# Tunnel Failures
# Hong Kong Case Histories

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## Overview

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

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# Construction of Tunnels

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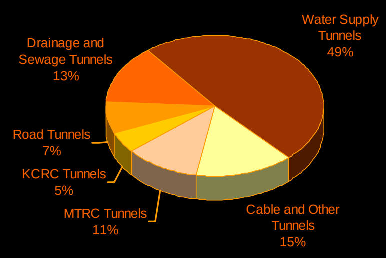
## Hong Kong Tunnels

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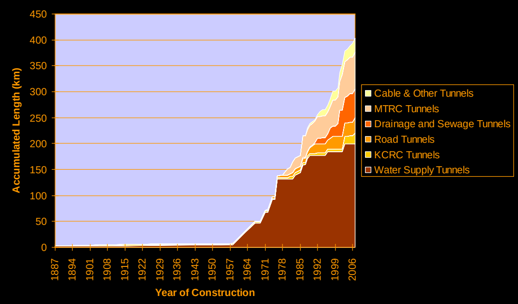
## Tunnel Construction




## Lion Rock Tunnel 1966

## High Island Reservoir 1972

## MTR Modified Initial Scheme 1977

## General Categories

- **Hard rock tunnels**
  - deep tunnels above sea level, predominately in rock and generally within less developed 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

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# Failure Cases

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## 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

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## MTR Modified Initial System, Prince Edward Station, 12 Sep 1977

- **Location: 745 Nathan Road**

MTR Contracts 101 & 107 – JL Kier Group, FJC Lilley Ltd and Gammon (HK) Ltd

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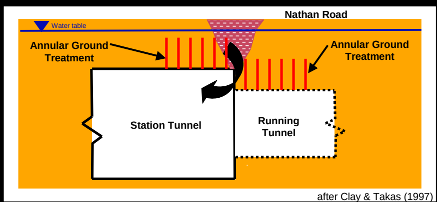
## MTR Modified Initial System, Prince Edward Station, 12 Sep 1977

- **Background**
  - A running tunnel (5m dia, 22 metres bgl) being constructed from a station tunnel (with larger diameter), ground above strengthened
- **The failure**
  - Soil ($300 m^3$) flowed into the tunnel, opening a crown hole below Nathan Road

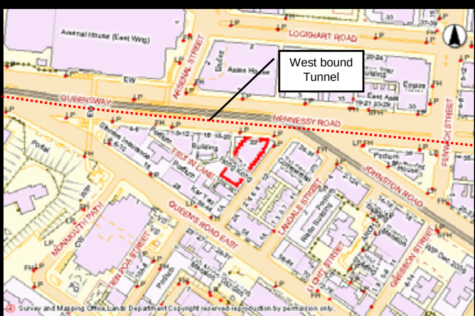



after Clay & Takas (1997)

## MTR Modified Initial System, Prince Edward Station, 12 Sep 1977

- **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

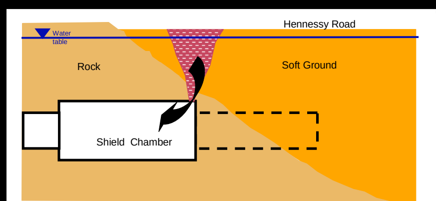
## MTR Island Line, 22 Hennessy Road, 1 Jan 1983




MTR Contracts 404 – Maeda Construction Co. Ltd

## MTR Island Line

- **Background**
  - Westbound tunnel (5.7m 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




after Clay & Takas (1997)

## MTR Island Line

- $1500m^3$ of material flowed into the tunnel creating a void $100m^2$ by 30m deep beneath the road surface

Tunnel Alignments_bw2.JPG

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## MTR Island Line

- **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

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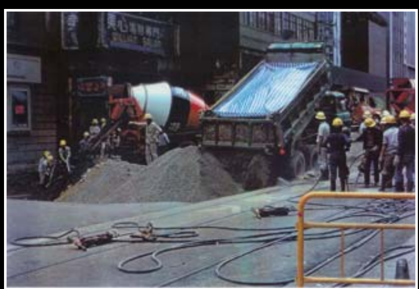
## MTR Island Line

