustic Doppler Current Profilers were placed directly outside the construction area

• Continuous current measurements during the first 10 minutes of every hour

• Wind, air pressure etc.
3 Hydrological Survey and Modeling

• Modeling of the Bosphorus in a hydrodynamic numerical simulation model (Delft3D-Flow)

• Additional current profile measurements in the tunnel alignment

• Validation of the models with measured data
3 Hydrological Survey and Modeling

- Water level difference
- Stratification

Salinity pattern along the straight line (psu)
- <18.0
- <22.4
- <26.8
- <31.2
- <35.6
- <40.0
- <20.2
- <24.6
- <29.0
- <33.4
- <37.8
- >40.0

Sea of Marmara
Black Sea

Tunnel alignment position
3 Hydrological Survey and Modeling

Water level difference $\Delta H$ is a function of:

• Black Sea river runoff (Danube) – slowly changing
• Wind and wave surges – some buildup time
• Air pressure differences – fast changing
• Standing waves (seiches) in the Black Sea or Marmara Sea, – predictable at all?
• Forecasts for all these parameters must be combined into a reliable Current Forecasting System
3 Hydrological Survey and Modeling

- Anchoring a placing barge
- Lowering a tunnel element

- Aligning a tunnel element
- Connecting tunnel elements

- Detaching a tunnel element
- Releasing anchor lines

Current force is deceased because a tunnel element in a trench is acted by slow flow.

Current force is more deceased because a tunnel element is detached from a placing barge.
3 Hydrological Survey and Modeling

2nd Function of modeling: create a reference condition for the current regime: RCV
4 Model Tests for Immersion Operations
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Scale 1:120  Water depth: 48 m  Flow: 1.0 - 1.5 - 2.0 m/s
4 Model Tests for Immersion Operations

During immersion:

• Down force $\pm 800$ ton
• Number of holding and adjusting wires: 13
• Maximum wire force: $\pm 140$ ton
• Adjusting wire force: $\pm 50$ ton
Thank you for your attention

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