

Tunneling Risks

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Tunneling risks
Summary

1 A Historical perspective

2 Review of Tunnelling methods

3 Review of Tunnelling risks

4 Tunneling underwriting

5 Underwriting information

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1. A historical perspective

A historical perspective
Preindustrial revolution

- Predecessors of modern tunnels were adits that transported water for irrigation, drinking, or sewerage
- First tunnel to be excavated from both ends is the Siloam Tunnel in Jerusalem around the 8th century BC
- First recorded use of gunpowder as a construction tool was for the Canal du Midi in France between 1666 and 1681 connecting the Atlantic Ocean to the Mediterranean Sea



Channel of the Qanats of Ghasabeh in Iran's Razavi Khorasan Province



Siloam Tunnel, Jerusalem



Malpas Tunnel carrying the Canal du Midi

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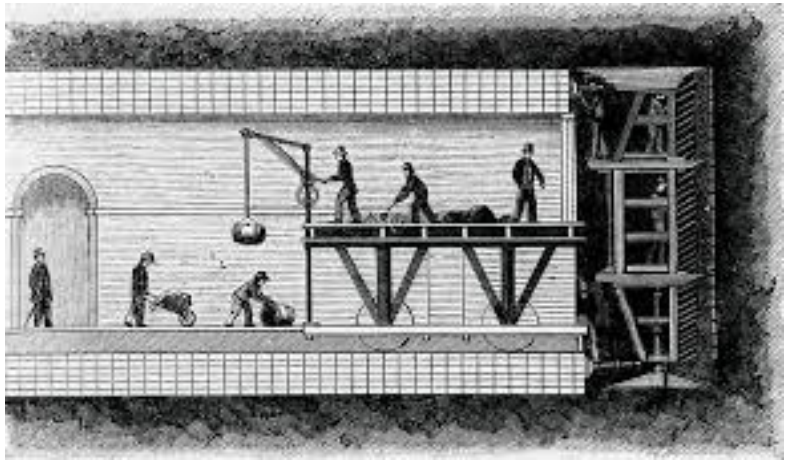
A historical perspective
Industrial revolution

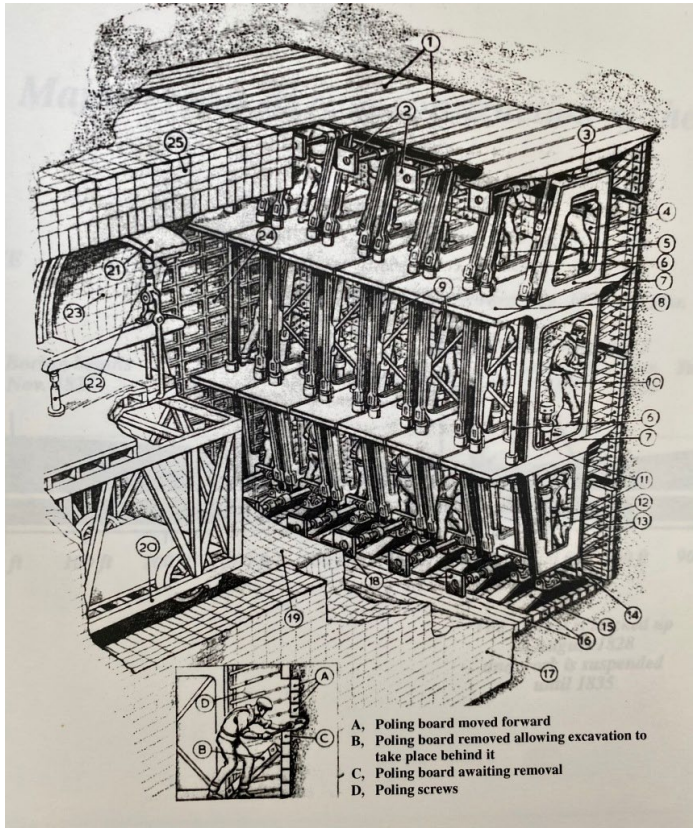
- First tunnel underneath a navigable waterway was a tunnel under the River Thames in London
- First use of a *shield*, technology developed by **Marc Brunel**
- Key function of *Brunel's shield* was to support the face and provide safety for the miners
- Construction of the 400m/1200ft long brick-lined pedestrian tunnel started in 1825 and finally opened in 1842 with major inundations claiming 6 lives



Brunel's shield used for first Thames Tunnel (2D)



Marc Brunel, 1812/1813



Brunel's shield used for first Thames Tunnel (3D)



Thames Tunnel, 1995

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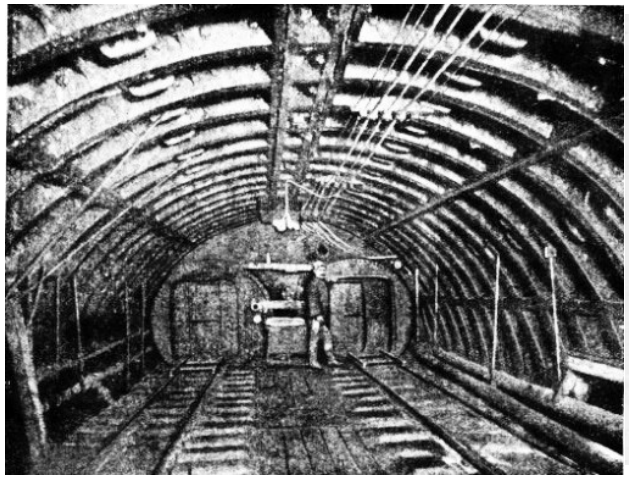
A historical perspective
Mid 19th century to Mid 20th century

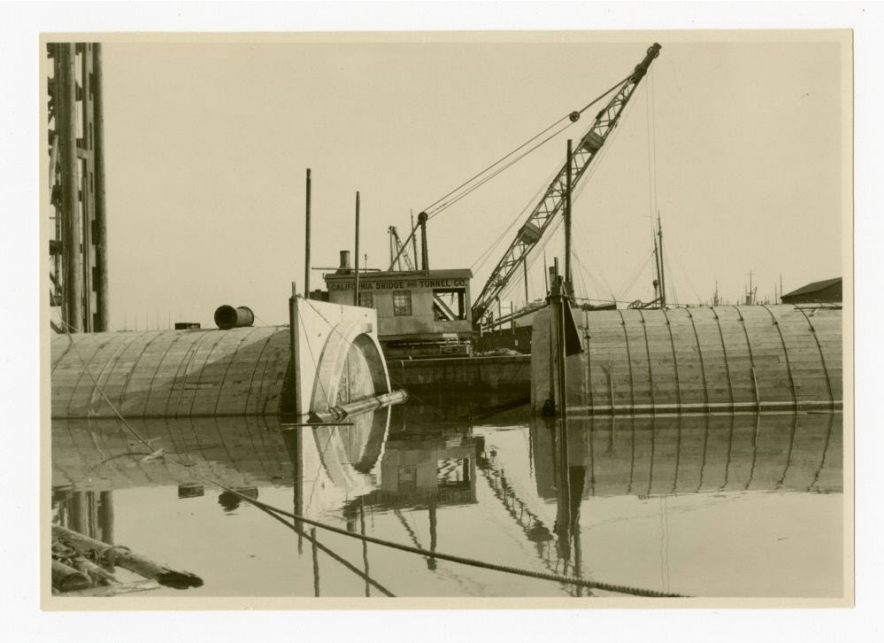
- A patent for working in compressed air had been taken out in 1830 by Lord Cochrane in the United Kingdom
- Compressed air was first used without a shield as a means of face support during the Hudson river tunnel in New York but a blowout caused 20 fatalities
- The first use of a combination of shield and compressed air was on the City and South London Railway completed in 1890 (now part of the Northern line)
- First immersed tunnel was the Posey Tunnel in California, opened in 1928



Twin air-lock, Hudson river tunnel



Greathead shield including compressed air arrangement



Construction of Posey Tunnel, California

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A historical perspective
Post mid 20th century – Modern tunnelling

- Since the modest beginnings, there has been an explosion of tunnelling all over the world
- On a technical level, tunnels can be built anywhere, through any ground
- The sustainability of megacities heavily relies on creating underground spaces
- Global tunnel construction market size estimated at USD 110 billion and expected to reach USD 208 billion by 2033.