- **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



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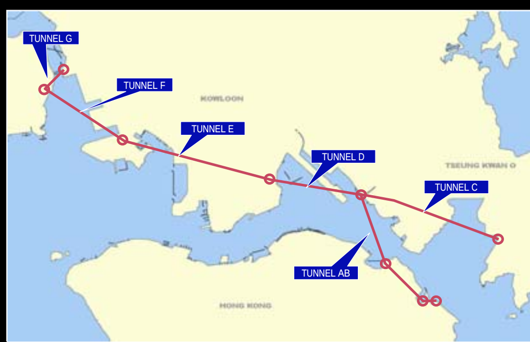
## HATS Stage I Project

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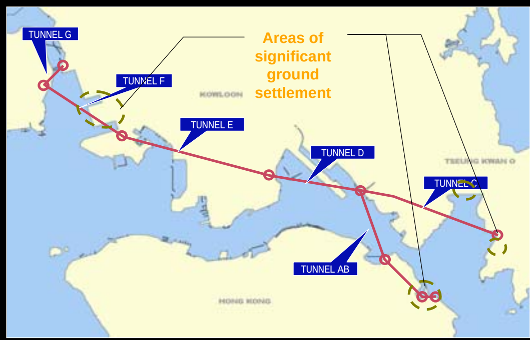
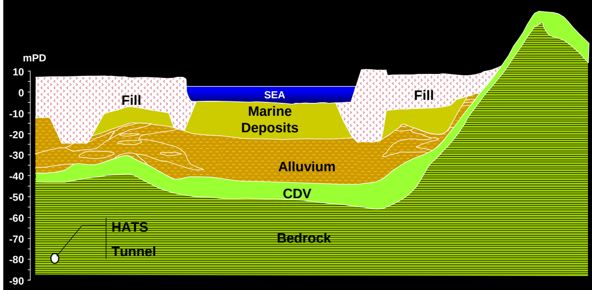
## HATS Stage I Project

- 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

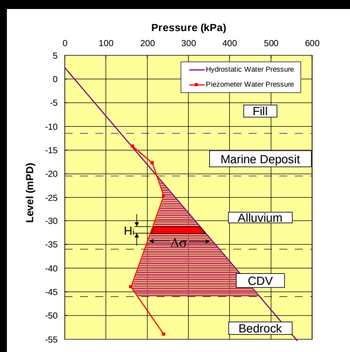
## HATS Stage I Project




## HATS Stage I Project – Tunnel C




## HATS Stage I Project – Tunnel C

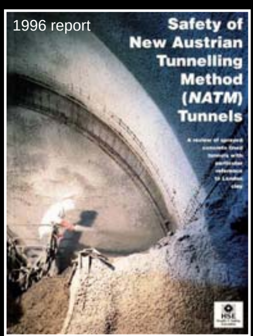


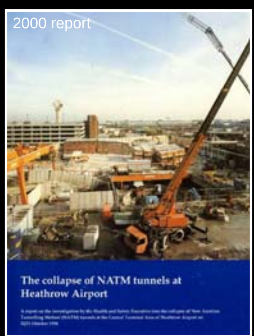
## HATS Stage I Project – Tunnel C

**Significant ground settlement**

## Forensic Investigations

## Heathrow Express Tunnel, UK, 21 Oct 1994

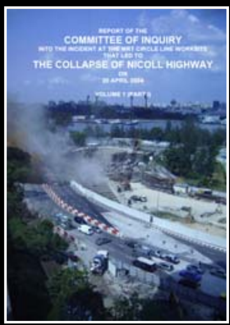



## Heathrow Express Tunnel, UK, 21 Oct 1994

- **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

## Risk Management

- **ABI Code of Practice (2003)**
  - *"Compliance with the Code at it applies to construction projects involving tunnel works should minimise the risk of physical loss damage and associated delays."*
- **ITA Guidelines (2004)**
  - *"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. 17/2004 on Impossibility/Unforeseen Ground Conditions/Utility Interference (1.6.2004)
- ETWB TC(W) No. 6/2005 on Systematic Risk Management (21.6.2005)
- ETWB TC(W) No. 15/2005 on Geotechnical Control for Tunnel Works (29.9.2005)

