WORKSHOP ON TUNNELING METHODS for TAGUS THIRD CROSSING

University of Lisbon

April, 2008
Parsons Tunnel
Expertise
TARP Chicago

- Tunnel and Reservoir Plan (TARP)
- 35 years design and construction experience
- 170 km of tunnels
Beacon Hill Station

• 2.6 km TBM Tunnel
• Mining 1 underground station with twin shafts
A Cutaway View of Tracks and Street

The trench will contain two railroad tracks and an access road. Cantilevered track and roadway will cover only some sections of trench.

1. Spur tracks on the surface for commercial areas along Alameda Street. The sidings will allow railroads to make deliveries and pick up goods from businesses and factories.
2. Concrete barriers and fences for safety.
3. Reinforced concrete walls will be three stories high.
4. Two railroad tracks from downtown to ports.
5. Track beds.
6. The floor of the trench will be made of reinforced concrete.
7. Both sides have channels for drainage.
North Fork Stanislaus

- 12 km TBM tunnel
T-Rex

- D/B Contract with Equity Role
- 730m outfall EPB TBM
Chattahoochee Interceptor

- 16 km TBM tunnel
Los Angeles Metro Rail Red Line

- 30 km TBM & Cut/cover tunnels
Washington DC Metro

80 km of Twin-bore Subway Tunnels and Station Caverns
Central Artery/Tunnel – Contract C11A1

Key Issues

- 670m Tunnel
- Mining 1m below MBTA’s Red Line
- Tolerance < 12mm vertical movement
- Extensive soil stabilization and dewatering
- Extensive utilities relocation
Central Artery/Tunnel – Contract C11A1
Long Island Rail Road
East Side Access Project
New York, New York
August 2001
Washington Dulles International Airport Expansion Program

Project Location: Washington, D.C.
Client: Metropolitan Washington Airports Authority
Construction Cost: $2 billion
Start Date: March 1988
Completion Date: May 2010

Tunnel Scope
An underground people-mover system connecting the existing terminal with the new midfield terminals
Channel Tunnel & CTRL
Egnatia Motorway

Project Location: Greece
Client: Egnatia Odos A.E. Highway Authority
Construction Cost: $1.7 billion (U.S.)
Parsons Central Portion Opened 2006
Egnatia

- 7500 meters of bored tunnel
Egnatia

- 24 million m³ of earthworks
MOTORWAY TUNNELS, GREECE

Maliakos - Kleidi

Corinth - Patra - Pirgos - Tsakona
Dublin Port Access Tunnel

- Location: Dublin, Ireland
- 5.6km twin-tube (11.4m TBM and cut-and-cover) under residential area of Dublin City.
THE ARC TUNNEL
THE ARC TUNNEL
Immersed Tube Tunneling Methods
Immersed Tube Tunneling
Immersed Tube Tunneling
Submerged Tunnels
Typical Immersed Tube Tunnel
# Parsons Immersed Tunnel Experience

<table>
<thead>
<tr>
<th>Tunnel</th>
<th>Location</th>
<th>Length (km)</th>
<th>Type</th>
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<tbody>
<tr>
<td>Washington Channel</td>
<td>USA</td>
<td>0.4</td>
<td>Rail/Transit</td>
</tr>
<tr>
<td>Second Downtown Elizabeth River Tunnel</td>
<td>USA</td>
<td>10.6</td>
<td>Highway</td>
</tr>
<tr>
<td>Anacostia River Tunnel</td>
<td>USA</td>
<td>0.4</td>
<td>Rail/Transit</td>
</tr>
<tr>
<td>Taichung Harbor Tunnel</td>
<td>Taiwan</td>
<td>0.5</td>
<td>Rail/Transit</td>
</tr>
<tr>
<td>Palm Jumeirah Island &amp; Lulu Island</td>
<td>UAE</td>
<td>1.0</td>
<td>Highway</td>
</tr>
<tr>
<td>Thessaloniki</td>
<td>Greece</td>
<td>3.0</td>
<td>Highway</td>
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</table>
Bridge-Tunnel Methods
Oresund Bridge-Tunnel
Oresund Immersed Tube Element
Oresund Bridge-Tunnel
Monitor Merrimac Memorial Bridge-Tunnel
Chesapeake Bay Bridge-Tunnel
Hampton-Roads Bridge-Tunnel
Potential Immersed Tube Tunnels

