Tunnelling and Underground Construction Technology

Akos TOTH

Course Information

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Project Assistants
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Objectives:

To acquire in-depth knowledge of underground space and underground construction technologies, including planning, construction methods, safety, and environmental considerations.
Exam: Oral Presentation

Course Information

Akos TOTH

2014 – DB ProjektBau
2013 – self employed
2010 – EPFL LMR →PhD
2006 – Bamco
2000 – BUTE, civil eng.

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Course Information

Literature:

- Széchy Károly - The Art of Tunnelling
- Hoek, Brown - Underground Excavations in Rock
- Hoek's corner - https://www.rocscience.com/education/hoeks_corner
- Bruland - Hard Rock Tunnel Boring
- Maidl, Thewes - Handbook of Tunnel Engineering Parts I and II
- Grundbau-Taschenbuch, 7.Auflage, Teil 1 Geotechnische Grundlagen
- Betonkalender 2014, including Eurocode 7

Tunnelling and Underground Construction Technology

Course Lectures

Part 1 – Introduction, Planning and Geological Investigation

Introduction

Global Demand of Space

Above Ground and Underground Space

Types of Underground Space

Prospects of Underground Construction

Global Demand of Space

Space Demanded by Global Population Growth and Urbanisation

Spaces are demanded for living, leisure, infrastructures, transport, storage, and other functions.

Above and Underground Space

Above Ground and Underground Space

Above ground space can be claimed from

- **Highrise building (up)**
- **Offshore reclamation (side)**

Underground space can be claimed from

- **Basement, tunnels and caverns below ground (down)**

Types of Underground Space

Types of Underground Space

Underground space can be in the forms of:

Transportation (metro, road, rail, passage)

Distribution (power, water, sewage)

Storage (water, goods, energy, car parks)

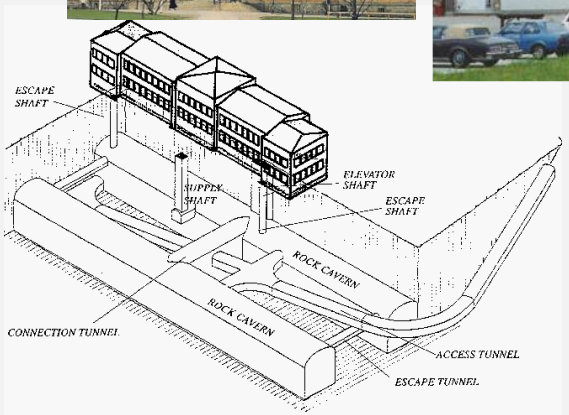
Recreation and commercial (sport, zoos, shopping)

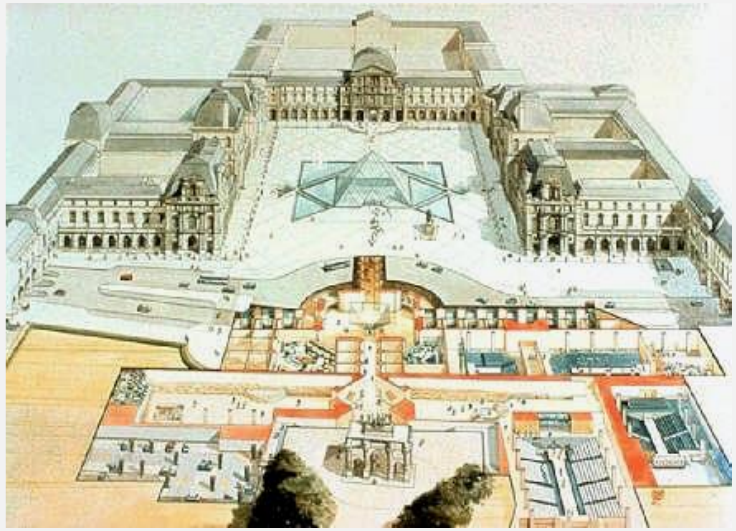
Education (library, test gallery)

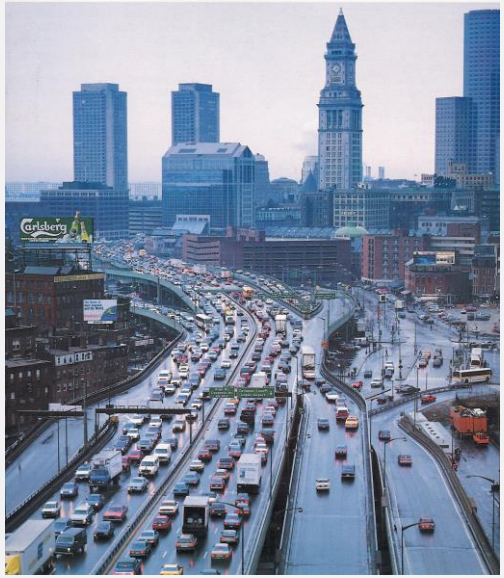
Industry (factory and workshop, office)

Defence (control centre, military installation)

And many others


ESCAPE SHAFT
ELEVATOR SHAFT
ESCAPE SHAFT
ROCK CAVERN
ROCK CAVERN
CONNECTION TUNNEL
ACCESS TUNNEL
ESCAPE TUNNEL

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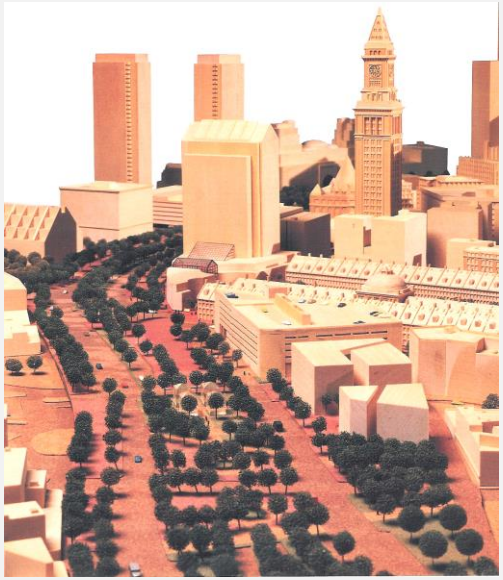


Prospects

European Vision of Underground Construction in 2030

“Free above ground space for the use of the citizens, taking infrastructures underground.”

