Advanced Course on
Risk Management in Civil Engineering
LNEC Lisbon
November 17-22 2008

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

The Heathrow Tunnel Collapse

Prof. Chris Clayton

University of Southampton

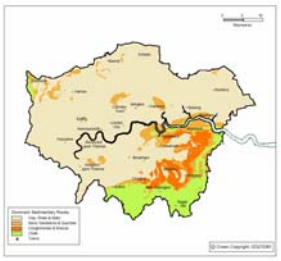
The Heathrow Tunnel Collapse

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

Ground conditions

Ground Conditions

123.8m	Existing ground level
	Made ground and Taplow Terrace Gravel
117.5m	Top of London Clay formation
112.5m	Compensation grouting zone
103.0m	Crown of Concourse Tunnel
94.0m	Invert of Concourse Tunnel
50.0m	Approximate top of Woolwich and Reading Beds



New Austrian Tunnelling Method (NATM)

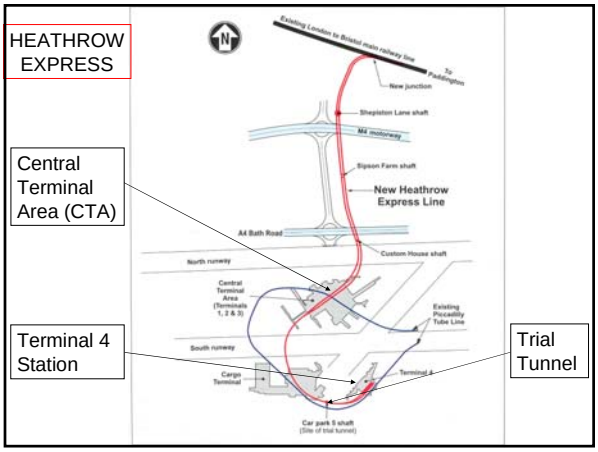
The UK - NATM or SCL?

- 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

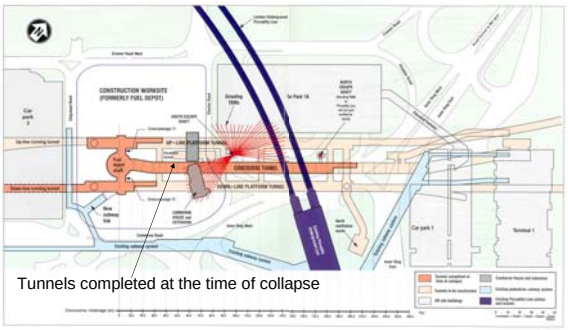
HSE preliminary review

- 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



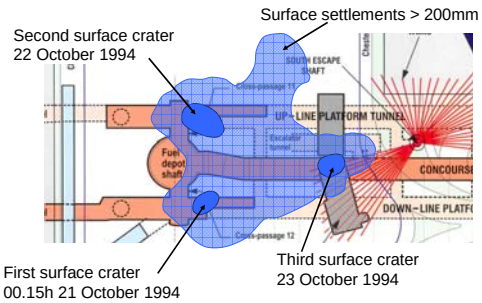
Plan of the CTA station



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.

