ITA - AITES WORLD TUNNEL CONGRESS 2007 PRAGUE

ITA Training Course 2007
TUNNELLING IN URBAN AREA
Prague, 04-05 May 2007

Specific Conditions and Requirements for Tunnelling in Urban Areas: General and Environmental Aspects

TRAINING MATERIAL PREPARED BY

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ASSOCIATION INTERNATIONALE DES TRAVAUX EN SOUTERRAIN
AITES

ITA
INTERNATIONAL TUNNELLING ASSOCIATION

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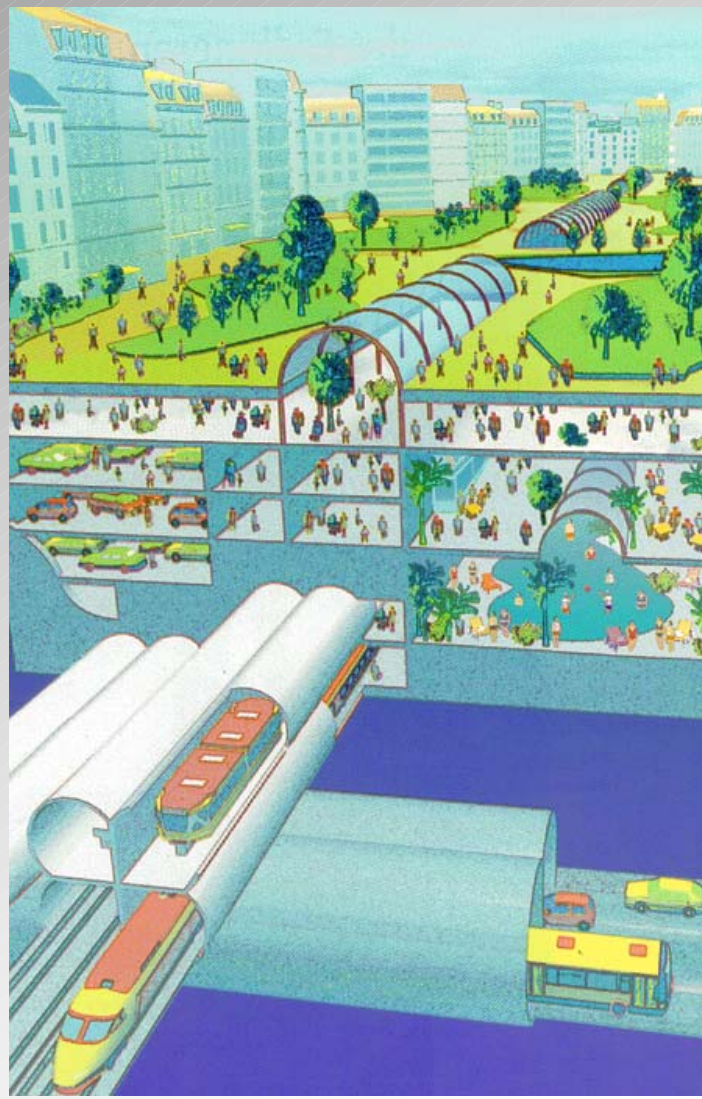
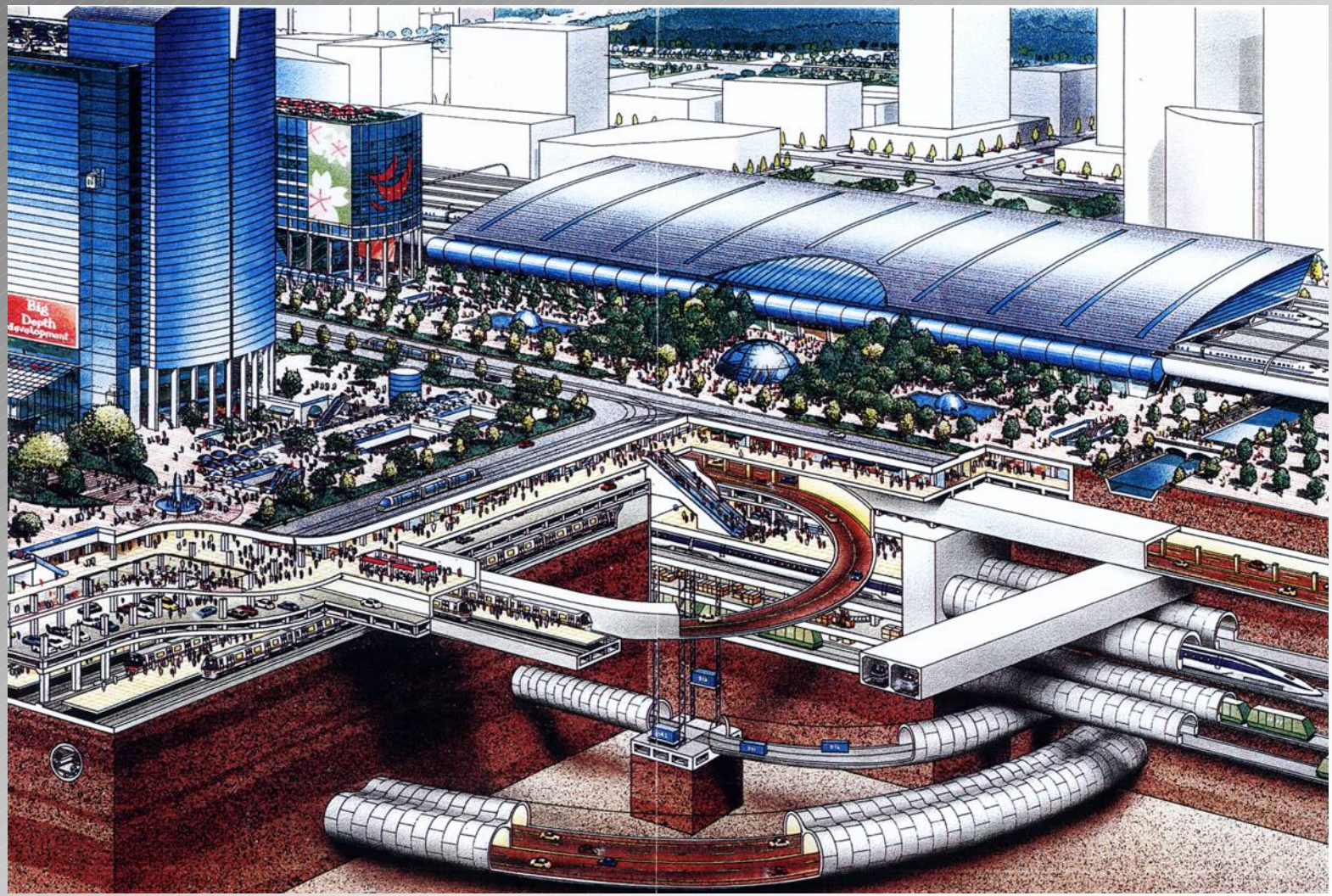
- Increase of the urban population (after the 2nd World War)
- Environmental Era (after 1960)
- Tunnelling technology



Environmental Era → Urban Trend



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Favourable Factors for Urban Tunnelling

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- **Better Behaviour Understanding**
  - **Control of settlements and displacements**
  - **Evaluation of induced damages**

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- **Technology Advances**
  - **Works safer, cheaper and built in short time**
  - **New generation of TBMs (pressurised face) – tunnelling in any geological conditions and urban environment**

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- **Seismic resistance**

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Demand of Urban Tunnelling

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- Mass Transit Systems and Motorways

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- Public Utilities (water, sewage, cables etc.)