“Underground construction will be safe and with no impact on the environment.”

--European Construction Technology Platform, 2006

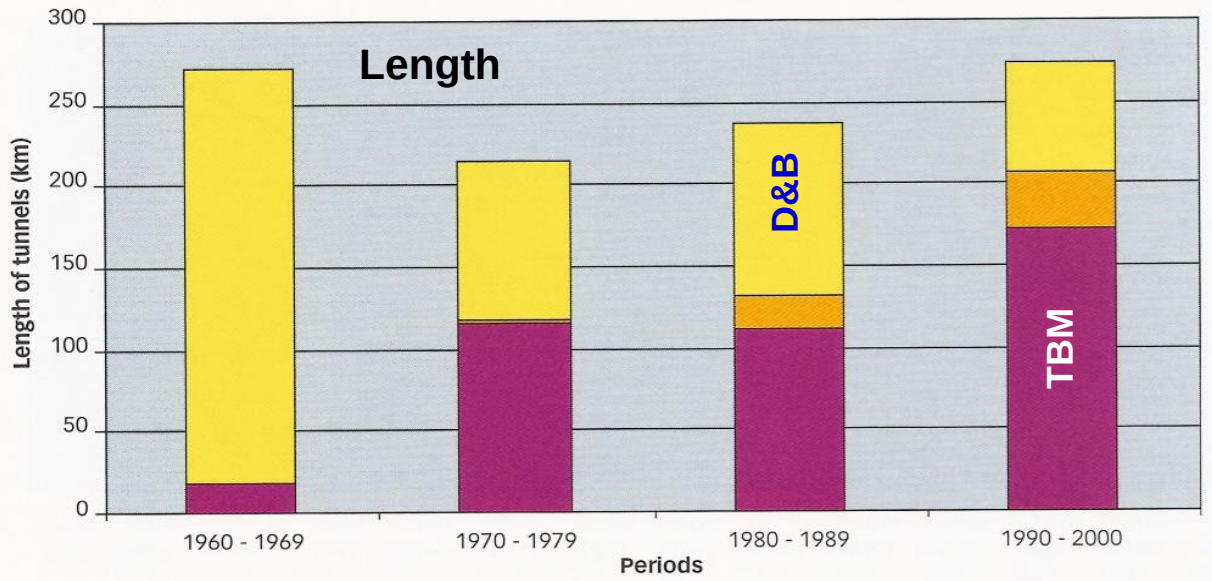
Prospects

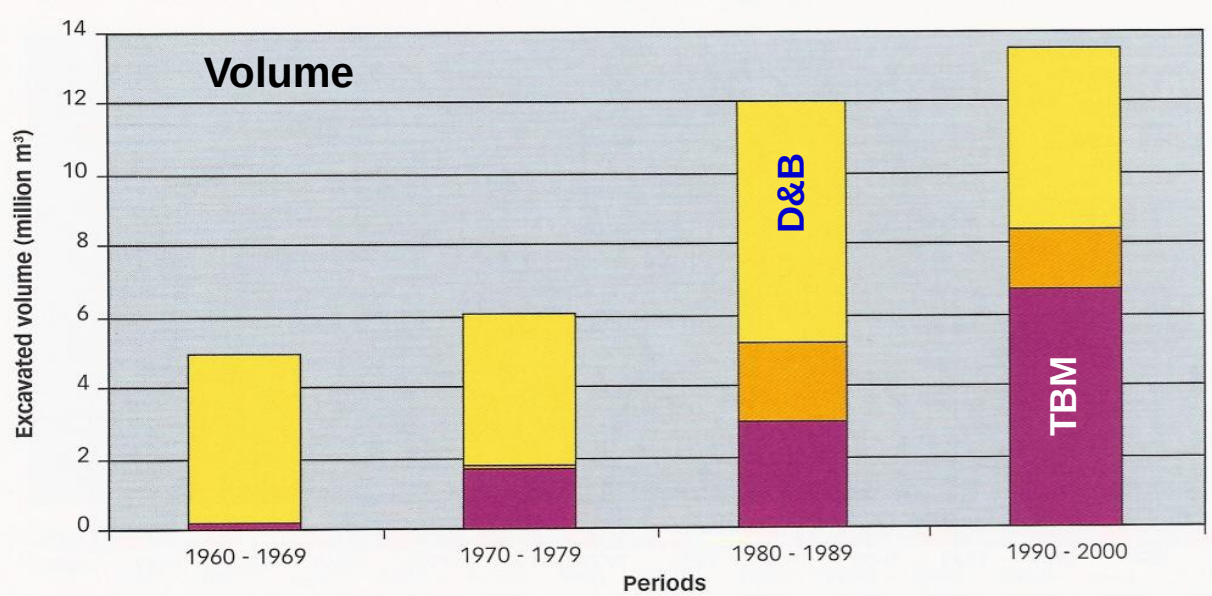
Tunnelling Activities in Europe by 2030:

- **2100 km new tunnel,**
- **Over 500 tunnels to be refurbished,**
- **Tunnelling a major European industry, involving 450,000 people.**

Prospects

Tunnelling in Switzerland





Prospects

European Vision of Underground Construction 2030 Break-through:

2010 – Self learning equipment (equipment making automatic modification during construction);

Cost efficient large diameter tunnels;

Intelligent lining system (automatic modification of lining with ground condition).