[Map showing potential immersed tube tunnels between Algés-Trafaria, Chelas-Barreiro, and Beato-Montijo]
Algés-Trafaria Crossing.
Beato-Montijo Crossing

Fig. 2 - Corte geológico simplificado dos terrenos de fundação da Ponte Vasco da Gama
Oresund Tunnel Element
Tokyo Port Tunnel
Immersed Tunnel Seals

- Gina and Omega gaskets (Trelleborg)
Immersed Tunnel Seals

- Gina gasket before initial contact (Trelleborg)
Immersed Tunnel Seals

- Gina and Omega gaskets after installation (Trelleborg)
Immersed Tunnels: Seismic

- Schematic of dynamic response analysis model
- Finite element soil-structure models
Aktion-Preveza Immersed Tube Tunnel
Aktion-Preveza Immersed Tube Tunnel

**Geotechnical Period**

<table>
<thead>
<tr>
<th>Geotechnical period</th>
<th>Stratum description</th>
<th>Soil unit</th>
<th>Unit weight</th>
<th>Consistency</th>
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<tbody>
<tr>
<td>Holocene</td>
<td>Recent material and fill</td>
<td>1</td>
<td>As for soil 2A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Silty sands</td>
<td>2A</td>
<td>18.0</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>Silts</td>
<td>2B</td>
<td>-</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>Clays and silty clays</td>
<td>2Γ</td>
<td>-</td>
<td>19.5</td>
</tr>
<tr>
<td>Upper Pliocene</td>
<td>Sandy clays and sandstone</td>
<td>3</td>
<td>Not found</td>
<td></td>
</tr>
<tr>
<td>Pliocene/Pleistocene</td>
<td>Silts, clays and marls</td>
<td>4</td>
<td>-</td>
<td>20.5</td>
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</tbody>
</table>

**Unit weight: kN/m³**
Aktion-Preveza Immersed Tube Tunnel

- Tunnel: 900m long
- Elements: 135m long, 12.5m wide, 8.6m high
- C&C: Aktion 152m, Preveza 500m

Prone to severe seismic activity

<table>
<thead>
<tr>
<th>Earthquake Magnitude</th>
<th>Return Period (years)</th>
<th>Peak Ground Acceleration</th>
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<tbody>
<tr>
<td>7.3</td>
<td>475</td>
<td>0.32g</td>
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<tr>
<td>7.5</td>
<td>949</td>
<td>0.40g</td>
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### Aktion-Preveza Immersed Tube Tunnel

<table>
<thead>
<tr>
<th>Location</th>
<th>Boreholes</th>
<th>CPTU</th>
<th>SCPTU</th>
<th>DPSH</th>
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<tbody>
<tr>
<td>On land</td>
<td>8</td>
<td>34</td>
<td>10</td>
<td>132</td>
</tr>
<tr>
<td>On Sea</td>
<td>6</td>
<td>38</td>
<td>10</td>
<td>136</td>
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</tbody>
</table>

**CPTU** = Cone Penetration Tests with pore pressure measurement  
**SCPTU** = Seismic Cone Penetration Tests with pore pressure measurement  
**DPSH** = Dynamic Probing (Super Heavy; 63.5kg, 750mm drop, cone 50mm diameter)