Advances in Tunnelling overcome challenges in urban areas

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2. Review of tunnelling methods

Review of tunnelling methods
Cut-and-Cover tunnels

- The method consists of excavating a trench, building a tunnel within and cover back the trench
- The trench can be built via retained excavation or an open cut
- Straightforward and cost-effective however causes significant surface disturbance
- Typically used for shallow tunnels, up to 30m/100ft deep



High Speed 2, Green tunnels during construction (left); Rendering of completed tunnel (right)



Calgary light rail tunnels built with cut-and-cover method

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Review of tunnelling methods
Tunnel Boring Machines // TBMs

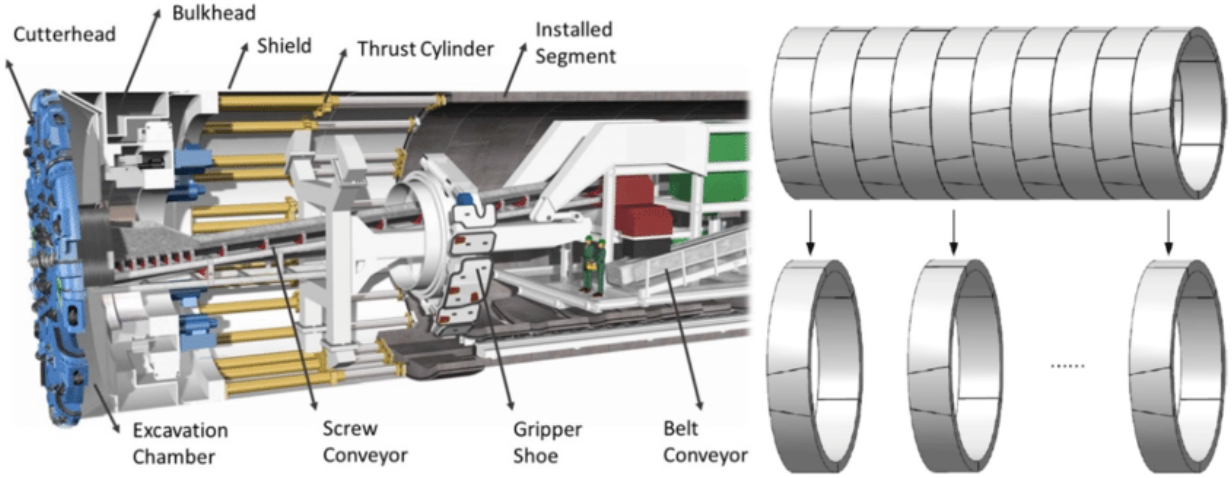
- Large machines used to excavate tunnels through rock or soil
- Closed-face TBMs operate by rotating a cutter head that grinds away material which is transported away on conveyor belts
- Open-face TBMs do not have frontal support, i.e. cutter head
- Typically supported with segmental lining
- Suitable for long tunnel but limited to circular shape, constant diameter and gentle alignment radii of curvature



Example of open-face TBM



Example of closed-face TBM



Details of a closed-face TBM and illustration of segmental lining

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Review of tunnelling methods
Pipe jacking and micro-tunnelling

- Trenchless method of installing pipelines, culverts, and other utilities using powerful hydraulic jacks to push pipes through the ground
- Similar principles to TBMs but thrust is applied from the launch pit and not on the installed lining
- Minimise surface disruption compared to a cut-and-cover solution
- Suitable to all ground conditions

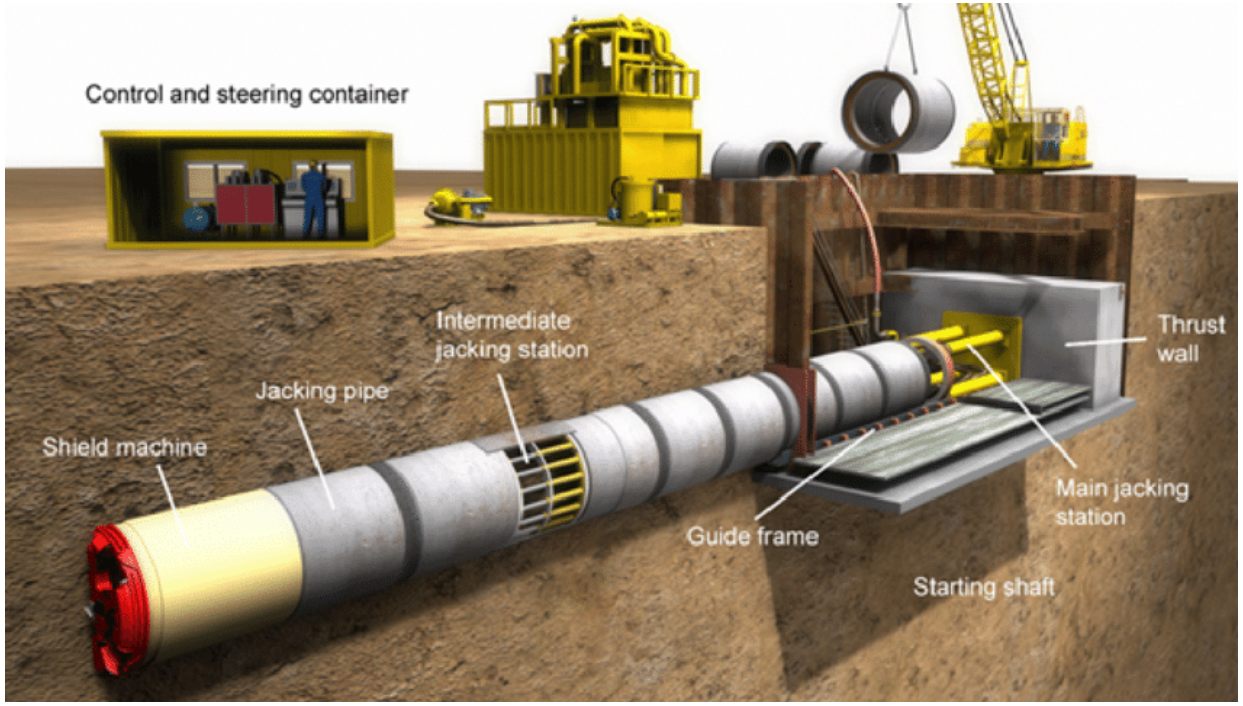

Illustration of pipe jacking method



Illustration of pipe jacking launch pit



Illustration of pipe jacking boring machine

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Review of tunnelling methods
New Austrian Tunnelling Method // NATM