2020 – Breakthrough in rock cutting technology (e.g., laser cutting);

Complete knowledge of geological conditions (transparent ground);

Universal tunnel boring machine.

Prospects

European Vision of Underground Construction 2030 Break-through:

2030 – No environmental impact (complete waste reuse and no air and water pollution);

Complete knowledge of underground facilities behaviour;

Similar cost for underground and above ground infrastructures;

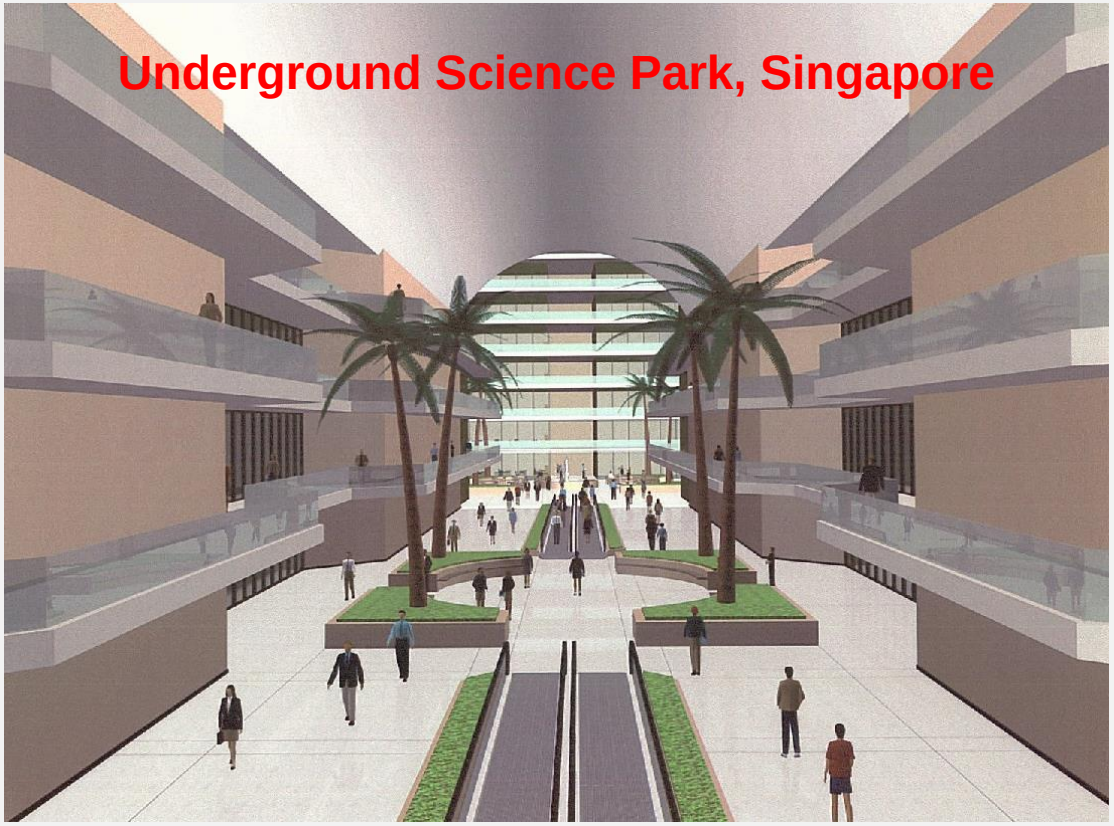
No workers inside tunnel during construction (totally automated remotely controlled tunnel construction work).

Prospects

Safety and Environment

Environmental integration during underground construction.

Architecture and environment in underground space utilisation.



Underground Construction Technology

Course Lectures

Part 1 – Introduction, **Planning** and Geological Investigation

Underground Space Planning

Underground Space Planning Considerations

Integrated Geo-Planning Process

Above Ground and Underground Space Integration

Master Planning and Application of GIS

Planning Considerations

Underground Space Planning Considerations

Underground space planning involves social, economic, environmental and engineering procedures. Engineering planning will have to consider and balance engineering feasibility, geologic and ground conditions, environmental constrains, economic viability, social and political needs.

Planning Considerations

Underground Space Planning Procedures

Typically, planning process involves stepwise screening:

Step 1. Screening to eliminate areas/routes where regulatory or legal constrains prohibit tunnel and underground space development.

Step 2. Screening to remaining areas/routes to select suitable locations for a particular tunnel and underground space applications.

Planning Considerations

Step 3. Screening to select locations/routes with suitable hydrogeologic features with consideration of tunnel and underground space application.

Step 4. Screening of geomechanical and engineering properties of the subsurface ground to match design criteria to site the tunnel.

Planning Considerations

Planning procedure should be coordinated, ideally, to be incorporated with the overall national/city planning. A typical planning procedure involves several parties, for example, for underground infrastructure development,

(i) Planning studies and procedures co-ordinated by the developing agency (e.g., city transport authority), with engagement of the city planning authority.

(ii) Site identification, feasibility study, project plan and development proposal by developer to the developing agency.

