The Heathrow Tunnel Collapse

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The Heathrow Tunnel Collapse

Ground conditions

New Austrian Tunnelling Method (NATM)

The UK - NATM or SCL?

The Heathrow Tunnel Collapse

• Ground conditions
• NATM
• The collapse at Heathrow CTA
  – Location
  – Events
• Investigation findings
• Lessons

Ground Conditions

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Layer Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>123.8</td>
<td>Existing ground level</td>
</tr>
<tr>
<td>117.5</td>
<td>Made ground and Taplow Terrace Gravel</td>
</tr>
<tr>
<td>112.5</td>
<td>Top of London Clay formation</td>
</tr>
<tr>
<td>103.0</td>
<td>Compensation grouting zone</td>
</tr>
<tr>
<td>94.0</td>
<td>Crown of Concourse Tunnel</td>
</tr>
<tr>
<td>50.0</td>
<td>Approximate top of Woolwich and Reading Beds</td>
</tr>
</tbody>
</table>

The UK - NATM or SCL?

• Used for “primary lining” - temporary works
• Design of “secondary” lining ignores presence of primary lining
• Both linings are fully designed before construction
• Process is not “design as you go”
• Very small permissible convergence under buildings
• Used in conjunction with compensation grouting
• Monitoring is to confirm adequacy of design, and inform compensation grouting
HSE preliminary review

– Major collapses had occurred worldwide (including Munich, just 1 month before)
– Open faces, a feature of NATM, are hazardous
– The Heathrow Trial had demonstrated that NATM could be built safely in this type of ground
– Once completed, NATM tunnels are as safe as any others

The Collapse at Heathrow CTA

The Collapse

• Occurred during the night of 20-21 October 1994
• Cost of recovery £150 million
• 6 months delay to project, and disruption to Jubilee Line Extension (London Underground)
• No loss of life, but successful HSE prosecution
• Fines - £1.2m + £0.5m, and legal costs of £0.2m.

Surface settlements
Investigation Findings

Investigation findings (1)

• Contractual arrangements and culture
  – Lack of awareness of risks
  – Self-certification of quality following competitive tender
  – Separation of permanent and temporary (NATM) works design
  – Separation of compensation grouting and tunnelling monitoring processes

Temporary and Permanent Works

“Temporary” works (250mm shotcrete) contractor designed

“Permanent” works (cast concrete) consultant designed

Monitoring systems

Ground level monitoring for compensation grouting

Tunnel monitoring for design check
Investigation findings (2)

- **Design**
  - Lack of appreciation of differences between hard rock and soft clay behaviour
  - Design not considered sufficiently robust
  - Joint buildability poor
  - flattened invert made construction tolerances more critical
  - Profile difficult to check because no lattice girders
  - Monitoring regime unsatisfactory
  - Ground conditions as expected

**Method of tunnel construction**

**Tunnel cross section - joint details & flat invert**

**Concourse tunnel eye before collapse**

**Concourse tunnel eye after collapse**
<table>
<thead>
<tr>
<th>Target</th>
<th>Vertical displacement (mm)</th>
<th>Transverse displacement (mm)</th>
<th>Longitudinal displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-8.4</td>
<td>0</td>
<td>2.8</td>
</tr>
<tr>
<td>3</td>
<td>-9.8</td>
<td>-4.4</td>
<td>-0.8</td>
</tr>
<tr>
<td>1</td>
<td>-9.5</td>
<td>4.6</td>
<td>-0.5</td>
</tr>
<tr>
<td>5</td>
<td>-1.5</td>
<td>-0.8</td>
<td>-0.2</td>
</tr>
<tr>
<td>4</td>
<td>-2.4</td>
<td>1.8</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Inferred shell movements and typical displacements at optical targets Heathrow T4

Investigation findings (3)

- Construction quality
  - Failure to produce correct wall profiles
  - Defective invert construction (rebound)
  - Defective joint construction (poor design detail)
  - Over-flat invert

Investigation findings (4)

- Construction management
  - Insufficient specialist staffing
  - Poor communication between different companies
  - Poor sequence of tunnel construction
  - Bad timing of invert repairs
  - No integration in planning construction activities
  - Compensation grouting over tunnel
  - Lack of awareness of instrumentation data warning of impending failure
Simultaneous tunnel construction

Simultaneous construction of two platform tunnels plus invert repairs

Invert repairs

Simultaneous construction of two platform tunnels plus invert repairs

Simultaneous construction of two platform tunnels plus invert repairs

Settlements over the T4 concourse and downline platform

Effect of compensation grouting

Downward movement of Concourse Tunnel crown

Grouting under Camborne House
5-19 August 1994

Downward movement of tunnel crown (mm)

Lessons

Lessons

- NATM can give excellent results (e.g. at Terminal 4)
- In general, failures are likely to arise from multiple causes
- Design - needs to consider ease of construction
- CDM
- Monitoring - should be continuous, auto-processed, and web-available
- Supervision - must be informed of design objectives
- Need for integration and communication of the team