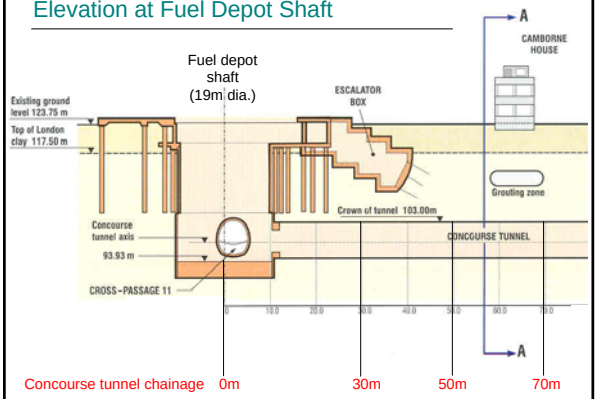
Surface settlements



Central Terminal Area after collapse

Fuel depot Shaft looking NE from Terminal 3 Car Park

Elevation at Fuel Depot Shaft

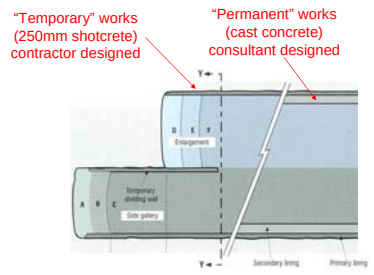


Investigation Findings

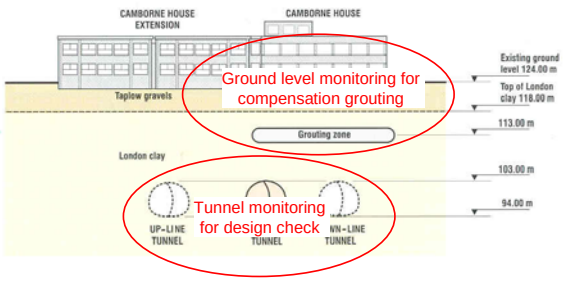
Investigation findings (1)

- 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

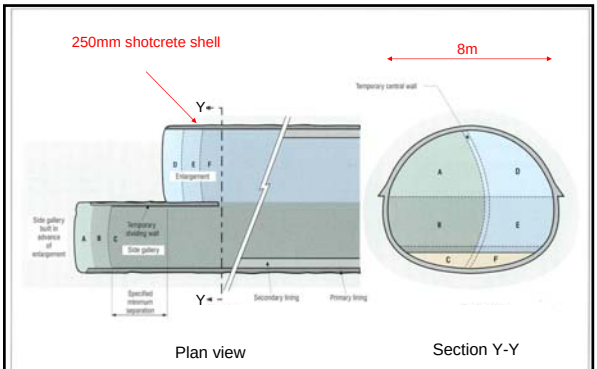


Monitoring systems



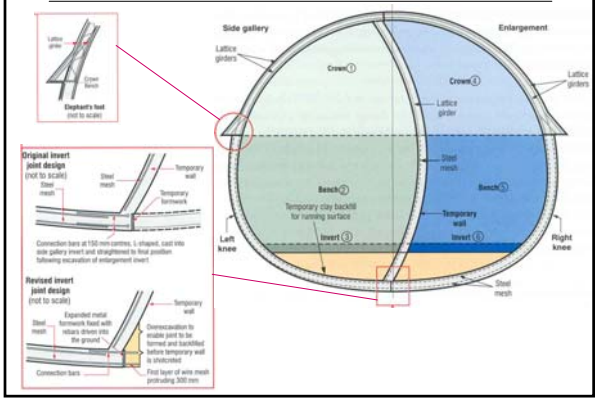
Investigation findings (2)

- 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



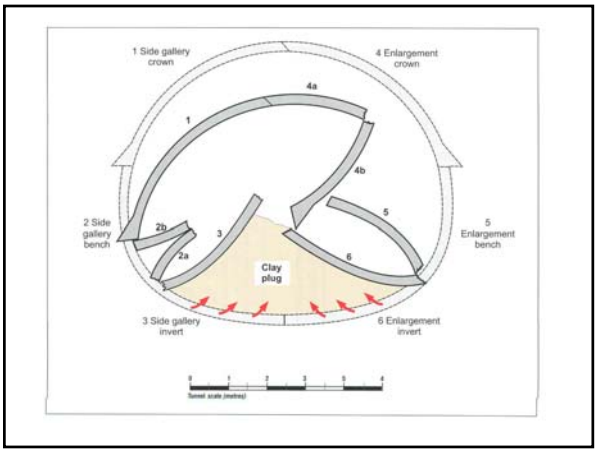
Method of tunnel construction

Tunnel cross section - joint details & flat invert

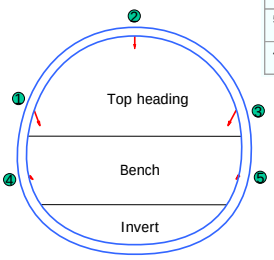


Concourse tunnel eye before collapse

Concourse tunnel eye after collapse

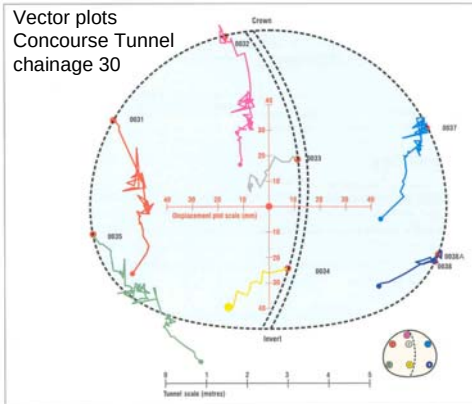


Target	Vertical displacement (mm)	Transverse displacement (mm)	Longitudinal displacement (mm)
2	-8.4	0	2.8
3	-9.8	-4.8	-0.6
1	-9.5	4.6	-0.5
5	-1.5	-0.8	-0.2
4	-2.4	1.8	-0.5