- Incremental tunnel excavation with support elements installed immediately after each excavation cycle
- Suitable in competent, self-standing rock
- Support elements are commonly a combination of shotcrete, wire mesh, rock bolts and steel ribs
- Based on the principles of the observational method
- Flexible tunnel geometry and alignment
- No limit to depth nor size of tunnel

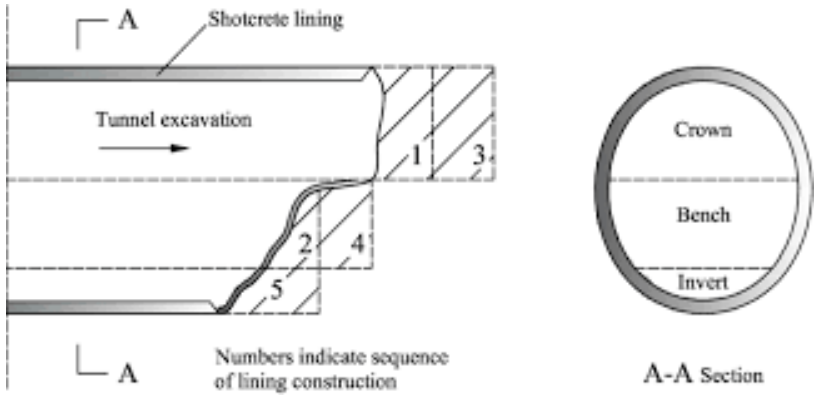
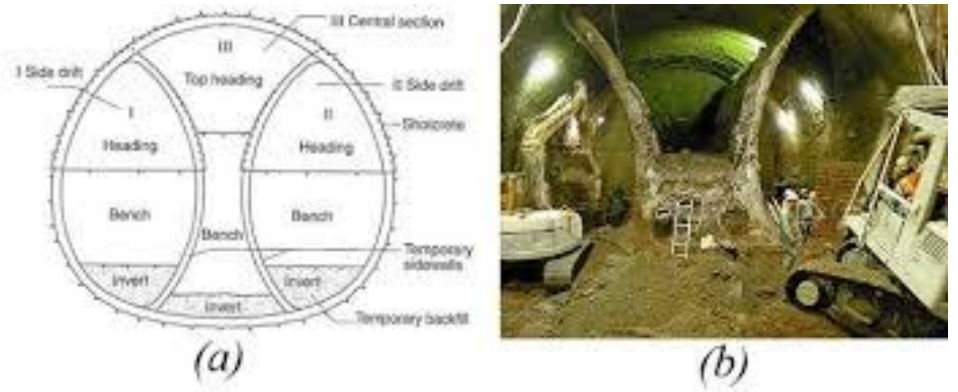


Illustration of sequential excavation with NATM

Illustration of pocket excavation with NATM





Bellevue Tunnel for Sound Transit, Washington, DC

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Review of tunnelling methods
Immersed tube tunnels

- Method comprising of prefabricating tunnel sections on land, floating them to site and submerging them into a pre-dredged trench on the seabed
- Sections are then connected to form a watertight continuous tunnel before the trench is backfilled
- Suited for crossings in relatively shallow water, i.e. <30m/100ft
- Not suitable if seabed is made of soft soil although ground improvement could mitigate this limitation



Pre-fabricated tunnel sections being floated, from Fehmern



Illustration of tunnel section immersion, from Fehmern

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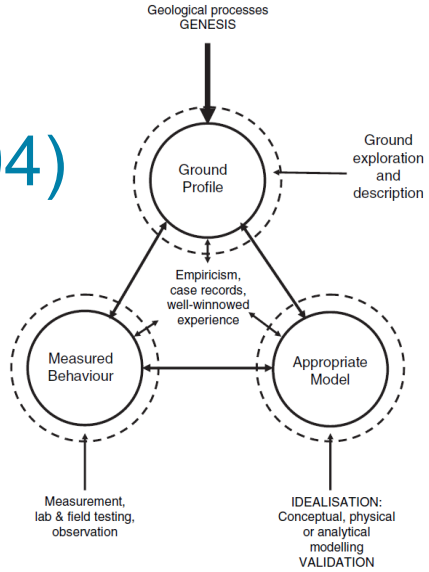
3. Review of tunnelling risks

Review of tunnelling risks

Tunnel collapse – Nicoll Highway collapse (2004)

- A tunnel collapse is a geotechnical collapse
- A comprehensive **site investigation**, adequate **design** and robust **instrumentation and monitoring** regime together with **experience** are indispensable to prevent a tunnel collapse
- The cut-and-cover tunnel collapse was a result of erroneous geotechnical analysis that led to **inadequate bracing connection design** together with a **disregard of monitoring of wall movements** breaching *Alarm* levels



The geotechnical triangle (Burland, 1987)



Inadequate strut to waler design, Nicholl Highway collapse



Image showing the aftermath of the Nicholl Highway collapse, 2004

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Review of tunnelling risks

Ground water ingress – Red line North, Doha metro TBM flood (2015)

- Ground water if not removed or prevented from face ingress can cause a tunnel flooding potentially damaging the lining, CPEs within including a TBM
- The flooding happened when the TBM hit a **pocket of water** whilst working in open mode during pilot tunnelling. The **gate to close off water ingress** and material could not be moved into place **quickly enough**
- **Probing** and **pre-excavation grouting** would have prevented such loss



Damaged TBM, Red line North Doha metro



Illustration of a flooded TBM (Not Doha metro)

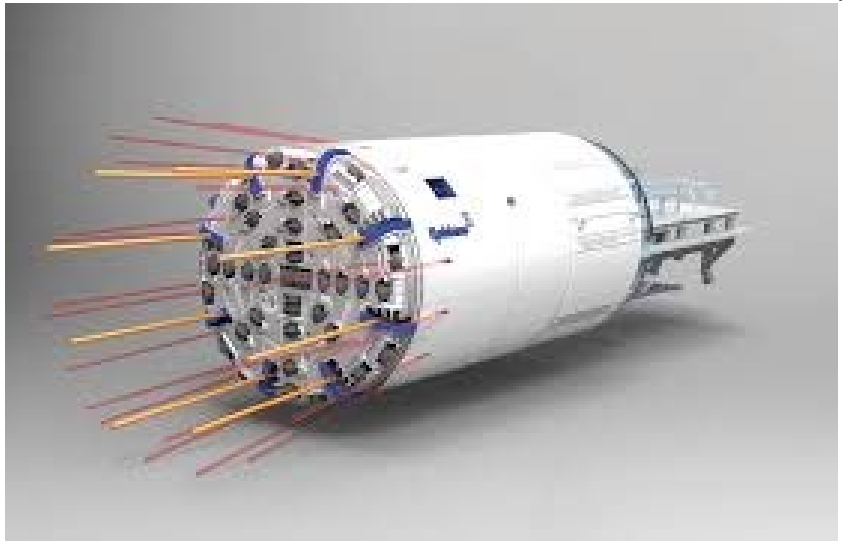

Illustration of probing and pre-excavation grouting equipment mounted on a TBM, from Robbins