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- Flood Control

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- Revitalisation of City Centres
- Public Buildings

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Difficulties in Deciding for Underground Structures

- Safety
  - During Construction
  - During Operation

- Costs

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Difficulties in Deciding for Underground Structures → Costs

Construction Methods	Cost Ratio
Surface *	1.0
Viaduct *	1.5
Cut & Cover *	2.5
Tunnel (single track)	3.0
Tunnel (double track)	3.0

** Not including surface land buying*

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Global Cost Assessment for Underground Structures

- Cost of the surface space
- Indenisation during construction (negative impacts of surface works)
- Devaluation of real estate nearby to infrastructure

Urban Tunnelling

Tunnelling Methods

- Conventional
- Mechanised
- Special

- **Soft Ground**
- Hard Ground
- Mix Ground

Introduction

Urban Tunnelling

→

Soft Ground Tunnelling

Conventional

- Ground Improvement

Mechanised

- Full Face Excavation

Special

- Trench Methods

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Soft Ground Tunnelling

- Main concern during excavation is the stability of the opening
- Most cases of soft ground tunnelling are in urban environment
- Tunnelling-induced displacement field may reach surface and affect existing nearby structures
- Design may be dominated by admissible-displacement criteria

Conditions and Requirements

Major concerns of soft ground and urban tunnelling are related to (Kovari & Ramoni, 2004):

- **Urban Environment**
- **Ground Conditions**
- **Risk Scenarios**

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Urban Environment

- Shallow overburden
- Existence of nearby structures
- Foreign objects inside the ground
- Constraints for alignment
- Restrictions for auxiliary works
- High visibility of damage

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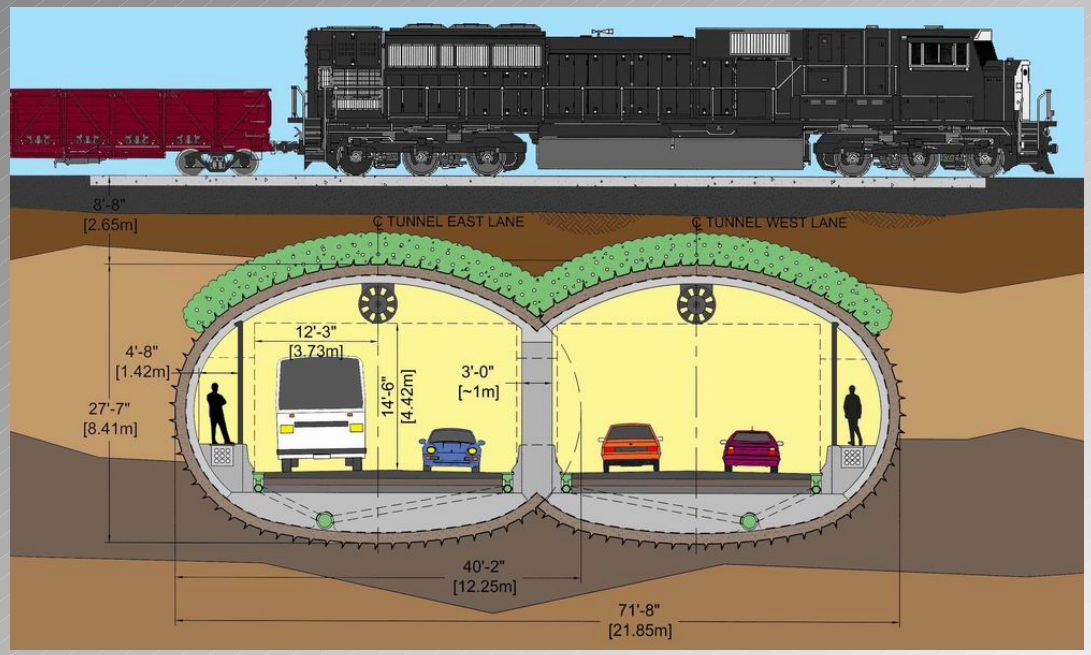
Shallow Overburden

- Access ways as shallow as possible
- Larger and larger tunnel diameters

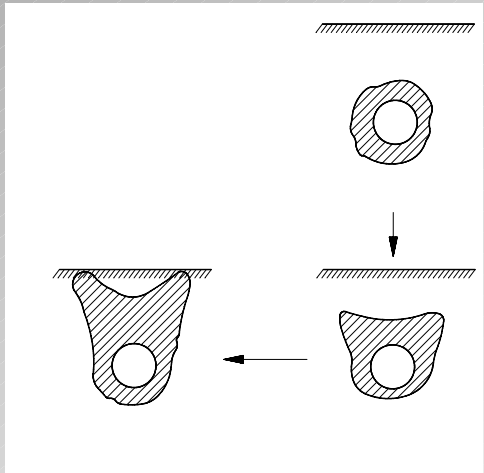
- Concept of Shallow Tunnel
  - Type of Failure
  - Displacement field up to surface or existing structures

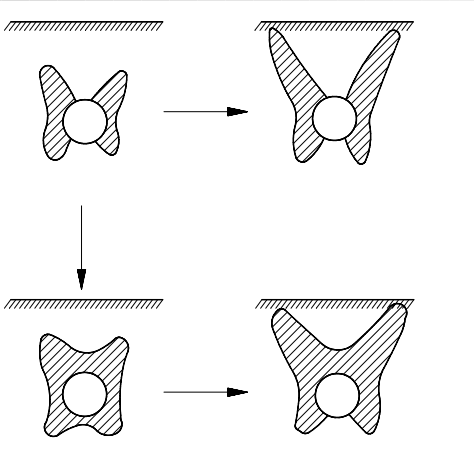
Conditions and Requirements

Shallow Overburden



(Sauer & Mergelsberg, 2003)





Existence of Nearby Structures

- Types of structures (transport ways, public utilities, buildings, historical sites etc.)
- Affected by the induced displacement field, but they also affect it
- Sensitivity to potential damages