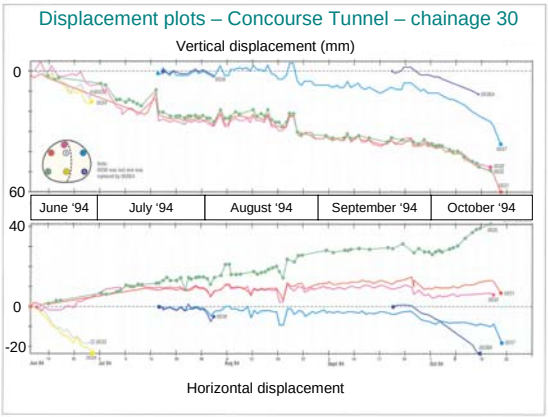


Inferred shell movements and typical displacements at optical targets Heathrow T4

Vector plots
Concourse Tunnel
chainage 30



Displacement plots – Concourse Tunnel – chainage 30



Investigation findings (3)

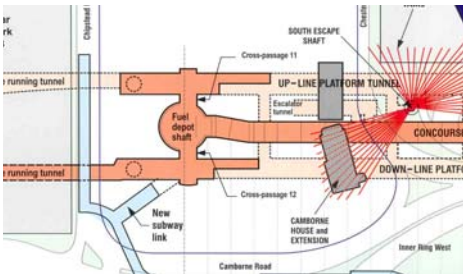
- Construction quality
  - Failure to produce correct wall profiles
  - Defective invert construction (rebound)
  - Defective joint construction (poor design detail)
  - Over-flat invert

Exhumed sections of invert and joint

Investigation findings (4)

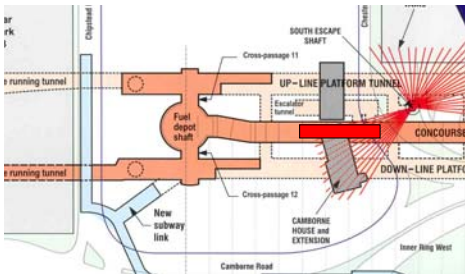
- Construction management
  - Insufficient specialist staffing
  - Poor communication between different companies
  - Poor sequence of tunnel construction
  - Bad timing of invert repairs
  - No integration in planning construction activities
  - Compensation grouting over tunnel
  - Lack of awareness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

Simultaneous tunnel construction

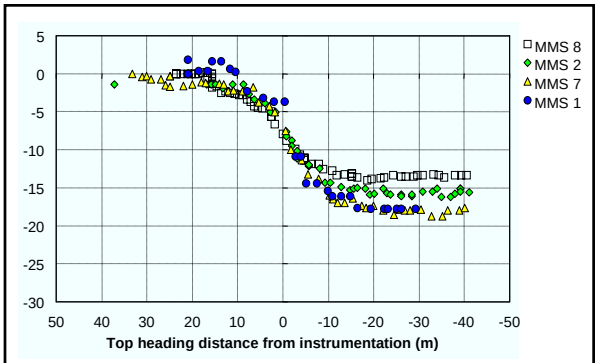


Simultaneous construction of two platform tunnels plus invert repairs

Invert repairs

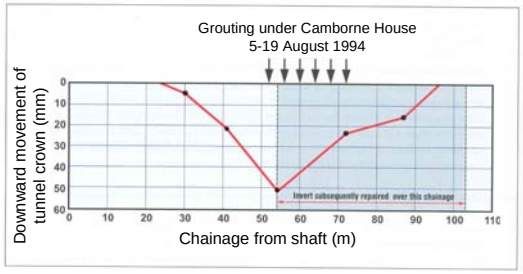


Simultaneous construction of two platform tunnels plus invert repairs



Settlements over the T4 concourse and downline platform

Effect of compensation grouting
Downward movement of Concourse Tunnel crown

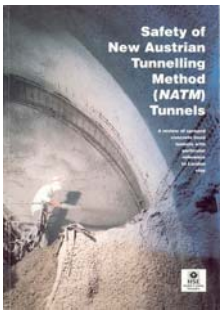


Lessons

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

ISBN 0-7176-1068-3



ISBN 0-7176-1792-0