Overview

- Construction of Tunnels in Hong Kong
- Hong Kong Tunnel Failures
- Forensic Investigations – Overseas Experience
- Risk Management
- Recent, Current & Proposed Projects
- Summary

Construction of Tunnels

Hong Kong Tunnels

- Water Supply Tunnels: 49%
- Drainage and Sewage Tunnels: 13%
- Road Tunnels: 7%
- KCRC Tunnels: 5%
- MTRC Tunnels: 11%
- Cable and Other Tunnels: 15%
General Categories

* Hard rock tunnels
  - deep tunnels above sea level, predominately in rock and generally within undeveloped areas e.g. Lion Rock Tunnels
  - deep sub-sea tunnels in rock e.g. HATS Stage I drainage tunnels

* Soft/mixed ground tunnels
  - shallow tunnels (<25m below ground), generally below the water table and generally within urban areas e.g. MTRC tunnels

Failure Cases

Tunnel Failures – Hong Kong Cases
Failures affecting third parties
  - MTR Modified Initial System, 12 Sep 1977
  - MTR Island Line, 22 Hennessy Road, 1 Jan 1983
  - MTR Island Line, Shing On Street, Shau Kei Wan, 23 July 1983
  - MTR Island Line, 140-168 Shau Kei Wan Road, 16 Dec 1983
  - HATS Stage I, 1995 - 2003

MTR Modified Initial System, Prince Edward Station, 12 Sep 1977
  - Location: 745 Nathan Road

MTR Contracts 101 & 107 – J.S. Kim Group, FJC Lilley Ltd and Gammon (HK) Ltd
MTR Modified Initial System, Prince Edward Station, 12 Sep 1977

- **Background**
  - A running tunnel (5m dia, 22 metres bgl) being constructed from a station tunnel (with larger diameter), ground above strengthened

- **The failure**
  - Soil (300m³) flowed into the tunnel, opening a crown hole below Nathan Road

- **Possible causes of failure**
  - Gap existed between the ground treatment above the station tunnel and that above the running tunnel allowing the soil to flow into the tunnel
  - Unexpected ground conditions
  - Inadequate interface arrangement between contracts?

- **Consequences**
  - 100 people evacuated from three buildings
  - Nathan Road closed
  - Major disruption to traffic

MTR Island Line, 22 Hennessy Road, 1 Jan 1983

- **Background**
  - Westbound tunnel (6.7m dia, 26 m bgl) formed by the drill and blast method

- **The Failure**
  - Water-bearing “fill” flowed into the tunnel, opening a hole at the road above
1500m$^3$ of material flowed into the tunnel creating a void 100m$^2$ by 30m deep beneath the road surface.

- **Possible causes of failure**
  - Misinterpretation of the ground condition
  - Blasting went too far, resulting in the tunnel penetrating the rock into soft ground

- **Consequences**
  - Cracks found in the granite masonry of the outside wall of a building at 22 Hennessy Road
  - At least 21 timber piles beneath an adjacent building of 22 Hennessy Road exposed
  - More than 150 people in 18-22 Hennessy Road evacuated
  - The building at 18-20 Hennessy Road reopened 3 hours after the incident and the building at 22 Hennessy Road 6 days later

- **Remedial measures**
  - The void was backfilled by grout
  - The floor slab of the building at 22 Hennessy Road pushed up by the grouting works by 50-75mm
HATS Stage I Project

- Engineer Design Contractor Build project
- Construction commenced in early 1995
- During construction, serious problems – high rates of water inflow into sections of tunnels
- Significant ground settlement in many areas – up to 1.8 km from the tunnels
- Major public concern due to the extent and magnitude of the impacts
- Major increase in cost and contract completion delayed (4.5 years)
- SETW/DDS reported to PAC on 23 June 2004 (extra $2.3B cf original sum of $6.2B) and presented a Review Report to the LegCo Panel on PLW on 29 June 2004
HATS Stage I Project – Tunnel C

Significant ground settlement

Forensic Investigations

Heathrow Express Tunnel, UK, 21 Oct 1994

Safety of New Austrian Tunnelling Method (NATM) Tunnels

1996 report

2000 report

Heathrow Express Tunnel, UK, 21 Oct 1994

- Lessons Learnt
  - Measures to ensure safety must be planned
  - Do not lose sight of critical technical issues in the pursuit of time and cost reduction
  - Whilst a number of factors contributed to the collapse, half of them were matters of management
  - However much engineers are pressured to build quickly and cheaply, the industry will be judged by its own failures
Nicoll Highway