Planning Considerations

(iii) Feasibility study, project proposal and design examined by the city engineering office and city planning authority, and other relevant authorities, such as environment office.

(iv) On approval co-ordinated by the city engineering office and city planning authority, implementation of the project.

(v) At completion, appraisal and approval by city engineering office for operation licence.

Planning Considerations

General factors in Underground Space Planning

Ownership and legislation

Existing and future surface land use

Population distribution and density

Transport, roads and accessibility

Geography and topography

Geology, hydrology and tectonic activity

Planning Considerations

Specific Engineering Factors in Planning

Fault and joint orientation

In situ stress and direction

Seepage and groundwater pressure

Rock and soil mechanical properties

etc….

Planning Considerations

Requirements for Specific Underground Facilities

Tunnel Type	Specific Geological Information Required
Highway tunnels	• Generally large-size tunnels; clear span width affects general behaviour. • Usual flexibility in alignment and grade. Investigation should support optimisation of tunnel location, length, grade, etc. Portals usually need special exploration to determine most economical location to place portal.
Rail tunnels	• Less flexible in choice of horizontal and vertical alignment; may not be able to easily avoid adverse geological features or difficult portal locations by moving alignment. Need to explore for all potential adverse features.
Rapid transit tunnels	• Need data to design protection of adjacent features and to estimate potential settlement and groundwater inflow. • Need to investigate one or more corridors as easily in program as possible to avoid expensive adverse geologic and/or environmental conditions. • Can benefit strongly from phased exploration approach.

Integrated Geo-Planning Process

Geology and Planning Process

Subsurface geology is a major factor in underground space planning. It influences site/route, size and shape, excavation and support method of a specific underground space project.

Integrated Geo-Planning Process

Geology Exploration at Planning Stage

At this stage, geological exploration is to aid the decision of whether the tunnel is feasible or better choice, and the alignment of the tunnel.

The above the decision is not just rely on geology, but also many other social, economic and environmental factors, including, e.g., integration with surface development. Geological factor is to ascertain the decision and to assist the definition of the alignment.

Integrated Geo-Planning Process

Geology Exploration at Planning Stage

A thorough literature review, collection of all the existing geological information from all the possible sources is a must. Previous works would have left with lots of geological information of the ground. Some justification and reinterpretation may be needed. Review should include the following:

- **Geological or geotechnical map of the area**
- **Topographic map of the area**
- **Surface plan, existing structures**
- **Plan of existing subsurface structures**
- **Geological and geotechnical information of the subsurface materials**

Integrated Geo-Planning Process

Geology Exploration at Planning Stage

In areas where uncertainty exists, exploration should be carried out:

- **Geophysical exploration, mainly seismic, radar or gravity**
- **Exploratory drilling and sampling**
- **Simple laboratory testing**

With the aid of exploration, an approximate ground profile can be prepared to indicate the ground condition at along tunnel alignment and at tunnel elevation. Tunnel alignment and elevation may be modified if he ground conditions are not favourable.

Integrated Geo-Planning Process

Interactive Geo-Planning Process

Engineering planning is a continuous process incorporating revealed geological information. Each project has its own primarily considerations in relation to geology.

With revealed geological information from exploration, planning will be constantly examined to achieve the most technically feasible and economically viable solution.

Integrated Geo-Planning Process

Geo-Planning for Long Deep Mountain Tunnels

Institutional Planning

Positions of end points A and B:
They are more or less fixed to make the connections (horizontal and vertical positions).

Usage and volume:
High speed rail and expected train volume, dimension can be determined.

Integrated Geo-Planning Process

Geo-Planning for Long Deep Mountain Tunnels

Route (horizontal and vertical):
Straight, curved, graded? What are the geological factors influence the selection?

Dimension (single/double track):
Decisions of single or double track related to ground condition.

Access and Portal:
Transportation access, length section length distribution, shaft locations, transport of equipment, transport of mucks

Excavation and Support
Selecting excavation method (TBM or D&B), and support (segment or B&S), with known ground along the route.

Integrated Geo-Planning Process

Geo-Planning for Urban Metro Tunnels

Institutional Planning

Positions of metro stations:
They are more or less fixed for the transport system (primarily horizontal).

Usage and volume:
Metro and expected train volume, dimension can be determined.

Integrated Geo-Planning Process

Geo-Planning for Urban Metro Tunnels

Route (horizontal and vertical):

Limited flexibility horizontally. Usually curved and graded. Are geological factors influence the selection?

Dimension (single/double track):

Decisions of single or double track related to ground condition.

Access and Portal:

Transportation access, shaft locations, transport of equipment, transport of mucks.

Excavation and Support

Selecting excavation method (TBM or conventional), and support (segment), with known ground condition along the route.

Integrated Geo-Planning Process

Geo-Planning for Oil and Gas Storage Caverns

Institutional Planning

General locations:
General location is planning for logistical reasons.

Usage and volume:
Total volume fixed, but not cavern dimensions.

Integrated Geo-Planning Process

Geo-Planning for Oil and Gas Storage Caverns

Location and Siting:
Specific locations, mostly governed by geology.

Geometrical configuration:
Orientation, dimension, depth and separation. governed by ground conditions.

Access and Portal:
Transportation access, shaft locations, transport of equipment, transport of mucks.

Excavation and Support
Selecting excavation method (D&B, sequence), and support (B&S), with known ground condition at site.