<table>
<thead>
<tr>
<th>Static</th>
<th>Unconfined Compression Tests</th>
<th>150</th>
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<tbody>
<tr>
<td></td>
<td>Triaxial + pore pressure measurement</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Direct simple shear tests</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Oedometer (loading/reloading)</td>
<td>30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynamic</th>
<th>Resonant column tests</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cyclic simple shear tests</td>
<td>18</td>
</tr>
</tbody>
</table>
Immersed Tube Tunnels

- Cone penetration testing and sampling (Fugro)
Immersed Tunnels: Seismic

- Stone columns 0.6m dia in 1.8m pattern supporting Aktion-Prevesa tunnel (NCE)
Aktion-Preveza Immersed Tube Tunnel

- Installation of stone columns
Aktion-Preveza Immersed Tube Tunnel

- 8782 stone columns, 600mm diameter
- 1.8m square grid
- 310mm vibroflot, 20m long
- Field Trial of 25 columns to 15m depth 5m by 5m square grid; Dynamic probing before and after

- Grout mattress of partitioned fabric attached to underside of elements
- Grout pumped to mattress while tunnel is supported on temporary foundation pads in the trench
- Prestressing cables installed across tunnel joints to arrest tension forces and joint movement from seismic events
Immersed Tunnels: Seismic

Summary of Measures used for Atkio-Prevesa Tunnel

- Stone columns;
- Gravel base course;
- Grout mattress under tunnel elements;
- Stronger shear keys at joints; and
- Prestressing cables across joints.
Tagus Immersed Tube Tunnels

Additional geotechnical, hydraulic, topographical and hydrographical data required to:

- Design the side slopes of the tunnel trench;
- Design the tunnel and its foundation to resist seismic forces;
- Design portal configurations;
- Select dry dock for element manufacture; and
- Establish reliable prediction of tunnel cost.
Immersed Tube Tunnels

Initial comments based on available data:

- Based on available geotechnical data seismic loading is unlikely to be problematic provided the supporting materials placed around and above the tunnel are not susceptible to liquefaction – to be supported by additional study and additional site investigations;
- It is likely that trench side slopes will need to be formed at 1:3 or more for stability;
- The environmental impact of dredging, including mitigation measures and dumping location for dredged material will need to be established; and
- Ventilation aspects should be carefully considered if both highway and rail are to be included in the same tunnel.
Immersed Tube Tunnels

Initial comments on ventilation:

- The Chelas-Barreiro and Beato-Montijo crossings exceed 5km in length, whereas the Algés-Trafaria crossing is about 2km long, resulting in differing ventilation requirements;
- If the longer crossings were used for rail crossings only, with ventilation ducts, it is likely that ventilation towers would not be needed.
- If the same tunnels were used for both road and rail traffic, it is likely that ventilation towers would be needed; alternatively, tunnel-bridge options could be considered; and
- The Algés-Trafaria alignment is suitable for road traffic because the gradients would not comply with road requirements; alternatively, longer approach tunnels could be constructed for a road and rail tunnel option.
Initial comments based on available data:

- Design and construction of immersed tube tunnels appears feasible;
- It is envisaged that the tunnel(s) would be at shallow depth, protected by rockfill, similar to Aktion-Prevesa tunnel (to minimize cost);
- Dual mode road and rail tunnels appear feasible at each crossing;
- Separate road and rail tunnels may be appropriate depending on future traffic predictions and ventilation requirements etc.; and
- Tunnel-bridge options may be feasible for the longer crossings.
**Concluding Remarks**

- Immersed tube tunnelling appears feasible for all three crossings;
- Additional studies are required to confirm feasibility and establish reliable cost estimates;
- This additional study is recommended because the total cost of immersed tube tunnels or tunnel-bridge is unlikely to exceed the cost of the equivalent bridge alternative;
- It is considered that the overall adverse impacts due to an immersed tunnel may be significantly less than those of the bridge equivalent.
Tagus Immersed Tube Tunnels

Algés-Trafaria

Chelas-Barreiro

Beato-Montijo