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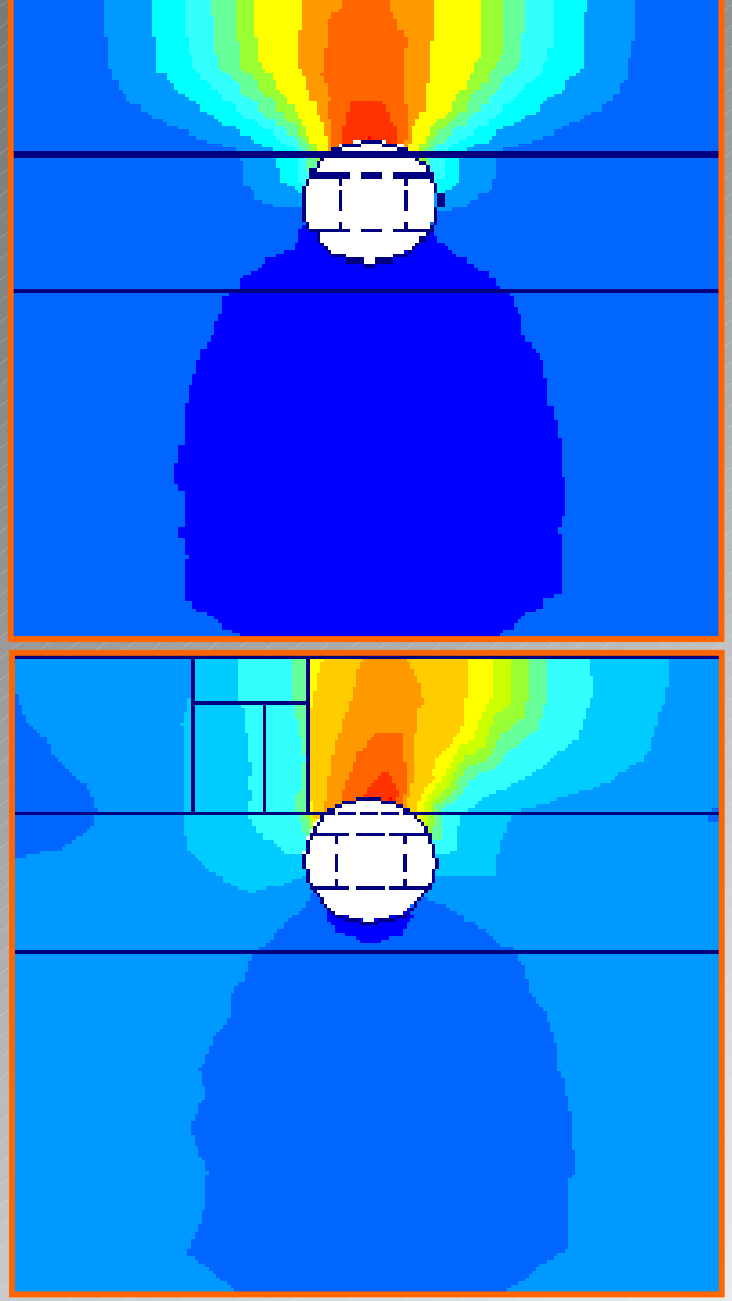
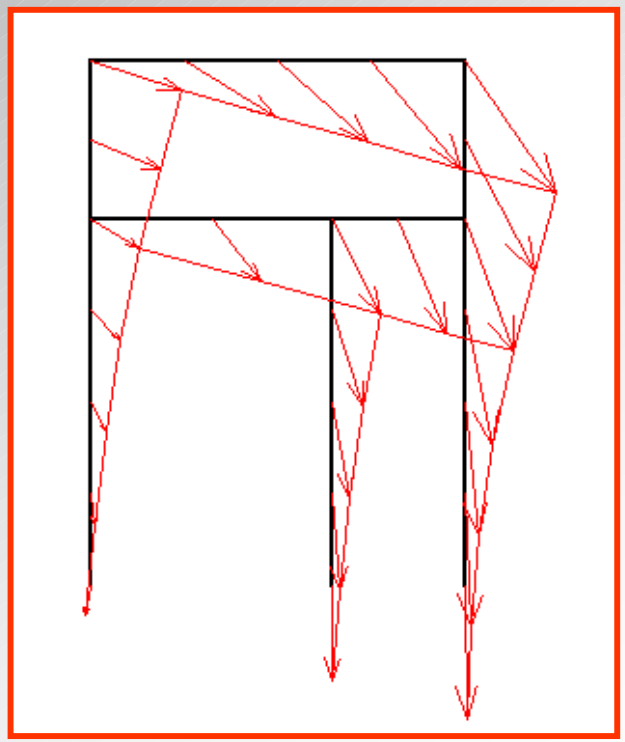


Existence of Nearby Structures



Foreign Objects inside the Ground

- Direct conflict with tunnel alignment
  - Structural elements (foundation, anchors, sheet piles)
  - Public utilities
  - Wells
  - Tree trunks and roots

Foreign Objects inside the Ground

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Constraints for Alignment

- Usually dominated by transport demand
- Influenced by urban constraints (p.ex. location of ventilation towers)
- Preferable under public ground
- Unavoidable to underpass existing structures
- Cope with existing ground conditions

Restrictions for Auxiliary Works

- Exploitation
- Shaft of attack
- Ventilation towers
- Muck transport and disposal
- Dewatering
- Ground improvement
- Monitoring

High Visibility of Damages

- Sensitivity of potential damages
- Loss of public confidence is very jeopardising to tunnelling industry

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Risk Scenarios

- Collapses up to surface
- Damages due to tunnelling-induced displacements

Design Criteria in terms of:
-Failure
-Admissible Displacements

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Ground Conditions

- Existing ground conditions
  - Recent geological formations
  - Fills
  - Frequent changing conditions (weathering)
  - Groundwater

- Ground Improvement and Reinforcement

Conditions and Requirements

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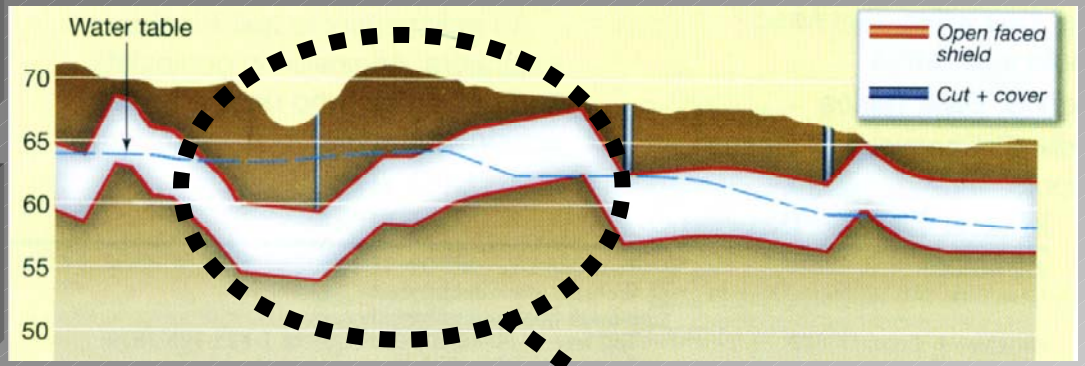
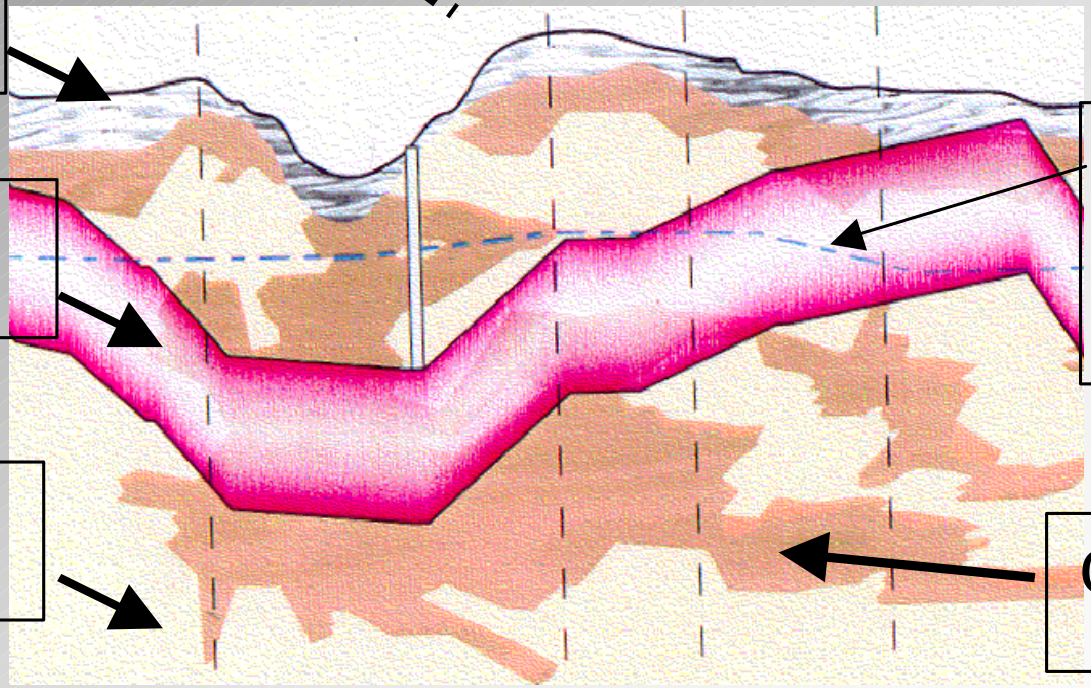