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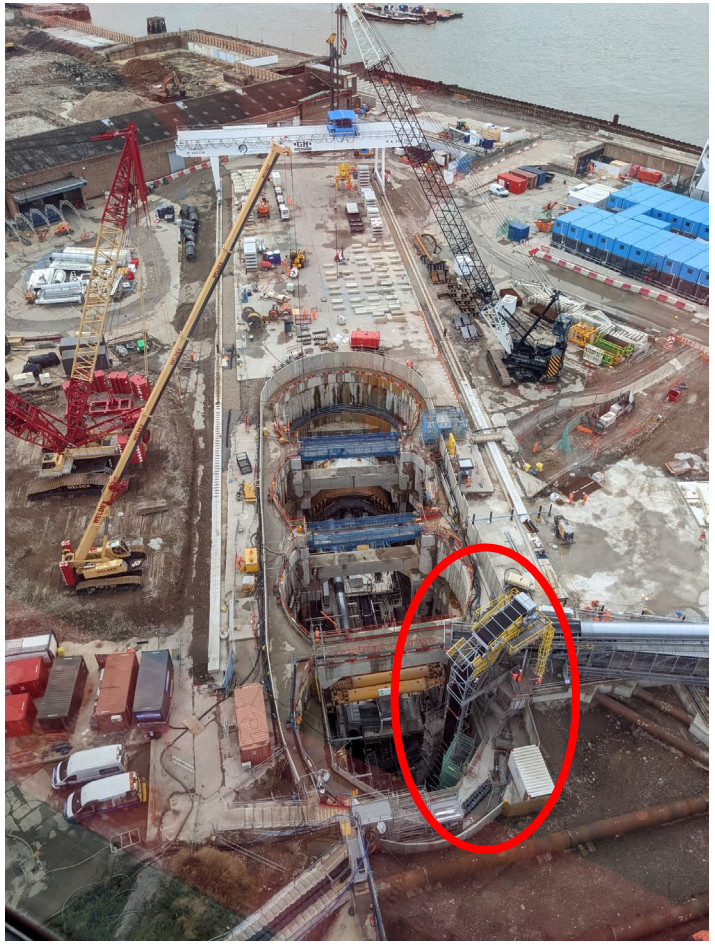
Review of tunnelling risks

Fire – Silvertown tunnel fire (2022)

- A fire often starts because of uncontrolled **smoking** or **hot works**
- The Silvertown tunnel fire was caused by hot works induced **smouldering fire** that spread over nearly **5h** to reach a very **combustible** material
- The fire damaged the TBM conveyor belt which was not operating at the time of the fire and there was no casualty
- High-risk hot works, e.g. near combustible materials, should be followed by **2h continuous watch with a thermal camera**



Silvertown TBM launch shaft, conveyor belt that burnt circled in red



Image from the Silvertown fire, 2022

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Review of tunnelling risks
Flood – XRL Hong Kong (2014)

- Underground works have significant potential for flood water ingress and damage due to the likely pooling effect of water finding its way to the lowest level and points of the site
- Black rainstorm in 2014 in Hong Kong led to partially flood an XRL bored tunnel in which the TBM was located and suffered substantial damage
- **Upstands** at shafts provide a simple and efficient flood protection during construction together with a robust **emergency flood preparedness plan**



XRL flooded bored tunnel – observed flood line



Example of 'upstand' at a shaft which provides flood protection during construction

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Review of tunnelling risks

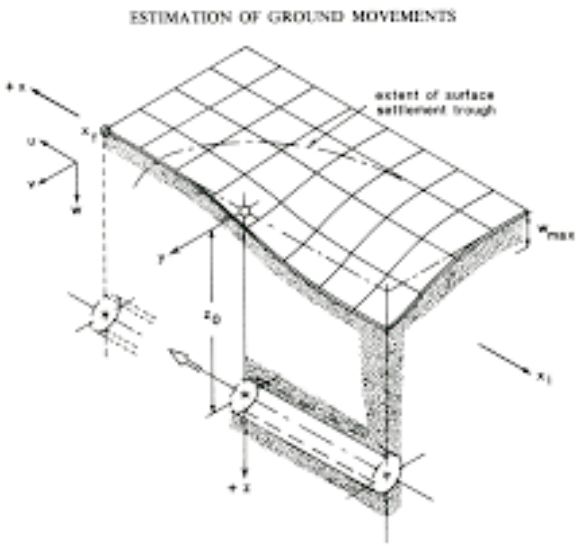
Ground movements and impact on existing or third-party assets

Daegu subway gas utility explosion (1995)

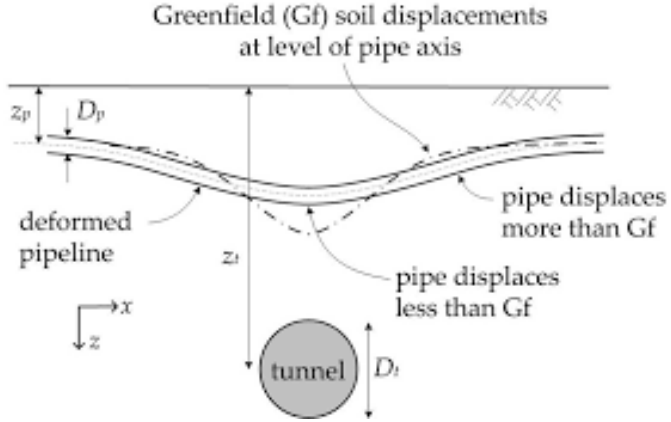
- Tunnelling can cause significant ground movements which in turn can damage structures and utilities
- The 1995 Daegu **gas utility explosion** was caused by **tunnelling induced ground movements** and killed 101 including 42 school students and injured 202
- **Ground movement assessment** by the **designer** helps identify **assets at risks** and provide **protection measures**, e.g. underpinning for buildings or utilities



Aftermath of the Daegu gas explosion, 1995



Estimation of tunnelling induced ground movements



Theoretical ground and utility deflections induced by tunnelling

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Review of tunnelling risks
Heathrow Express collapse (1994)

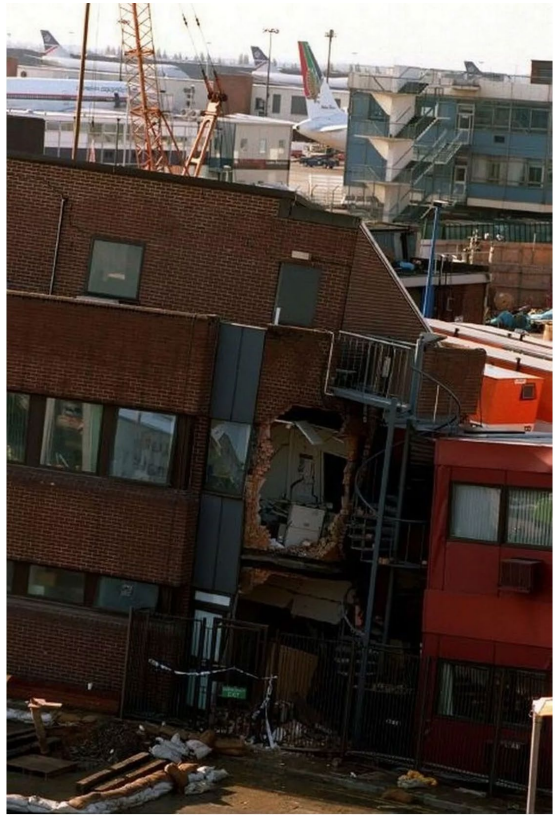
- Three tunnels collapsed due to **substandard construction**, **inadequate repairs** and the **construction of a parallel tunnel in failing ground**
- Tunnels were quickly filled with foamed concrete
- 60m diameter and 30m deep shaft around the collapsed area was built to conduct repairs and continue construction
- **Insurance loss of £140m**, more than double the **ECV of ~£60m**