Above and Underground Integration

Influence of Above Ground on Underground Space Development

Surface access to UG space

Existing AG structures restrict UG development

UG restricts future AG development

Connectivity of AG and UG facilities

Above and Underground Integration

Integrating Above and Underground Facilities

UG basement car parks with AG offices and shops

UG metro station with AG commercial centres

Combined AG and UG museums and libraries

UG links for shopping districts

UG oil storage with AG refinery factory

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Master Planning and Application of GIS

Master Plan of Urban Underground Space

Master planning is particularly important for urban development due the limited land area. Master planning will optimise the use of space, both above and under ground, and also optimise the integration with urban feature and environment.

Master Planning and Application of GIS

Geographic Information System (GIS)

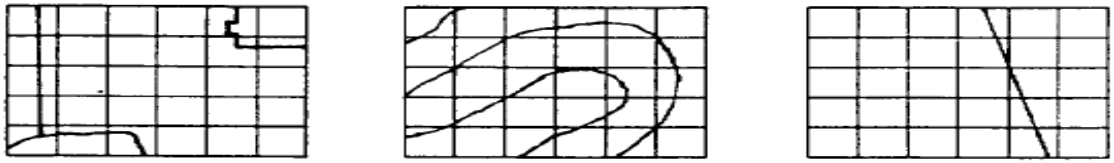
A geographic information system (GIS) combines layers of information about a place to give you a better understanding of that place. What layers of information you combine depends on your purpose – finding the best location for a new store, analyzing environmental damage, viewing similar crimes in a city to detect a pattern, and so on. (from GIS.com web site).

GIS layers can also extended to subsurface, and therefore gives the possibility using GIS for underground space planning.

Master Planning and Application of GIS

Use of GIS for Underground Space Master Planning

Digitized maps with grid overlay



Weighting scores (for example only)

8	8	4	4	E	E
8	8	4	4	E	E
8	8	8	4	4	4
8	8	8	8	8	4
E	E	E	8	4	4

Factor = 4

24	18	12	12	12	12
18	12	12	12	12	12
12	12	6	6	6	12
12	6	6	6	12	12
6	6	6	12	12	12

Factor = 6

6	6	4	2	4	6
6	6	4	2	4	4
6	6	4	4	2	4
6	6	6	4	2	4
6	6	6	4	2	4

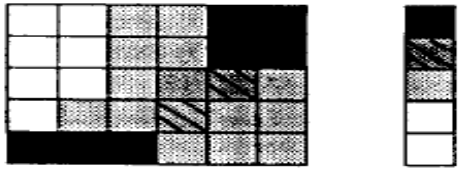
Factor = 2

Composite scores

38	32	20	18	E	E
32	26	20	18	E	E
26	26	18	14	12	20
26	20	20	18	22	18
E	E	E	24	18	20

Score and composite score:
higher number → higher favourability

Composite map for site selection with favourability



Excluded
Low favourability
Middle favourability
high favourability
very high favourability

Master Planning and Application of GIS

Use of GIS for Tunnel Route Selection

With data input from geological exploration (boreholes and geophysical surveys) , GIS is able to interpret the geological features in 3D. GIS can give various cross section (vertical and horizontal) profiles for tunnel alignment plan.

Hazard mapping is also possible with GIS, so the alignment can be selected in consideration of environment and hazards.

Underground Construction Technology

Course Lectures

Part 1 – Introduction, Planning and **Geological Investigation**

Geological Exploration

Need of Geological Exploration

Geological Information for Tunnelling

Geological Exploration Methods

Geological Sections and Profiles

Investigation Techniques for Mountain Tunnels

Need of Geological Exploration

Input from geological exploration in tunnelling (I):

- **Developing sufficient understanding of regional geology and hydrogeology for project design and construction;**
- **Defining the physical characteristics of the materials that will govern the behaviour of the tunnel;**
- **Helping define the feasibility of the project and alerting the engineer and contractor to conditions that may arise during construction for the preparation of contingency plans;**

Need of Geological Exploration

Input from geological exploration in tunnelling (II):

- **Providing data for selecting alternative excavation and support methods and, where project status permits, determining the most economical alignment and depth;**
- **Providing specific rock, soil, and hydrogeologic design parameters;**
- **Minimising uncertainties of physical conditions for the bidder;**
- **Improving the safety of the work;**

Need of Geological Exploration

Input from geological exploration in tunnelling (III):

- **Predicting how the ground and groundwater will behave when excavated and supported by various methods;**
- **Establishing a definitive design condition (geotechnical basis for the bid) so a "changed condition" can be fairly determined and administered during construction;**
- **Providing specific data needed to support the preparation of cost, productivity, and schedule estimates for design decisions, and for cost estimates by the owner and bidders.**

Geological Information for Tunnelling

Information Dictated by Tunnel Type (I)

Highway tunnels

- **Generally large-size tunnels; clear span width affects general behaviour.**
- **Usual flexibility in alignment and grade. Investigation should support optimisation of tunnel location, length, grade, etc. Portals usually need special exploration to determine most economical location to place portal.**

Rail tunnels

- **Less flexible in choice of horizontal and vertical alignment; may not be able to easily avoid adverse geological features or difficult portal locations by moving alignment. Need to explore for all potential adverse features.**

Geological Information for Tunnelling

Information Dictated by Tunnel Type (II)

Rapid transit tunnels

- **Need data to design protection of adjacent features and to estimate potential settlement and groundwater inflow.**
- **Need to investigate one or more corridors as easily in program as possible to avoid expensive adverse geologic and/or environmental conditions.**
- **Can benefit strongly from phased exploration approach.**

Geological Information for Tunnelling

Information Dictated by Tunnel Type (II)

Water tunnels

- Drainage – Need data to predict inflow into tunnel
- Irrigation – Need data to predict inflow into tunnel
- Trans-mountain diversion – Need data to predict inflow out into tunnel
- Groundwater recharge
- Fresh water supply

Sewage tunnels

- Permeability for water inflow and discharge
- Traditional geotechnical requirements

Geological Exploration Methods

Principle Elements of Investigation (I)

Investigation has generally the following methods:

(a) Literature review – review all the existing information, including maps and photographs.