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## TGN 25 - Geotechnical Risk Management
### - Examples of Geotechnical Hazards

| Examples of Geotechnical Hazards | Risk Treatment Options |
|---|---|
| Variable rockhead and mixed ground conditions | Avoid/reduce the risk, e.g. by selecting a suitable tunnel alignment based on adequate site investigation |
| Presence of buried obstructions (e.g. corestones, boulders, disused piles, old seawalls and other artifacts) | |
| Presence of foundations and other subsurface installations | Reduce the risk, e.g. by specifying or selecting appropriate tunnelling method(s) with adequate additional site investigation during construction |
| 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 insitu stress | Treat the risk, e.g. by specifying appropriate ground support (e.g. precast segmental linings with back grouting), ground strengthening, groundwater control and containment measures, and implementing preventive or protective works |
| Presence of explosive or poisonous gas (e.g. methane) or other aggressive chemicals | |
| Salinity of groundwater | |
| Contaminated ground, e.g. due to ingress of leachate from landfill | |

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## TGN 25 - Geotechnical Risk Management
### - Examples of Construction Method-related Risks

| Construction Method-related Risks | Associated Tunnelling Method |
|---|---|
| Excessive ground settlement/lateral displacement due to ground loss (including rock falls within the tunnel and tunnel face collapse) caused by unsuitable tunnel construction method/equipment/control measures, resulting in adverse impacts on life or property | 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 | All methods |
| Excessive ground vibration, causing damage to adjacent facilities | All methods that use vibratory equipment, or that could induce ground vibration such as drill and blast |
| Ejection of rock and protective material (e.g. blast door) at the tunnel portal or areas with a thin ground cover, due to explosion and/or gas pressures, causing dangerous occurrence | Drill and blast |
| Blow out or ground heave for tunnelling under high compressed air or slurry or grouting pressure, resulting in dangerous occurrence | All methods that create pressure in the ground, e.g. compressed air or slurry TBM and grouting |

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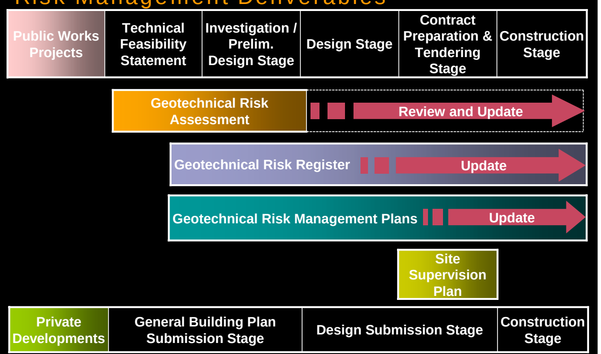
## Geotechnical Control
### - Risk Management Deliverables

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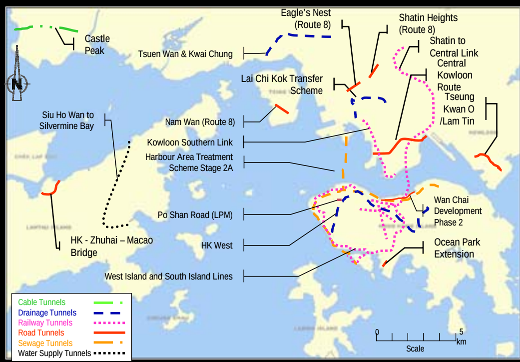
# Recent, Current & Proposed Projects