Sinkhole formed between two runways



Recovery built to enable repairs and continue construction



Damaged airport building



Image of one of the collapsed tunnel

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4. Tunnelling underwriting

Insurance for Tunnelling Project

History – around 2000s

Heathrow Express Tunnel Collapse

One of the biggest tunnel insurance loss
~USD 140m insurance settlement (in 1994 currency)

Essentially - Disproportionate Cost of Reinstatement

- Project ECV circa £60m + DSU
- Collapse in Central Terminal Area
- Cost of reinstatement circa £100m
- Greater than the ECV!!
- This cause insurers significant problems as they had not foreseen this size of loss.





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Insurance for Tunnelling Project

History – around 2000s

And many other Tunnel Incidents around the Globe

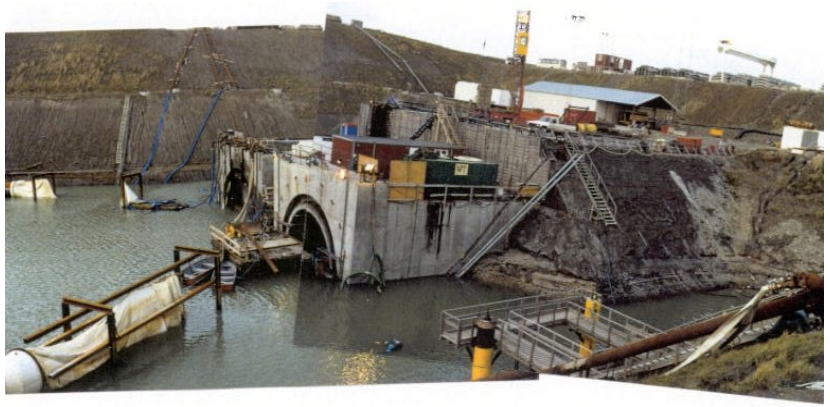

Plate 2 Portal area during dewatering (5th November 1991)







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Insurance for Tunnelling Project

History – around 2000s

Year	Project	Location	Cause	Insurance Loss
1994	Great Belt Link	Denmark	Fire	USD 33m
1994	Munich Metro	Germany	Collapse	USD 4m
1994	Heathrow Express	UK	Collapse	USD 141m
1995	Taipei Metro	Taiwan	Collapse	USD 31m
1995	Los Angeles Metro	USA	Collapse	USD 9m
1999	Hull Sewage Tunnel	UK	Collapse	USD 55m
1999	TAV Bologna	Italy	Collapse	USD 21m
1999	Bolu Tunnel	Turkey	Earthquake	USD 115m
2000	Taegu Metro	South Korea	Collapse	USD 24m
2002	Taiwan Highspeed Railway	Taiwan	Collapse	USD 30m
2002	SOCATOP Tunnel	France	Fire	USD 8m
2003	Shanghai Metro	China	Collapse	USD 80m
2004	Singapore Metro	Singapore	Collapse	USD 80m

- High frequency and high severity of insurance claims
- Tunnelling insurance had become extremely unprofitable for Insurers
- Some Insurers had questioned the insurability of Tunnel Projects, and hence withdrawing from insuring
- Very difficult for Owners / Contractors to procure an insurance cover. Even when they did, the insurance coverage is very limited with very high premium
- The World Trade Centre tragedy made things even the situation even worse … for Insurers and hence their clients



Decision (jointly from the insurers and the tunnel industry) to develop a Code of Practice for Risk Management of Tunnel Works

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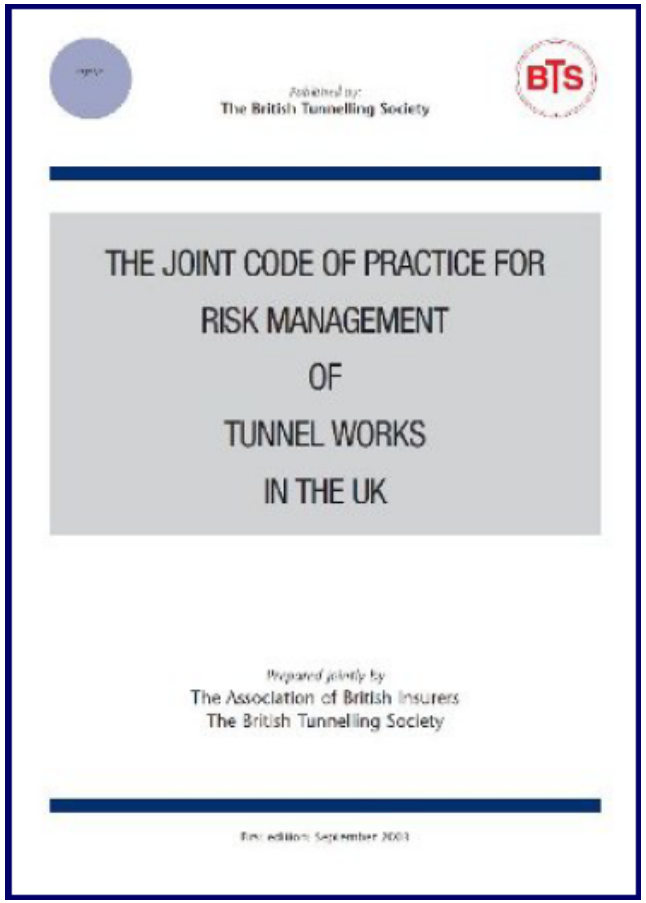
Insurance for Tunnelling Project

The Joint Code of Practice for Risk Management of Tunnel Works



- The JCoP was developed by
  - Association of British Insurers
    - Underwriters
    - Insurance Risk Engineers
  - British Tunnelling Society (BTS) / Institution of Civil Engineers (ICE)
    - Tunnelling Contractors
    - Designers & Consultants
    - Health & Safety Executive (HSE)