(b) Reconnaissance – general appreciation and surface mapping.

(c) Geophysical survey – fast and low cost subsurface exploration, commonly used methods include seismic refraction, seismic reflection, electrical resistivity, eletromagnetic, and radar.

Geological Exploration Methods

Principle Elements of Investigation (II)

(d) Drilling and logging – subsurface drilling, sampling, and field logging, including downhole logging in the borehole, such as video camera, sonic velocity, resistivity and other geophysical and conventional means.

(e) In situ test – various field tests, including deformation tests, groundwater measurements, and in situ stress.

Geological Exploration Methods

Principle Elements of Investigation (III)

(f) Laboratory test – tests of soil/rock samples, such as strength, deformation modulus, consolidation, swelling, durability, creep, hardness and abrasive properties;

(g) Model test – small to full scale physical model for detailed features;

(h) Tunnel monitoring – monitoring deformation, stress and groundwater during and after construction.

Detail list in Table 2.2.1a.

Geological Exploration Methods

Methods and Techniques of Geological Exploration:

Literature Review and Photographic Studies

Field Reconnaissance and Recognition

Geophysical Exploration

Borehole Drilling, Sampling and Logging

Downhole and In Situ Testing

Laboratory Testing

Trial Excavation

Construction Monitoring

Geological Exploration Methods

Literature Review and Photographic Studies

Desk study is to search through records, maps and other literature relevant to the geology of the area.

(a) Acquire and interpret maps, papers, air photographs, imagery and satellite data relating to the site

(b) Seek additional information from various institutions.

(c) Visit the site to collate all the data so far obtained, and to identify areas where engineering difficulties may exist and areas where particular investigations are needed.

Geological Exploration Methods

(d) Compile a report recording the geological and geotechnical data.

The proposed engineering works at the site should be considered, to ensure investigation suiting both the geology and the engineering.

Aerial photographs provides useful information on the larger scale geological features such as faults, bedding planes and continuous joint sets. The photographs will give information on position, length and continuity of these features. Structural mapping can be performed from the photographs.

Geological Exploration Methods

Field Reconnaissance and Recognition

Field reconnaissance commences with a preliminary survey to confirm the basic geology of the region and the site, and geological mapping of structures and material types, as well as some simple tests may be undertaken.

Geological mapping of surface outcrops usually furnishes the fundamental information on site conditions, and is often the basis for many subsequent engineering decisions such as relocation of the structure, or the need for rock reinforcement, as well as the type of structure that will be built.

Geological Exploration Methods

Field Investigation – Geophysical Exploration

Seismic refraction	**Measures velocities of induced seismic wave travelling in soil and bedrocks.**	**For all rock types, land or water. Determine stratum depths and characteristic velocities,**
Seismic reflection	**Measures average velocity of seismic wave travelling between the surface and a reflecting surface, to calculate depths to lithological changes.**	**Primarily sedimentary rocks and offshore. Measures depth and continuity of rock layers. Indicates discontinuities and stratigraphic conditions.**
Electrical resistivity	**Measures relative electrical resistivities of rocks**	**Locates ore bodies, aquifers, gravel deposits, and bedrock profiles.**

Geological Exploration Methods

Electro-magnetic	Measures amplitude and phase angle of electromagnetic field. Point coverage	Mainly used for aquifer location.
Magneto-meter	Measures total magnetic intensities in gammas. Point coverage, measures field intensity	Discloses presence of local metallic bodies. Detects faults and igneous intrusion.
Graviti-meter	Measures total density of rocks. Coverage is spherical around point	Measures lateral change of rock types. Locates cavities, faults, domes, intrusions.
Radar probing profiling	Measures electromagnetic wave VHF energy	Provides subsurface profile. Used to locate buried pipe, bedrock, boulders.

Geological Exploration Methods

Field Investigation – Borehole Drilling and Logging

Wash boring	**Power rotation of a boring head as circulating water removes (washes) ground-up material from hole.**	**Boring through all type of soils. Soil samples can be obtained by different samplers.**
Rotary coring	**Power rotation of a core barrel as circulating water removes ground-up material from hole. Water also acts s as coolant for core barrel bit.**	**Coring through all type of rocks, and obtaining core samples with diameter from 50 to 150 mm.**

Geological Exploration Methods

Wire-line coring	**As rotary coring. Core samples obtained by inner barrel retrieved by a wire-line through drilling rod.**	**As rotary coring. Fast and Efficient for deep coring on land and offshore.**
Percussion drilling	**Power chopping of material by heavy bits. Slurry is removed by bailers or sand pumps.**	**Making hole in any rock material. Useful for probing cavities.**
Horizontal direction drilling	**As wire-line rotary coring. Coring inclination can be change to horizontal. A direction change device is used to control the direction.**	**Deep coring through all type of rocks, and obtaining samples. Coring in inclined and horizontal direction.**

Geological Exploration Methods

Borehole Logging

a) Hole number, location, and surface elevation

b) Depth of the upper and lower limits of the layer being described.

c) Name of the primary constituent first and then, as a modifier, the name of the second most prominent constituent, for example: sand, silty.

d) Texture, size, shape and arrangement of individual minerals or particles.

e) Features of rock structure, bedding, laminations, cleavage, joining, concretions, or cavities.

