Challenges to Tunnel Design
A Case History of the Bolu Tunnel

Johann Brandl
Major Tunnelling Projects along the Turkish Motorway Network

Bolu Tunnel

Alignment of Bolu Mountain Crossing
Bolu Tunnel

Elmalik Portal View
Bolu Tunnel

Theoretical Regular Cross-Section
Bolu Tunnel

Typical Excavation Sequence for NATM
Bolu Tunnel

Geological Condition Elmalik (1997)

MAX. EXPECTED SETTLEMENT 250 mm

clayey fault gauge
flyshoid sequence
metacrystalline basement

station 300 200 100

ROOF SETTLEMENTS
Bolu Tunnel

Settlements and Reexcavation at Elmalik Portal
Bolu Tunnel

Slip Mechanism of Fault
Bolu Tunnel

Principle of Reexcavation
Support Classes Option 3 and Option 4

Bolu Tunnel

OPTION 3

SHOTCRETE LINING, \( d = 40 \text{ cm} \)
INTERMEDIARY CONCRETE LINING
\( d = 60 \text{ cm} \)
CONCRETE INNER LINING
\( d = 60 \text{ cm} \)

OPTION 4

SHOTCRETE LINING, \( d = 30 \text{ cm} \)
INTERMEDIARY CONCRETE LINING
\( d = 80 \text{ cm} \)
INNER CONCRETE LINING
\( d = 60 \text{ cm} \)
<table>
<thead>
<tr>
<th>Date</th>
<th>Earthquake</th>
<th>Distance</th>
<th>Magnitude</th>
<th>Accelerations</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 1999</td>
<td>Kocaeli Quake</td>
<td>150 km</td>
<td>7.4</td>
<td>0.2 – 0.3 g</td>
<td>No damage to tunnels and viaducts</td>
</tr>
<tr>
<td>November 1999</td>
<td>Düzce Quake</td>
<td>20 km</td>
<td>7.1</td>
<td>0.6 – 0.8 g</td>
<td>Severe damages to tunnels and viaducts</td>
</tr>
</tbody>
</table>
Bolu Tunnel

Seismic Record of Düzce Quake 1999
Bolu Tunnel

Damages due to Düzce Earthquake

Sinkhole above Tunnel

Damage to Pilot Tunnel
Bolu Tunnel

Realignment after Earthquake on Nov. 12, 1999

Initial Portal ASARSUYU

Final Portal ASARSUYU

Excavation Face on 12.11.1999

Start of Collapse

Inner Lining installed

Initial Portal ELMALIK

Final Portal ELMALIK

ISTANBUL

ANKARA

REALIGNMENT
Bolu Tunnel

Alignment of Bolu Mountain Crossing
Bolu Tunnel

Seismic Joints in Inner Concrete Lining
Bolu Tunnel

Seismic Joints at Concrete Invert
Opening of the Bolu Tunnel to Traffic in December 2006