- Published in 2003 and often being referred as the UK Code

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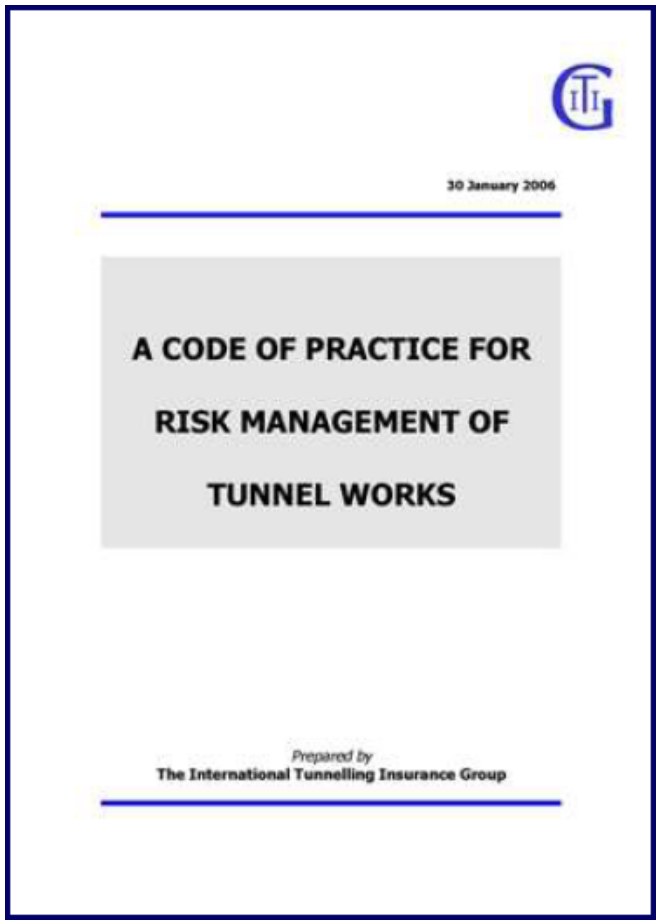
Insurance for Tunnelling Project

The Code of Practice for Risk Management of Tunnel Works



- International version of The UK Code
  - Prepared by International Tunnelling Insurance Group (ITIG)
  - Supported & endorsed by International Tunnelling Association (ITA)
- Published in 2006 and often being referred as the International Code
- Follows the framework and fundamental principles of the UK Code but refer to Local National Standard and/or Codes of Practice for respective country where the International Code to be used
- 2nd edition of International Code published in 2012, with official acknowledgement from ITA and IMIA (International Assocaiation of Engineering Insurers)

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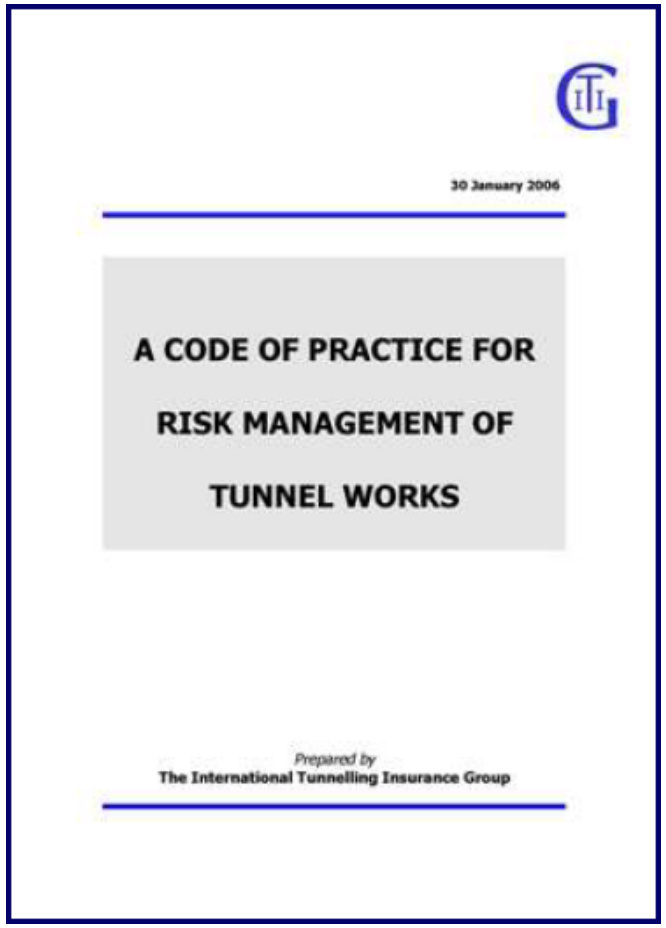
Insurance for Tunnelling Project

The Code of Practice for Risk Management of Tunnel Works



- ITIG reconvened
  - ITIG reconvened in March 2017 with successful uptake of original members from tunnelling and insurance industries
  - General agreement to review the penetration and effectiveness of the Codes around the work

- Scope and Objective of Review – Comprehensive Picture
  - The experience of tunneling projects before and after release of the Code and with / without ‘application’ of the Code
  - Regional variations in the application of the risk management methods
  - Other developments in risk management practices and how they have impacted the environment in which tunnelling projects are delivered

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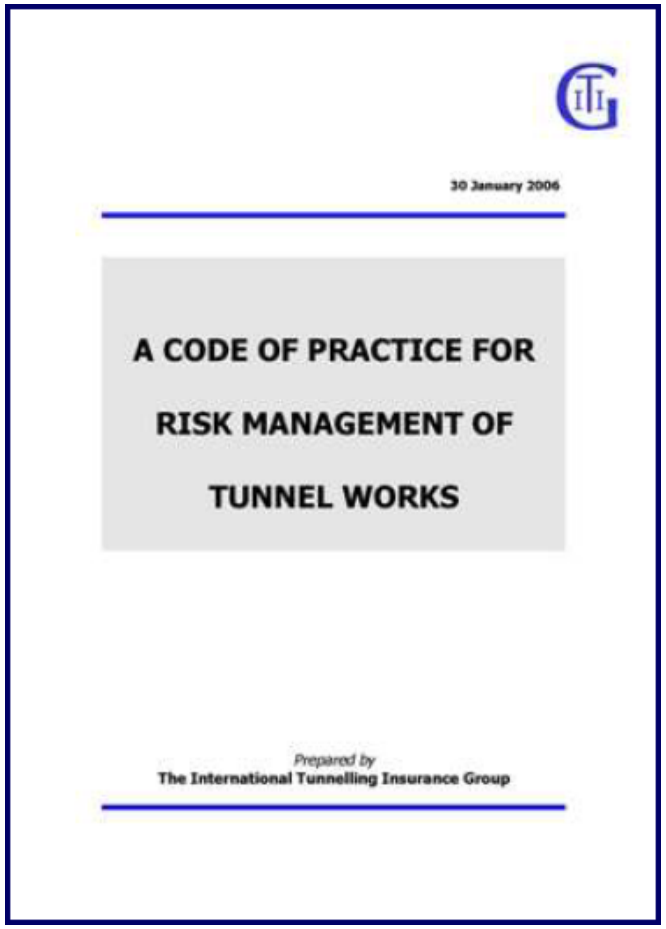
Insurance for Tunnelling Project

The Code of Practice for Risk Management of Tunnel Works



- Preliminary Areas identified for further consideration
  - Review the need to expand certain areas, i.e. Instrumentation and Monitoring, Recognizing the role of digital systems
  - Aligning the Code with other recognized risk standards