Geological Exploration Methods

f) Colour.

g) Moisture content.

h) Mineral content and the approximate percentage of the more abundant minerals.

i) Permeability.

j) Geological age, name, and origin.

k) Strength and condition of rock, degree of weathering, and degree of cementation.

Geological Exploration Methods

l) Consistency and degree of compactness of fine materials as very soft, soft, medium, stiff, very stiff, and hard. Describe degree of compactness of coarse grained soils as very loose, loose, medium, dense, and very dense.

m) Unified Soil Classification Symbol.

n) SPT count and the test elevation or depth.

o) Other field tests, results and describe each test.

Geological Exploration Methods

p) Miscellaneous information, such as any drilling difficulties, core and sample recovery and reasons for any losses, type and mixture of drilling mud used to prevent caving or sample loss, loss of drilling fluid, and any other information that may help in interpreting the subsurface condition.

q) Water levels, the static water level and the date of measurement.

Geological Exploration Methods

Downhole and In Situ Testing

a) Joint orientation

(i) Impression packer

Uses plastic rubber packered against borehole wall to obtain impression of fractures and hence orientation.

(ii) Borehole camera

Views directly through a camera of fractures and hence orientation.

(iii) Borehole acoustic imaging

Uses a pulsed acoustic signal and reflection to obtain impression of fractures and hence orientation.

Geological Exploration Methods

b) In situ stresses

(i) Flatjack

Uses stress compensation principle by inserting a flat jack in a cut slot in rock and jack the rock to its original position before cutting.

(ii) Overcoring

Uses stress relief principle. A small borehole is instrumented, and then overcored. Deformation is measured during overcoring, as the stresses are released. From deformation and elastic properties of the rock, stresses can be estimated.

(iii) Hydraulic fracturing

A borehole is sealed and pressurised. In situ stress is induced from pressures to open a fracture and to keep the fracture open and propagating.

Geological Exploration Methods

c) In situ modulus

(i) Dilatometer

Inserts dilatometer and measure deformation with applied pressure.

(ii) Pressuremeter

Inserts pressuremeter in a borehole and measure deformation with applied pressure.

(iii) Plate load test

Applies load at a plate normal to rock surface and measure deformation with load.

(iv) P- and S-wave velocities

Measures P- and S-wave velocities and hence dynamics elastic and shear moduli.

Geological Exploration Methods

d) Groundwater

(i) Piezometer

Measures groundwater level and change.

(ii) Packer permeability

Measures permeability of a packered section. Usually applies 5 different pressures.

(iii) Falling and rising head

Uses falling or rising of water head to measure the permeability.

Geological Exploration Methods

d) Groundwater

(iv) Constant head

Pumps in or out water in a borehole to maintain constant water head, and measures permeability.

(v) Pumped well

Uses pumping wall and observation walls for large scale pumping tests.

Geological Exploration Methods

Laboratory Testing (I)

Mineralogy: Petrography

Physical: Density (dry, saturated or natural), porosity, water content, sonic velocity

Weathering: Visual examination, rock-soil ratio, petrography

Strength: Point load, uniaxial compression, triaxial compression, direct tensile, Brazilian tensile, shear strength

Geological Exploration Methods

Laboratory Testing (II)

Modulus: Uniaxial compression, triaxial compression, sonic velocity

Durability: Slake durability,

Swelling: Swelling index test

Permeability: Falling head, constant head

Joint properties: Normal stiffness, shear strength, permeability

Geological Exploration Methods

Trial Excavation

Various geological features and properties of the ground an be verified by trial excavation, e.g., experimental shafts and tunnels. In site tests can also be performed during the trail excavation.

Geological Exploration Methods

Construction Monitoring

Detailed assessment of geological features as exposed during actual construction through regular and systematic inspection and mapping of the tunnel face.

Monitoring measurements during construction, e.g., displacement and settlement are used to back calculate ground properties to compare with predicted ground conditions.