Ground Conditions



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Principles of Tunnelling

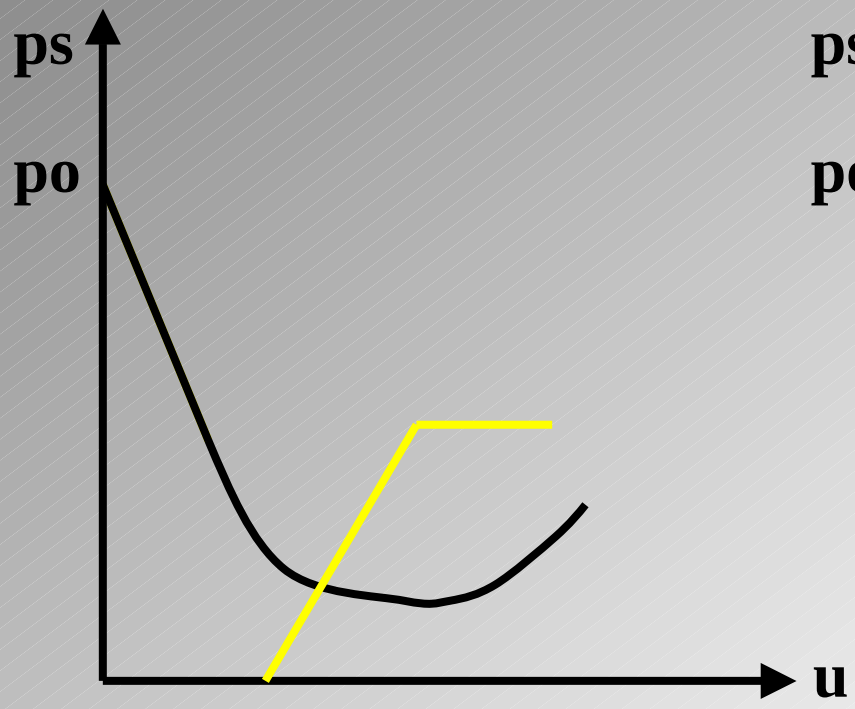
- Ground excavation →
- Support installation →

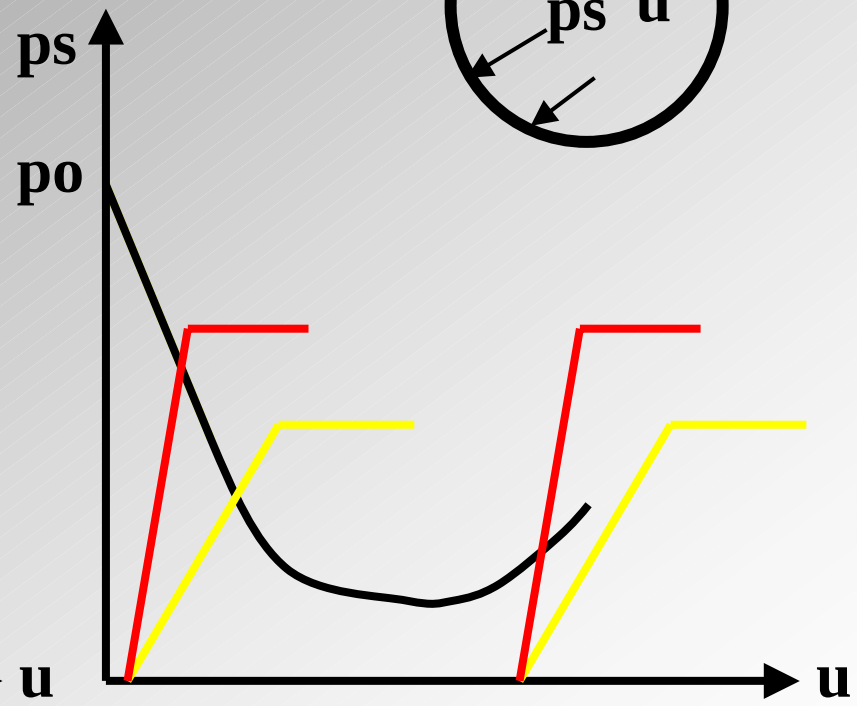
Ground-Support Interaction → Bearing Ring of Reinforced Ground

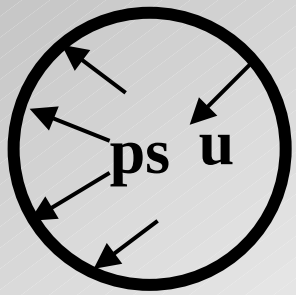
- Monitoring →

Observational Method

Ground-Support Interaction







Design Aspects

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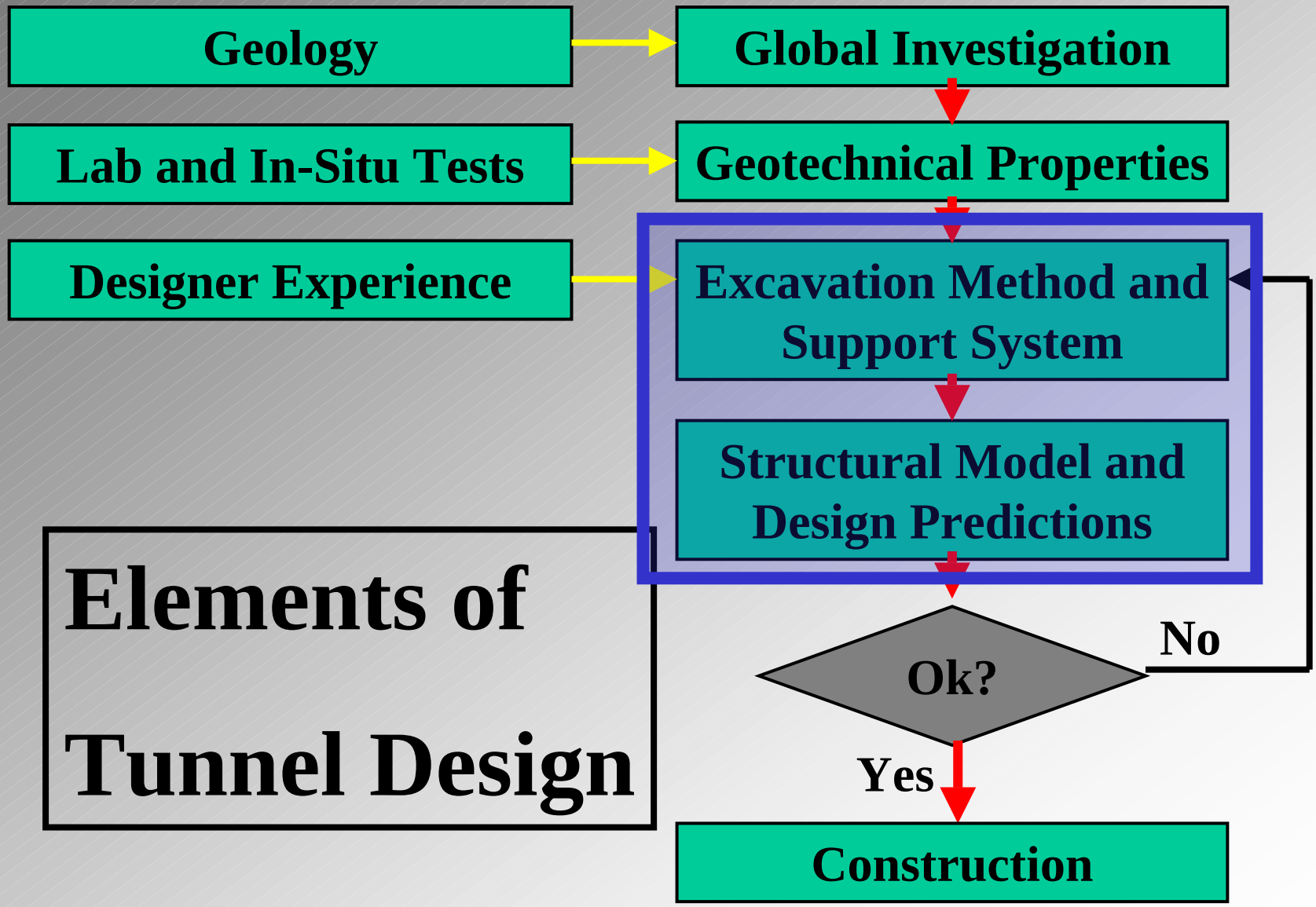