3rd edition of the code in final draft and to be published shortly

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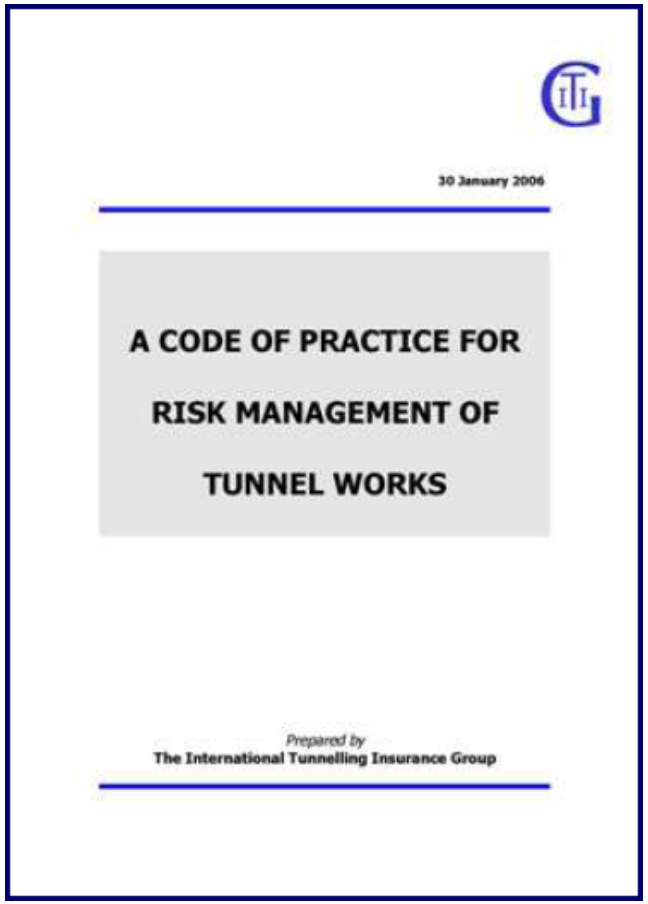
The Code of Practice for Risk Management of Tunnel Works



- To define “best practice” for risk management by setting out a framework of “project management procedures” in terms of design and construction management procedures and including risk management procedures

- The Code is based on a “project stage” basis rather than a task basis with four identified stages
  - The Project Development Stage
  - The Construction Contract Procurement Stage
  - The Design Stage
  - The Construction Stage

- introduces the concepts of risk assessment and risk registers

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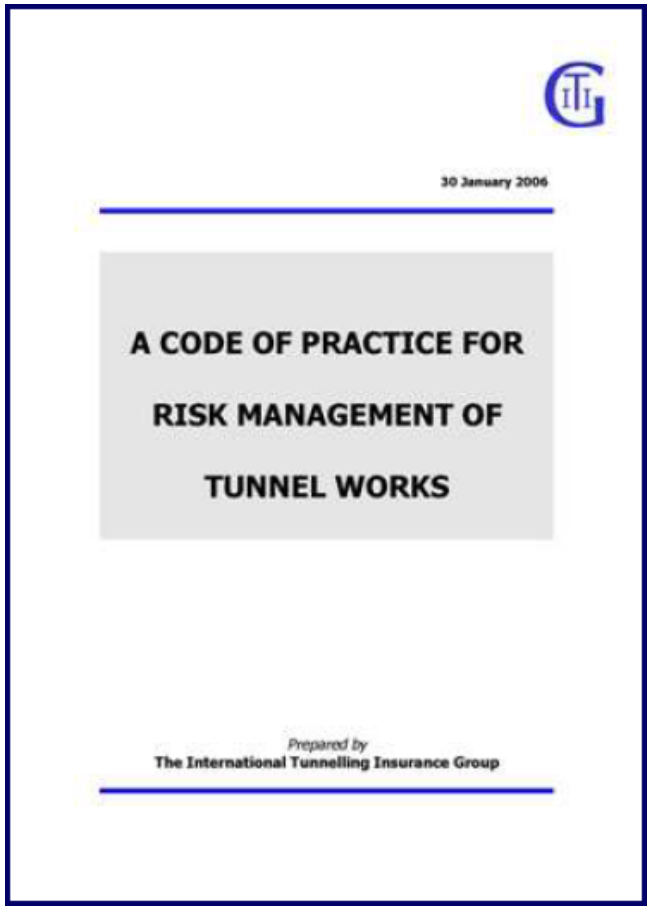
The Code of Practice for Risk Management of Tunnel Works



- **sets out project management procedures and systems for contract procurement, design and construction activities**
- sets out clear responsibility between different parties
- provides guidance on ground investigation and introduce the concept of “Ground reference conditions”
- requires hazard identification during each of the four stages of a project on a project-specific basis, and to be recorded / summarized in risk registers include the identification of the responsible party
- Risks shall be managed to ensure their reduction to a level “as low as reasonably practicable”

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What a Tunnel is ?

Tunnel Definition

A Code of Practice for the Risk Management of Tunnels

Tunnel Works - Tunnels, caverns, shafts and associated underground structures howsoever constructed and including the renovation of existing underground Structures

LEG Tunnel Works Clause

Tunnel Works – tunnels, caverns, shafts and associated underground structures howsoever constructed and including the renovation of existing underground Structures.

This definition shall not apply to non structural elements of the tunnel construction such as cladding, fit-out, monitoring, contracts for electrical and mechanical fit-out, cable installation and building services and the like.

Both definitions are the same

This does not include open cuttings and cut & cover structures

A further clarification has been added for fit out works

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What a Tunnel is ?

Tunnel Definition

Wording Issues to be careful of:

Tunnelling means the construction of artificial subterranean passage and/or subterranean roads used for the movement of pedestrians or vehicular traffic that is open at both ends, and is constructed by boring, drilling, excavating or digging through the earth, but shall not include Horizontal Directional Drilling or work to existing tunnels which do not involve boring, drilling, excavating or digging through the earth. This definition shall not apply to open excavation work (e.g. trenches, cut-and-cover, pits and other similar operations) nor to other works within the confines of the subterranean passage.

Construction means that this definition (and therefore the Tunnelling limit) only applies during the construction of the tunnel or ring. So once this is complete the limit no longer applies.

Open at both ends – what about an adit? Open at both ends – when?

Shaft

Work to existing tunnels

Drill & blast

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Tunneling Clause

Munich Re Tunnel Clause 101

Endorsement 101
Special conditions concerning the construction of tunnels, galleries, temporary or permanent subsurface structures or installations

It is agreed and understood that otherwise subject to the terms, exclusions, provisions and conditions contained in the Policy or endorsed thereon, the Insurers shall not indemnify the Insured in respect of the expenses incurred for

– alterations in the construction method or due to unforeseen ground conditions or obstructions,

– measures which become necessary to improve or stabilize ground conditions or to seal against water ingress unless necessary to reinstate indemnifiable loss or damage,

– removing material which has been excavated, or due to overbreak in excess of the design profile and/or for refilling cavities resulting therefrom,

– dewatering unless necessary to reinstate indemnifiable loss or damage,

– loss or damage due to breakdown of the dewatering system if such loss or damage could have been avoided by use of standby facilities,

– the abandonment or recovery of tunnel-boring machines,

– the loss of bentonite, suspensions, or any media or substance used for excavation support or as a ground-conditioning agent.

In the event of indemnifiable loss or damage the maximum amount payable under this Policy shall be limited to the expenses incurred to reinstate the insured property to a standard or condition technically equivalent to that which existed immediately before the occurrence of loss or damage but not in excess of the percentage as stated below of the original average per-metre construction cost of the immediate damaged area.

Maximum percentage payable: **%**

However feedback from the Market Insurance (including brokers, loss adjusters and underwriters) is that there is a general lack of clarity within this clause (and others incl SwissRe) leading to disputes over the level of cover offered.