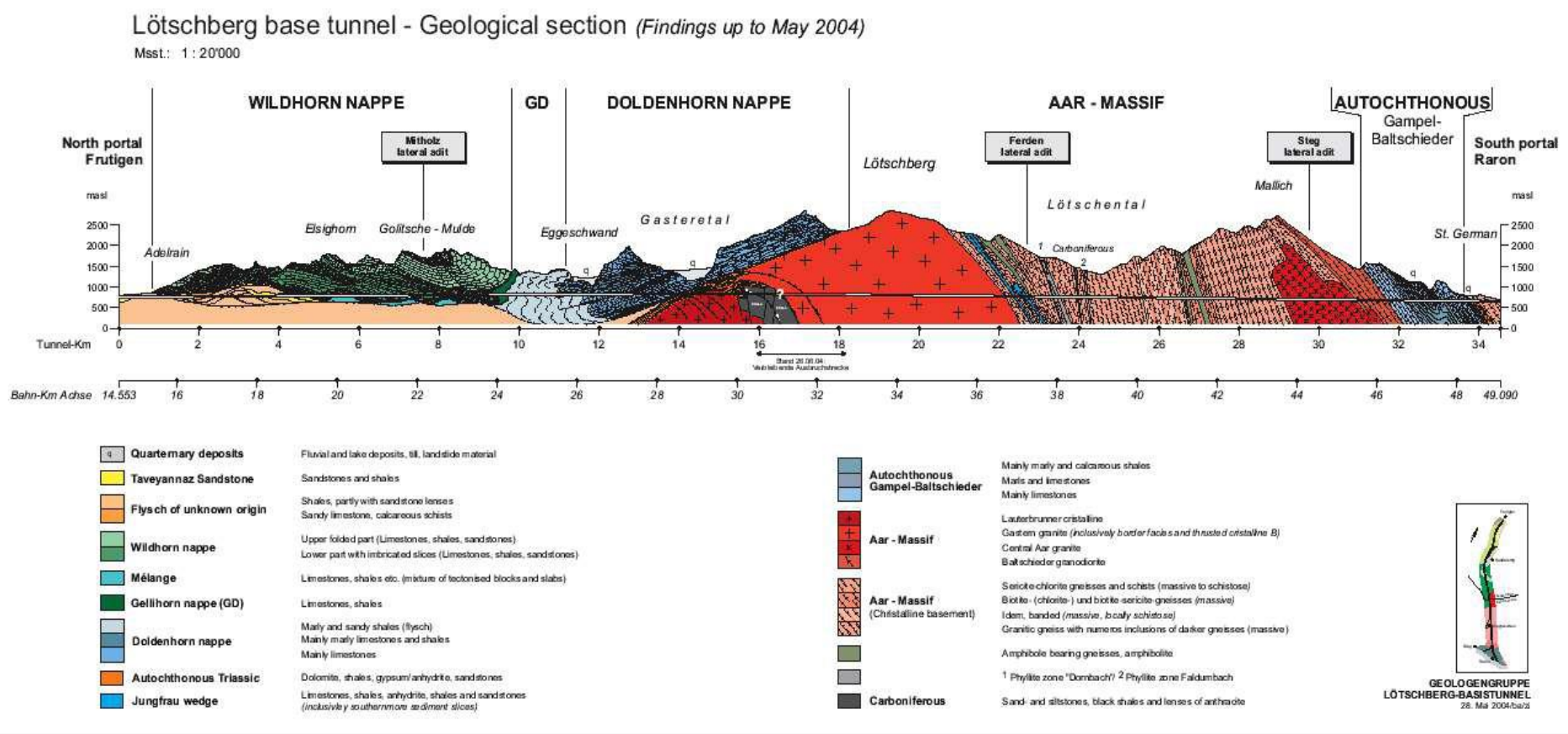
Geological Exploration Methods

Limitation of Geological Exploration

- **Engineering properties change with a wide range of conditions, such as time, season, rate and direction of loading, sometimes drastically.**
- **Groundwater is the most difficult condition/parameter to predict and the most troublesome during construction.**
- **Even comprehensive exploration programs recover a tiny drill core volume compared to the excavated volume of the tunnel (<0.0005%).**

Geological Sections and Profiles

Geological Section along Tunnel Route



Geological Sections and Profiles

Key Information in Geological Section

Major Information

- Rock formation types
- Geological structures
- Elevation and distance chainage

Specific Information

- Strength (UCS)
- Mineral content (quartz)
- Rock mass quality (RQD, RMR, Q)
- Water flow (flow rate, pressure, permeability)
- Other information relevant to construction

Geological Sections and Profiles

Scales of Geological Section

For public use

- **Generally very large scale with suitable size.**

For engineering use

- **Horizontal scale: 1:2000 (urban tunnels) to 1:5000 mountain tunnels**
- **Vertical scale: 1:500, generally is 1:5 to 1:10 to horizontal**

Investigation for Mountain Tunnels

Special Challenges for Mountain Tunnels

- **High cover of tunnel**
- **Unknown stress situation for the tunnel**
- **Potentially high in situ temperature**
- **Cover combined of quaternary deposits and rocks**
- **Restrictions for access**
- **Increased efforts for investigations**

Investigation for Mountain Tunnels

Selection of Tunnel Alignment

– **Project criteria**
- Portals
- Required slope of the tunnel
- Internal pressure / rock stress required

– **Intermediate adit tunnels**
- required for project layout
- required for construction

– **Geological criteria**
- Minimum rock cover
- Orientation to major structures

Investigation for Mountain Tunnels

Basic Requirements – Investigation from Surface

– Geological surface mapping

- Lithology / borders
- Geological structures, bedding schistosity, orientations
- Rock mass description – visual

– Studies of aerial photos and satellite photos

- Lineaments
- Major geological structures
- Quaternary deposits

Investigation for Mountain Tunnels

Hydrogeological Investigations

- **Survey of rivers: annual flow monitoring**
- **Survey of springs: annual flow monitoring**
- **Groundwater level: annual level monitoring**
- **Chemical water analysis**
- **Restrictions by protected areas for groundwater resources**
- **Groundwater temperature**

Investigation for Mountain Tunnels

Basic Requirements – Investigation Underground

– Portal area

- Investigation drillings
- Geophysical investigations
- Investigation tunnel

– Along the tunnel alignment

- Investigation drillings
- Geophysical investigations
- Pilot tunnel

Investigation for Mountain Tunnels

Basic Requirements – Excavation and Support (I)

– Rock mass Classification

- Rock Mass Rating RMR
- Q-System
- Geological Strength Index GSI

– Temporary support

- Stability required
- Relevant time (time interval to final lining)
- Specific requirements – aggressiveness of ground water

Investigation for Mountain Tunnels

Basic Requirements – Excavation and Support (II)

– Permanent lining

- Long term stability required
- Special requirements by the project
- Durability of lining

Investigation for Mountain Tunnels

Basic Requirements for Laboratory Testing

– **Drill and blast method**
- Rock strength
- Rock abrasivity, drillability index

– **TBM excavation method**
- Rock strength, rock boreability index
- Rock abrasivity, cutter life index
- Rock mineralogy
- Rock anisotropy