Elements of Tunnel Design

Stress-Strain-Displacement Analysis

- Empirical Formulations
- Closed-Form Solutions
  - Simple Geometry
  - Homogeneous and Isotropic Media
  - Linear Elastic Behaviour
- Numerical Methods
  - Boundary Element
  - Finite Element
  - Discrete Element

Media

CHILE

Media

DIANE

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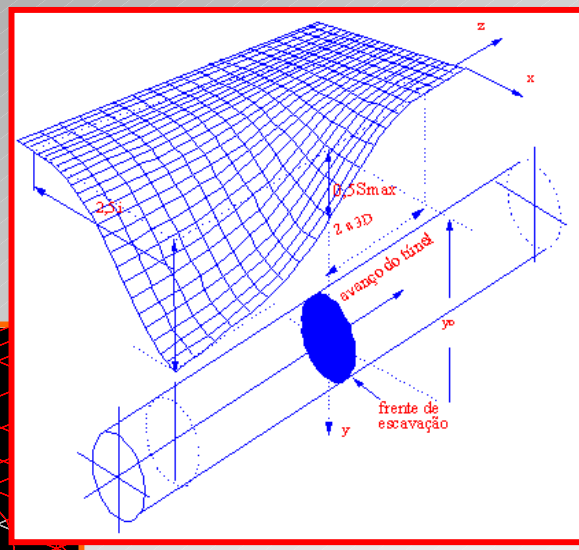
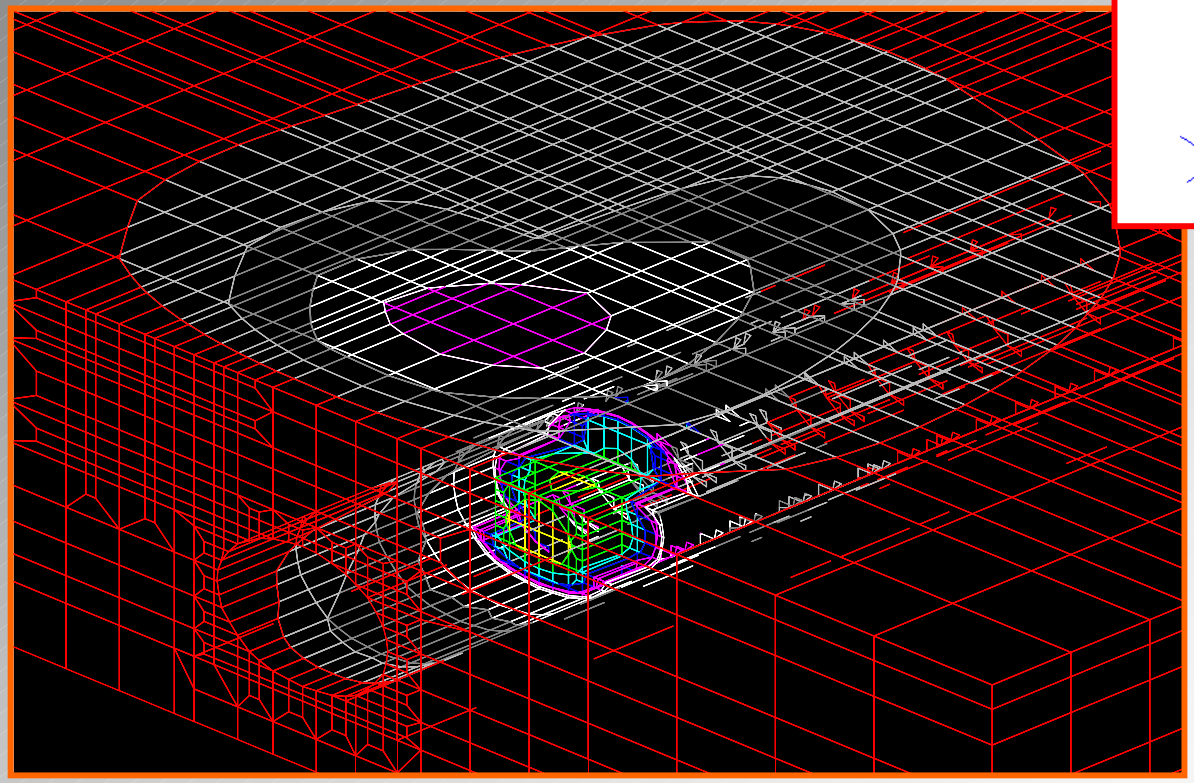
Tunnelling-Induced Displacements





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Checking for Tunnelling-Induced Damages

- Calculate the green field settlement trough
- For structures inside the settlement trough, check potential damages due to green field settlements and distortions
- For those in critical state, run a more accurate analysis taking into account the structure stiffness
- Perform reinforcement when required