## Recent, Current and 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!

## Munich Underground, Germany, Sep 1994

## 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**

## Selected References:


**MTRC Tunnels**

- Clay, R.B. & Takacs, A.P. (1997). Anticipating the unexpected - Flood, fire overbreak, inrush, collapse. Proceedings of the International Conference on Tunnelling under Difficult Ground and Rock Mass Conditions, Basal, Switzerland, pp 223-242.
- GEO file GCI 3/6/50.
- SCMP (1977). South China Morning Post. 13 Sept. 1977, Hong Kong.
- SCMP (1983). South China Morning Post. 2 Jan. 1983, Hong Kong.

**HATS STAGE I**

- Director of Audit (2004). Harbour Area Treatment Scheme Stage I. Report No. 42 of the Director of Audit, Chapter 3, 31 March 2004, Audit Commission, Hong Kong, 68 p.
- Kwong, A. K. L. (2005). Drawdown and settlement measured at 1.5 km away from the SSDS Stage I Tunnel C (A perspective from hydro-geological modelling). Proceedings of the K. Y. Lo Symposium, London, Ontario, Canada, Session D, pp 1-24.
- LegCo (2004). Harbour Area Treatment Scheme Stage I. Public Accounts Committee (PAC) Report - 23 June 2004, Chapter 3, Legislative Council, HKSAR, 28 p.

**Heathrow Express Tunnel, UK, 21 Oct 1994**

- Ground Engineering (2000). *Catalogue of disaster.* August Issue, pp 10-11.
- HSE (1996). Safety of New Austrian Tunnelling Method (NATM) Tunnels. Health & Safety Executive, UK, 86p.
- HSE (2000). The Collapse of NATM Tunnels at Heathrow Airport. Health & Safety Executive, UK, 116p.
- ICE (1998). HSE signs up QC Carlisle for HEX prosecution. New Civil Engineer, Institution of Civil Engineers, March Issue, pp 4-5.
- ICE(1999). Heathrow Express court cases kicks off. New Civil Engineer, Institution of Civil Engineers, January Issue, p 6.

**Nicholl Highway Collapse**

- Government of Singapore (2005). Report of the Committee of Inquiry into the Incident at the MRT Circle Line Worksite That Led to the Collapse of Nicoll Highway on 20 April 2004. Government of Singapore, Land Transport Authority. <http://www.lta.gov.sg/home/index_home_nicoll.htm> (31 Jan. 2007).

**Risk Management**

- CIRIA (1978). The control of risk through improved contract procedures. CIIRIA Report 79, UK.
- ITIG (2005). A Code of Practice for Risk Management of Tunnel Works. The International Tunnelling Insurance Group (in Association with the Munich Re Group), 37 p.
- HSE (2006). The risk to third parties from bored tunnelling in soft ground. Research Report 453, Health & Safety Executive, UK. pp. 67.


## Selected References:


**HK Geotechnical Standards, Guidance, Procedures & Resources**

- GEO (2005). GEO Technical Guidance Note No. 25. Geotechnical Risk Management for Tunnel Works. Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong. <http://www.cedd.gov.hk/eng/publications/index.htm> (5 February 2007).
- GEO (2006). GEO Information Note 3/2006. Disused Tunnels. Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 2 p.
- GEO (2007a). Engineering Geological Practice in Hong Kong. GEO Publication No. 1/2006. Geotechnical Engineering Office, Civil Engineering and Development Department. Hong Kong. (In press).
- GEO (2007c). Bibliography on the Geology and Geotechnical Engineering of Hong Kong (Interactive Online). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong. <http://www.cedd.gov.hk/eng/publications/index.htm> (5 February 2007).
- GEO (2007d). Catalogue of Notable Tunnel Failure Case Histories. Special Project Report SPR 1/2007. Mainland East Division, Geotechnical Engineering Office, Civil Engineering Development Department, Hong Kong.