These included:

- Clarity of exclusion language and buybacks
- Monetary Limit or Percentage Limit or Hybrids thereof (whichever is the lesser / greater)
- Definition of Tunnel Works
- When the clause applies
- Inclusive of cover extensions or cover extensions in addition
- Practicalities of calculating indemnity
  - Average per metre construction cost
  - Immediate Damaged Area
- Application to shafts

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Tunneling Clause

Example of LEG Tunnelling Clause

LEG London Engineering Group

Unique Market Reference:

LEG Tunnel Works Clause

Exclusions:

It is agreed and understood that otherwise subject to the terms, exclusions, provisions and conditions contained in the Policy or endorsed thereon, the Insurers will not indemnify the Insured in respect of:

a)

i) alterations in the construction method

ii) unforeseen ground conditions or obstructions

iii) improving or stabilising ground conditions or sealing against water ingress

iv) dewatering

unless necessarily and reasonably incurred following indemnifiable physical loss or physical damage.

b) overbreak or over-excavation in excess of the design profile and/or for refilling of cavities resulting therefrom

c) damage due to breakdown of the dewatering system if such damage could have been avoided by the use of standby facilities

d) loss of bentonite, suspensions, or any media or substance used for excavation support or as a ground-conditioning agent

e) the abandonment of sections of Tunnel Works that are not subject to indemnifiable physical loss or damage

f) the abandonment or recovery of Tunnel Boring Machines

Clarity of exclusion language and buybacks

Tunneling Clause

Example of LEG Tunnelling Clause

Limits:

In the event of indemnifiable physical loss or physical damage to Tunnel Works during the Period of Insurance the maximum amount payable under this Section of the Policy in respect of Tunnel Works shall be limited to the expenses incurred to reinstate the insured property but not in excess of the applicable Monetary Limit as specified herein. Where no Monetary Limit is specified then the Percentage Limit shall apply.

The Monetary Limit shall be inclusive of all applicable cover Extensions under this Section of the Policy. The Percentage Limit shall be exclusive of all applicable cover Extensions under this Section of the Policy. In the event that one occurrence affects two or more Tunnel Works Elements, Insurers will pay no more than the highest single Limit that is applicable in the circumstances.



Clarity of exclusion language and buybacks



Monetary Limit or Percentage Limit or Hybrids thereof (whichever is the lesser / greater)



Inclusive of cover extensions or cover extensions in addition

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Tunneling Clause

Example of LEG Tunnelling Clause

Definitions:

Tunnel Works – tunnels, caverns, shafts and associated underground structures howsoever constructed and including the renovation of existing underground structures.

This definition shall not apply to non structural elements of the tunnel construction such as cladding, fit-out, monitoring, contracts for electrical and mechanical fit-out, cable installation and building services and the like.

Period of Insurance – As per the schedule

- Clarity of exclusion language and buybacks
- Monetary Limit or Percentage Limit or Hybrids thereof (whichever is the lesser / greater)
- Inclusive of cover extensions or cover extensions in addition
- Definition of Tunnel Works
- When does the clause apply

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Tunneling Clause

Example of LEG Tunnelling Clause

Percentage Limit - calculated in accordance with the following formula: Immediate Damaged Length x Original Per-Metre Construction Cost x Percentage Multiplier

Percentage Multiplier [ ] % (if no percentage is specified then 100% shall apply).

Immediate Damaged Length – the length of Tunnel Works permanently physically lost or physically damaged. This shall exclude sections of Tunnel Works that are unaffected except for the presence of water or debris. This definition is solely for calculating the Percentage Limit under this Tunnel Works Clause.

- Clarity of exclusion language and buybacks
- Monetary Limit or Percentage Limit or Hybrids thereof (whichever is the lesser / greater)
- Inclusive of cover extensions or cover extensions in addition
- Definition of Tunnel Works
- When does the clause apply
- When Practicalities of calculating indemnity :
  - Average per metre construction cost
  - Immediate Damaged Area

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Other Clauses

- MR 106 Warranty concerning sections.
- MR 114 Serial Losses.
- EPI 46 Ground Water Pumping Operations.
- Section Warranty for Tunnel works: Unlined/unprotected section of tunnel max x meters
- Abandonment of TBMs or Shafts
- MR 102 Underground Cables, Pipes and Other Facilities.
- MR 120 Vibration, Removal or Weakening of support.
- Pumping capacity, high toe wall,…

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5. Underwriting information

Trends and Challenges

- Longer: longer construction period and high severity losses leading to extensive project delay
- More expensive: expensive TBM, increase cost of material, cost overruns are getting common
- More complicated: deeper and bigger tunnels/TBMs in unknown or more complicated geology
- Globalization: many projects with many contractors leading with lack of material and lack of experienced labour
- New Perils: secondary perils such as surface flood are not secondary now
- Reputable risk: workers trapped, fatalities, losses to third parties in urban areas, impact of social medias

Tunnel project trends lead to more sophisticated risk transfer to insurance companies and require long term insurance partners

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Why ?

Heavy civil underground construction projects are very technical and complexe risk leading to substancial losses and therefore requiring a large amount of underwriting information in order to establish that:

- Pricing is accurate and reflects the exposure
- Potential losses have been correctly assessed to define the line size
- All risk exposures have been addressed and all mitigations measures are in placed

Requesting and obtaining the crucial underwriting information is fundamental for a full and good risk assessment

List of SCOR underwriting queries for UG/tunnelling works is provided in attachment

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What ? Pricing

Tunnel Pricing depends on:

- Ground conditions (rock/soil good, medium or bad)
- Water table (below ?)
- Tunnel diameter
- Tunnel methodology (TBM vs NATM vs conventional vs C&C)

C&C Pricing depends on:

- Ground conditions (rock/soil good, medium or bad)
- Water table (below ?)
- Excavation depth

Underground projects TPL Pricing depends on:

- Environnement (urban or standard or remote area)
- Insurance conditions: duration, cross liability

Geotechnical report including geotechnical profile & water table

Project Location

Overall Alignment

Cross section drawings

TBM specification

Construction Methodology

Construction schedule

ECV breakdown by occupancy

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What ? Loss assessment

Earth

- Collapse, Subsidence, Landslide
- Earthquake

Water

- Water Ingress
- Water damage
- Flood

Fire

Others

- Lack of experience in construction and design
- Quality, safety, environmental issues

Different loss scenarios should be considered for MPL and NLE assessment:

Collapse of a tunnel section or a cross passage or a shaft

Subsidence of existing and third parties' properties

Landslide at Portal

Flood and Fire damaging TBMs, tunnel linings, E&M, signaling or at storage areas or at the precast yards

Other AoG (Earthquake)

...

=> Detailed ECV cost breakdown by occupancy (TBM, C&C, CP, NATM, E&M, others), and detailed design should be made available

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What ? Mitigation Measures

Ground conditions

Geotechnical report

Adequate methodology/TBM and supports/lining vs ground conditions

GBR provided during tender stage and part of the contract

Contract form / unforeseen ground conditions risk mechanism and sharing

Additional investigations

Monitoring plan

Existing Properties and third party

Third Parties preconstruction survey

Third Parties monitoring plan

Flood

Project location including precast yards and storage areas

Hydrological report / Flood study

Flood mitigation plan

Stakeholders

Owners, designers & contractors experiences

Third parties' involvement

Risk, quality and HSE management

Construction risk register

Emergency response plan

QA/QC & HSE plans

Environmental impact assessment

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Q&A



Thank You

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