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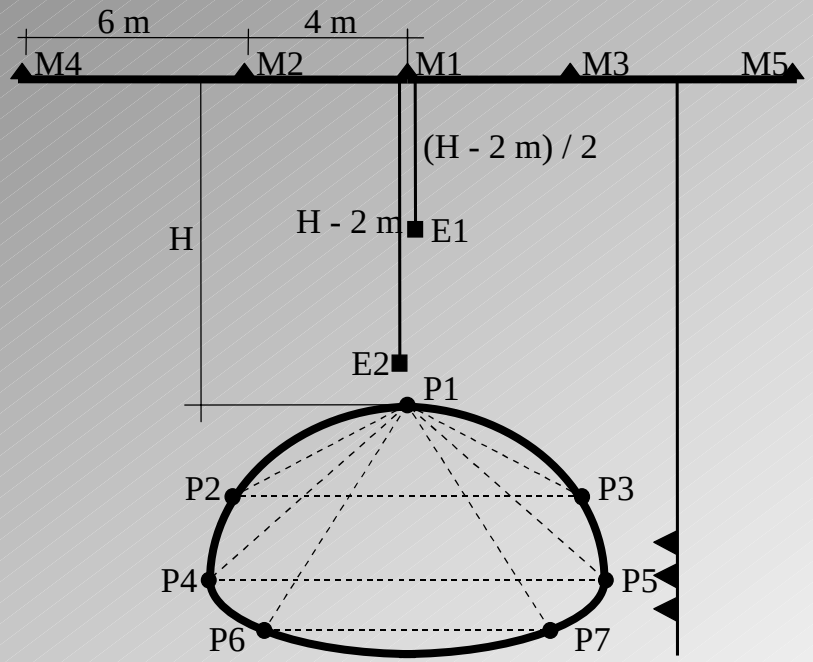
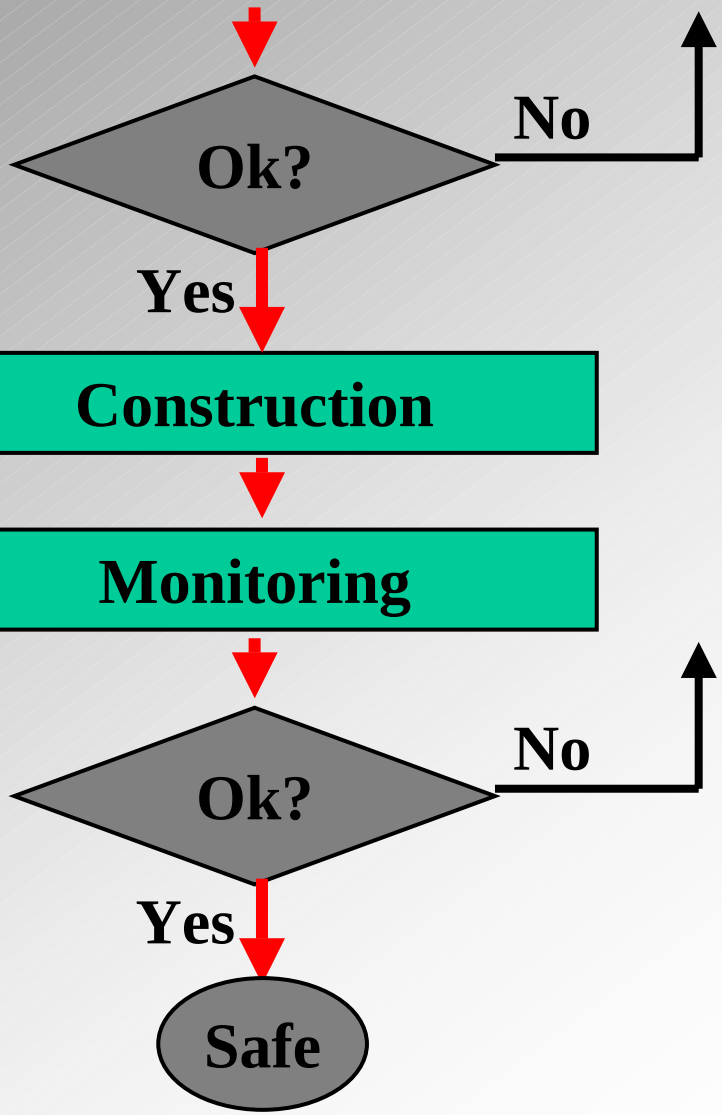
Elements of Construction

Construction Methods

Contractor Experience → Construction





Construction Methods

Soft Ground Tunnelling

- **Conventional**
  - Ground Improvement
- **Mechanised**
  - Full Face Excavation
- **Special**
  - Trench Methods

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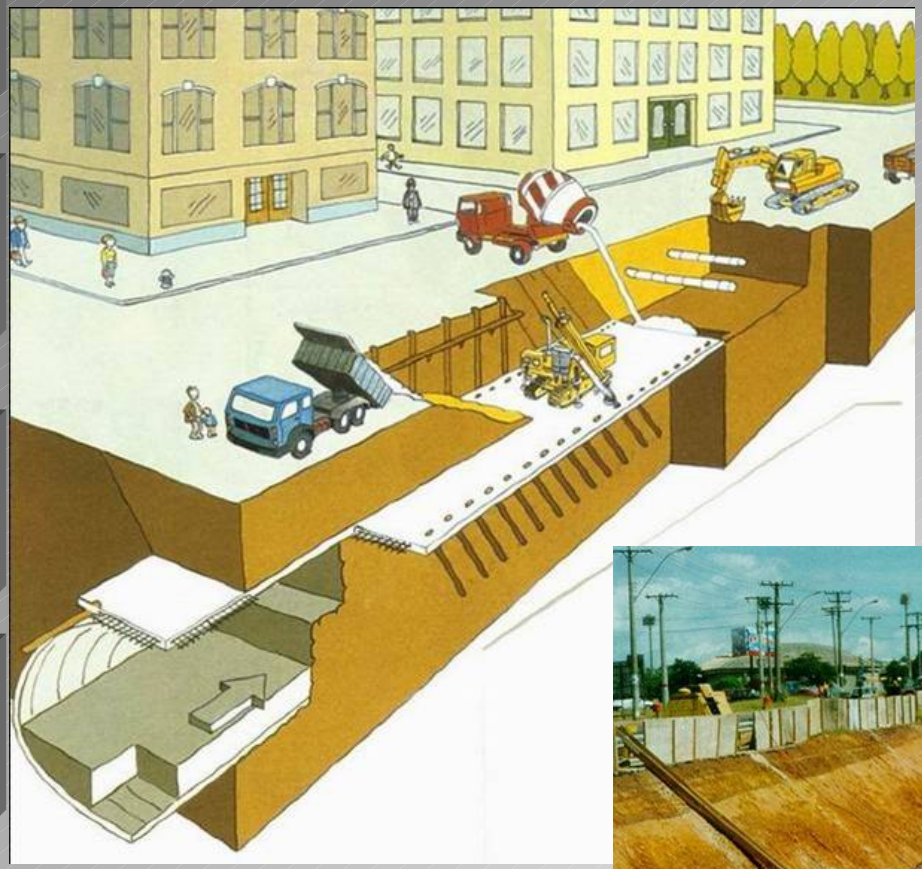
Special Methods

- Open Trenches
- Cut-and-Cover Structures
  - Direct and Inverse Excavation
- Door-Frame Method

- Immersed Tunnels
  - Caisson and Door-Frame Methods



Door Frame Method

(Sauer & Mergelsberg, 2003)

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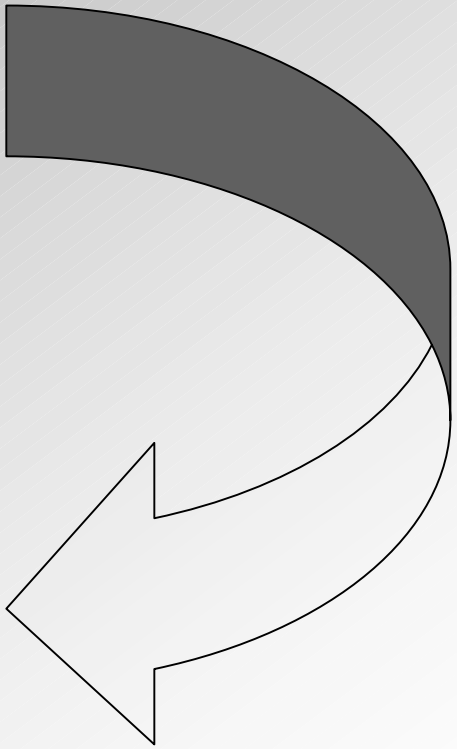
Conventional Tunnelling