Tunnel Failures
- Forensic Investigations – Singapore

• Lessons Learnt
  • A need for:
    • robust design, risk management, design review and independent checking,
    • purposeful back analysis,
    • an effective instrumentation, monitoring and interpretation regime,
    • an effective system of management of uncertainties and quality during construction, corporate competencies and safety management.
  • The safety of temporary works is as important as that of permanent works and should be designed according to established codes and checked by competent persons.

Risk Management

• ABI Code of Practice (2003)
  • “Compliance with the Code all it applies to construction projects involving tunnel works should minimise the risk of physical loss damage and associated delays.”

  • “The guidelines provide owners and Consultants with what is modern-day industrial practice for risk assessment, and describes the stage of risk management throughout the entire project implementation from concept to start of operation”.

• ITIG Code of Practice (2005)
Developments in ETWB Policy on Risk Management and Government Tunnel Works

- ETWB TC(W) No. 15/2005 on Geotechnical Control for Tunnel Works (29.9.2005)

TGN 25 - Geotechnical Risk Management

- Examples of Geotechnical Hazards
  - Variable rockhead and mixed ground conditions
  - Presence of buried obstructions (e.g. corestones, boulders, disused piles, old seawalls and other artifacts)
  - Presence of foundations and other subsurface installations
  - Presence of permeable zones that may be subject to high groundwater pressure or that may convey large quantities of inflow
  - Presence of weak or compressible ground (e.g. weak/fractured zones, faults, fissures, clay-coated discontinuities, granular soils and soft/compressible soils). Ground under very high or very low in situ stress
  - Presence of explosive or poisonous gas (e.g. methane) or other aggressive chemicals
  - Contaminated ground, e.g. due to ingress of leachate from landfills

- Risk Treatment Options
  - Avoid/reduce the risk, e.g. by selecting a suitable tunnel alignment based on adequate site investigation
  - Reduce the risk, e.g. by specifying or selecting appropriate tunnelling methods with adequate additional site investigation during construction
  - Treat the risk, e.g. by specifying appropriate ground support (e.g. precast segmental lining with back grouting), ground strengthening, groundwater control and containment measures, and implementing preventive or protective works

TGN 25 - Geotechnical Risk Management

- Examples of Construction Method-related Risks
  - All methods that create pressure in the ground, e.g. compressed air or slurry TBM and grouting
    - Blow out or ground heave for tunnelling under high compressed air or slurry or grouting pressure, resulting in dangerous occurrence
  - All methods that use vibratory equipment, or that could induce ground vibration such as drill and blast
    - Excessive ground vibration, causing damage to adjacent facilities
  - All methods
    - Excessive ground settlement/lateral displacement due to groundwater inflow/drawdown caused by inadequate tunnel construction method (e.g. pre-grouting not carried out in difficult ground), or inadequate ground treatment or groundwater control or inadequate consideration of changes in ground stresses or groundwater regime, resulting in adverse impacts on life or property

Geotechnical Control - Risk Management Deliverables
Recent, Current & Proposed Projects

Summary

- “Tunnelling is a form of engineering construction, carried out in an uncertain and often hostile environment, and relying on the application of special knowledge and resources” (CIRIA, 1978)
- Many tunnels have been built successfully, but many tunnel failures with serious consequences have also occurred, worldwide, over recent years
- There has been development of geotechnical risk management internationally and locally
- “Unexpected” geotechnical problems have served as catalyst for change, but we have to learn from our mistakes
- We have many challenging tunnel works projects ahead!
Three Pacific Place MTRC Subway

The Way Forward

"Fifty years ago, tunnelling was dominated by empirical methods in design, by traditional craft practices in construction. Today, design and construction of tunnels are based on a set of specialised technologies, with the success of each project dependent on their synthesis, on continuity between design and construction, and on appropriate means of project procurement. The art of tunnelling does not lend itself to inflexible rules or prescriptive codes of practice; engineering judgement remains the key factor."

Obituary for Colin Kirkland. The Times, January 24 2005