- Excavation
- Ground Conditioning
- Support Installation



Stress Relaxation

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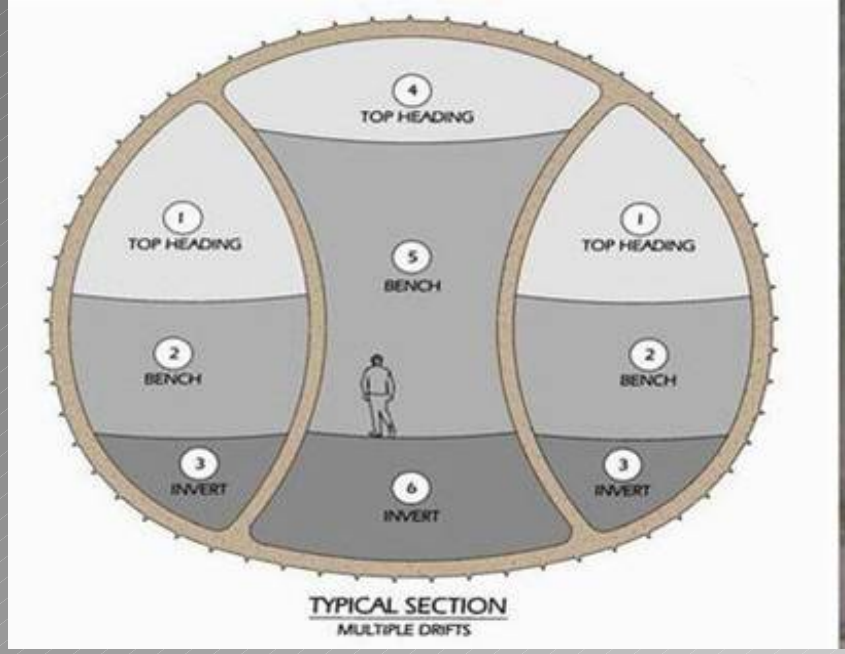
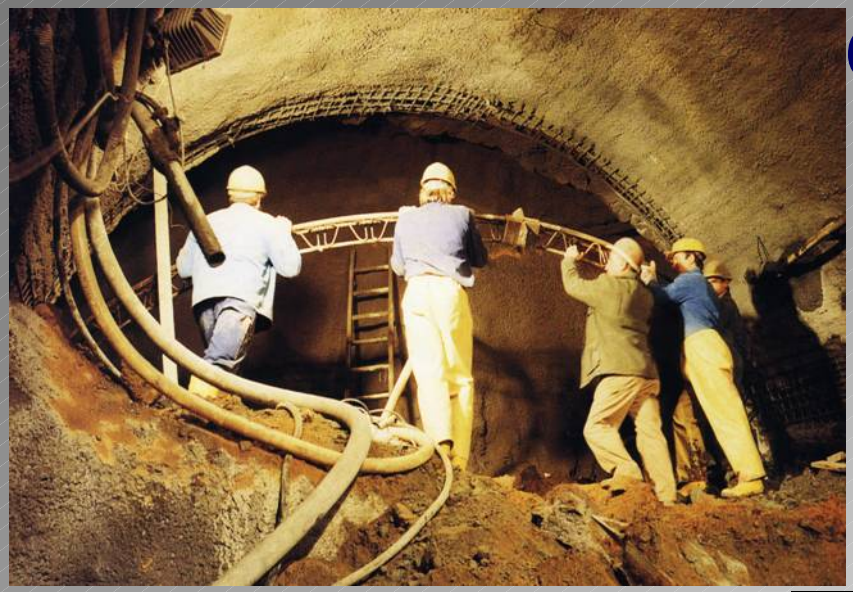


(Sauer & Mergelsberg, 2003)

Construction Methods

Support Installation



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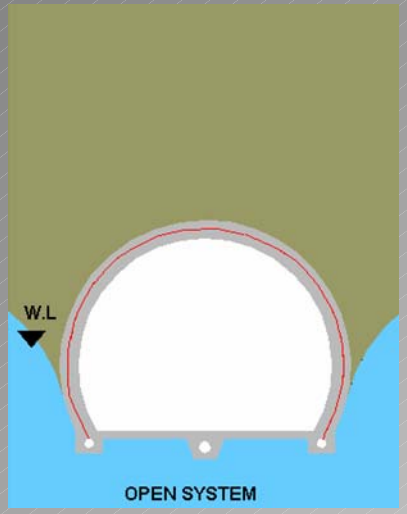
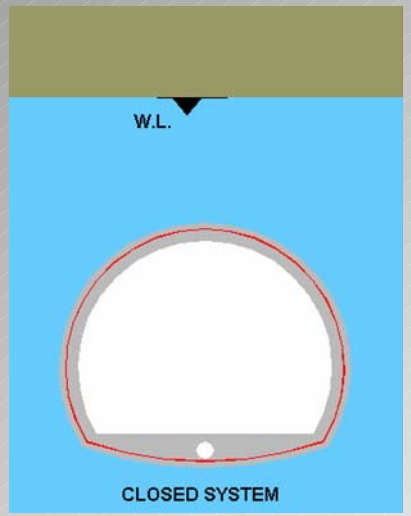
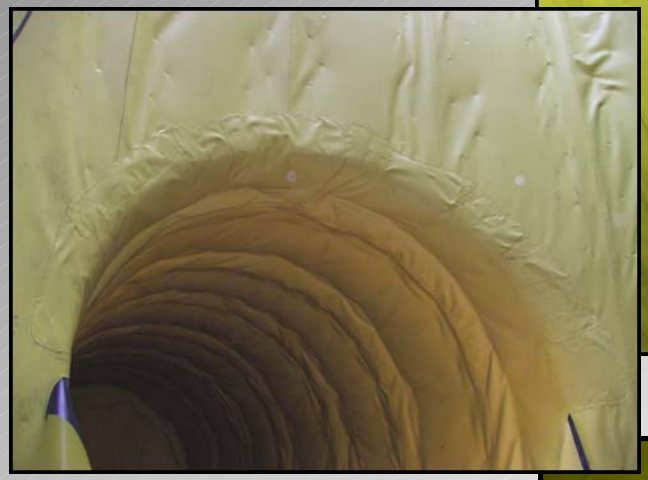
Tunnel Waterproofing







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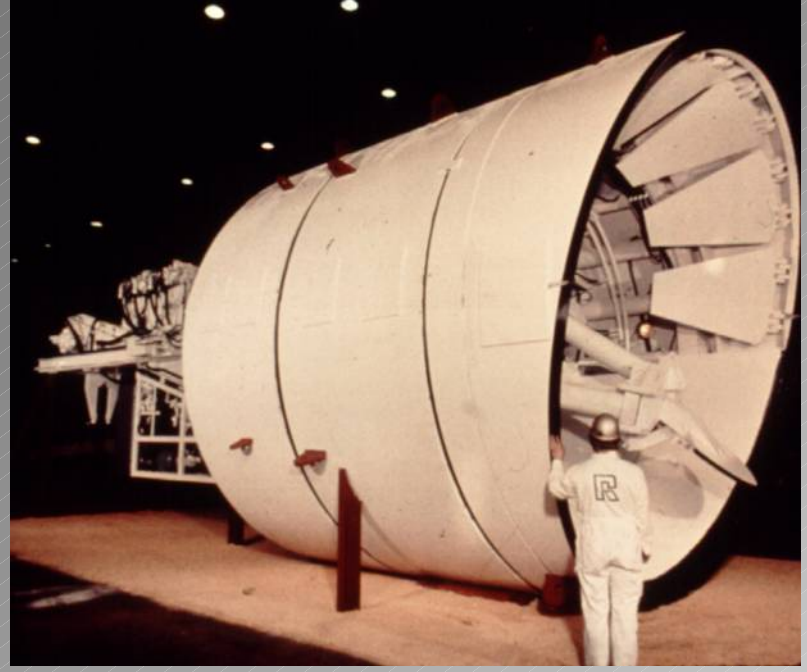
Mechanised Tunnelling

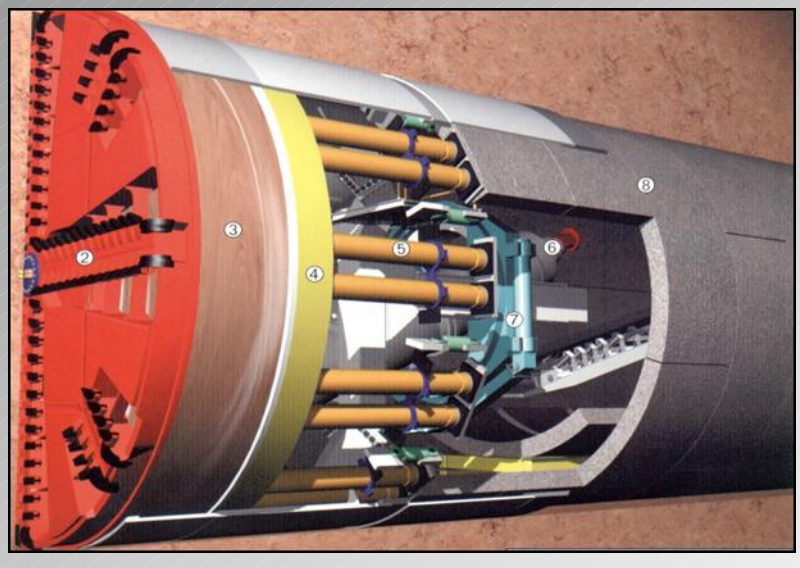
- Excavation
- Support Installation

Avoid or Minimise Stress Relaxation

Construction Methods

Mechanised Tunnelling





Relevant factors for the TBM selection are (Kovari & Ramoni, 2004):

- Grain size distribution
- Type of predominant mineral (quartz contents)
- Soil strength (cohesion)
- Overburden
- Heterogeneity (mix ground, weathering)
- Piezometric pressure

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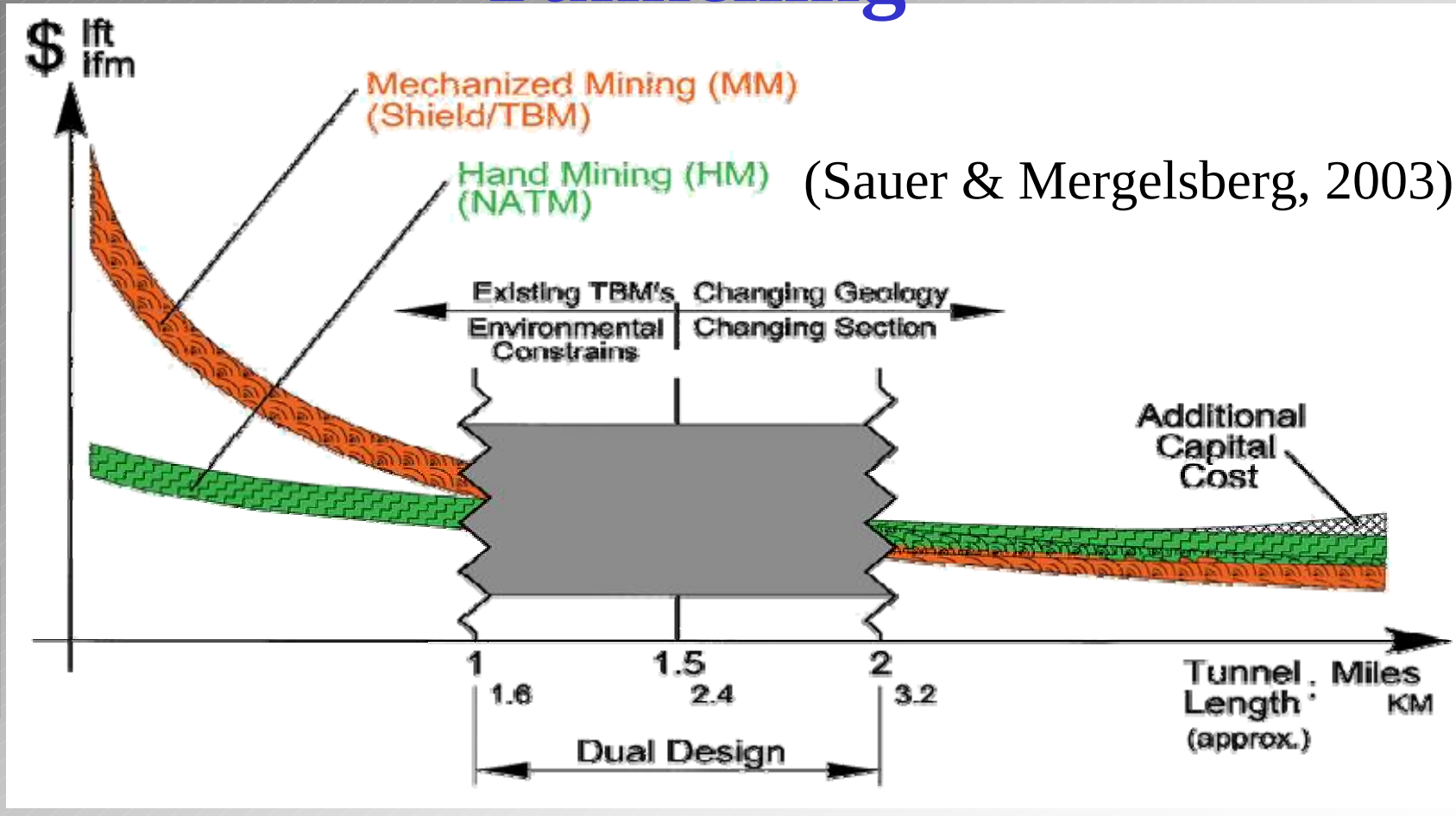
Conventional versus Mechanised Tunnelling

- Geometry Flexibility
- Geology Flexibility
- Contractual Flexibility
- Political Flexibility
- Lower costs for short tunnels and cheaper labour

- Lower impact to ground
- Higher and more constant quality (industrial process)
- Lower load to workers
- Safer
- More accurate costs and schedule

Construction Methods

Conventional versus Mechanised Tunnelling



(Sauer & Mergelsberg, 2003)

Conclusions and References

- Majors concerns are opening stability and control displacement field
- Soft ground tunnelling is likely dominated by failure and admissible displacement criteria
- Ground conditioning (improvement and reinforcement) plays an important role
- Tunnelling methods and technology vary depending on geology, tunnel location, length and geometry, local tradition etc.

Conclusions and References

- Assis, A.P. (2005). Conventional Tunnelling: The Example of the Brasilia Metro. ITA Training Course, ITA / Technical University of Istanbul, Istanbul, Turkey (www.ita-aites.org).

- Kovari, K. & Ramoni. M. (2004). Urban Tunnelling in Soft Ground Using TBMs. International Congress on Mechanised Tunnelling: Challenging Case Histories, Keynote Lecture, Politecnico di Torino, Turin, Italy (www.ita-aites.org).

- Sauer, G. & Mergelsberg, W.A. (2003). Tunnelling and its toolbox (Tunnelling… and beyond). Conference on Earth Retention Systems, ASCE / DFI / ADSC, New York, USA.

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- to promote advances in planning, design, construction, maintenance and safety of tunnels and underground space, by bringing together information thereon and by studying questions related thereto.

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