General report on Conventional Tunnelling Method

ITA Working Group
Conventional Tunnelling

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>> SUMMARY

ITA created the Working Group 19 in 2001, on the occasion of the 27th General Assembly at Milan. After collecting various national reports about the particular experiences made with Conventional Tunnelling in the member countries, after the 30th General Assembly at Singapore the working group started on the elaboration of the inter-national report and completed the Work during the 32nd General Assembly at Seoul.

The aim of the working group is to create a report as a guideline for clients, contractors and tunnelling engineers to promote international understanding by unifying the terminology and by presenting an overview of the current state of the art. The contents are valid for most parts of the world. Therefore the report highlights only the most important principles, but does not deal with the details.

The report starts with a definition of Conventional Tunnelling and illustrates some principles of Conventional Tunnelling. The high flexibility and the wide field of application of Conventional Tunnelling are highlighted.

The following main subjects will be dealt with this report:

Design, Construction Methods, Monitoring During Construction, Construction Contract and Site Organisation.

The report is applicable basically to all types of underground structures, such as traffic tunnels, caverns, hydro tunnels, pipe tunnels and shafts. However, specific questions (e.g. concerning shaft and cavern construction) are not covered.

Not all items are specific to Conventional Tunnelling but some generally applicable information has to be given to gain a better understanding.

This report is not a recipe book that would enable inexperienced readers to make decisions.

Especially in Conventional Tunnelling the knowledge of experienced engineers is essential for successful construction.

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1 >> Introduction

1.1. DEFINITION OF CONVENTIONAL TUNNELLING

The definition of what is “Conventional Tunnelling” is rather arbitrary, and subject to variations, depending on the concept adopted.
If the concept is based on excavation equipment, the term conventional tunnel could apply to any tunnel that is not excavated by a Tunnel Boring Machine (TBM). But today in tunnelling the TBM method has become very common and thus could also be regarded as “conventional”.

> Conventional Tunnelling in the context of this report means the construction of underground openings of any shape with a cyclic construction process of
>
> - excavation, by using the drill and blast methods or mechanical excavators except any full face TBM
> - mucking
> - placement of the primary support elements such as
>   - steel ribs or lattice girders
>   - soil or rock bolts
>   - sprayed or cast in situ concrete, not reinforced or reinforced with wire mesh or fibres

1.2. PRINCIPLES OF CONVENTIONAL TUNNELLING

Conventional Tunnelling is carried out in a cyclic execution process of repeated steps of excavation followed by the application of relevant primary support, both of which depend on existing ground conditions and ground behaviour. An experienced team of tunnel workers (miners), assisted by standard and/or special plant and equipment shall execute each individual cycle of tunnel construction.
The Conventional Tunnelling Method mainly using standard equipment and allowing access to the tunnel excavation face at almost any time is very flexible in situations or areas that require a change in the structural analysis or in the design and as a result of this also require changes in the support measures.

A standard set of equipment for execution of Conventional Tunnelling may consist of the following items:

- Drilling jumbo to drill holes for blasting, rock bolting, water and pressure release, grouting etc.
- Road header or excavator in cases where blasting is not possible or not economic
- Lifting platform allowing the miners to reach each part of the tunnel crown and of the tunnel face
- Lifting equipment for steel sets
- Loader or excavator for loading excavated ground onto dump trucks
- Dump trucks for hauling excavated ground
- Set of shotcrete manipulators for application of wet or dry shotcrete.

Using this standard set of equipment the following changes can easily be applied during construction if ground conditions change or if monitoring results require action:

- Increase or decrease of support, e.g. the thickness of shotcrete, number and/or lengths of rock bolts per linear meter of tunnel, spacing and dimensions of steel arches, number and lengths of spiles, application of shotcrete at the tunnel face, bolting the face etc.
- Variation of ring closure time - which is the time between the excavation of a section of the tunnel and the application of partial or full support - or variation of ring closure distance from excavation face
- Introduction of primary support ring closure
- Variation of explosives charge per blasting round and variation of detonator sequences.

Other variations in the design enable one to react to changes in the stand-up time of the ground encountered:

- Increased or decreased length of excavation round (common round lengths vary from 0,5 m to 4,0 m)
- Partial excavation by splitting the excavation face into the crown, bench, and in-vert excavation steps or even further in pilot and sidewall galleries and in stag-gered bench/ invert excavations

In case exceptional ground conditions are encountered - regardless of whether predicted or not - the Conventional Tunnelling Method can react with a variety of auxiliary construction technologies like

- Grouting: consolidation grouting, fissure grouting, pressure grouting, compensation grouting
- Technologies to stabilize and improve the ground ahead of the actual tunnel face like forepoling, pipe umbrella, horizontal jet grouting, ground freezing etc.

1 >> Introduction

Conventional Tunnelling in connection with the wide variety of auxiliary construction methods enables experienced project managers to make the most appropriate choice to achieve safe and economic tunnel construction even in situations with changing or unforeseen ground conditions. It allows reacting in both directions - depending on the ground - either changing to the less favourable or towards the more favourable side. This flexibility makes Conventional Tunnelling the most advantageous tunnelling method in many projects.

Underground works, constructed by Conventional Tunnelling, include linear tunnels such as railway tunnels, motorway tunnels or hydro tunnels, but also hydroelectric caverns, underground storage caverns, metro and railway stations. They can be located at a shallow depth or under high overburden, in stable or loading ground, under genuine rock pressure, below the phreatic surface or in dry conditions.
The Conventional Tunnelling Method (CTM) is the best for projects with highly variable ground conditions or for projects with variable shapes.

Conventional Tunnelling enables:

- A greater variability of the shapes
- Better knowledge of the ground by using systematic exploratory drillings at tunnel level ahead of the face
- Greater variability in the choice of excavation methods according to the ground conditions
- Greater variability in the choice of excavation sequences according to the ground conditions
- Easier optimisation of the primary support using the observational method in special cases
- A greater variability in the choice of auxiliary construction methods according to the ground conditions

Conventional Tunnelling is especially convenient for:

- Difficult ground with highly variable ground conditions
- Projects with highly variable shapes of cross section
- Projects with a higher risk of water inflow under high pressure
- Projects with difficult access
- Short tunnels

It is the responsibility of experienced engineers to make the most appropriate choice according to the science of engineering and their personal experience for a safe and economic tunnel construction.

2.1. INTRODUCTION

The design work includes in general:

- The determination of the geometric layout of the underground structures, i.e. the horizontal and vertical alignment of the tunnels, the location and axis direction of the caverns and the choice of the tunnel system
- The determination of the shape and size of the profile (tunnel cross section)
- The determination of the type of excavation (full-face or partial-face excavation, sequence of excavation phases along the tunnel axis), of the temporary and final support measures as well as of auxiliary construction measures such as drainage or ground improvement.

The scope and degree of refinement of design depends on the design phase (Section 2.2) and on the type of contract.
The project is the result of an optimisation process involving the evaluation of variant de-signs. The aim is to determine the most economic solution for the construction, use, operation and maintenance of the underground works, taking into account:

- The planned use of the structure
- The functional requirements for the equipment
- The requirements for user safety
- The design working life
- The requirements for waterproofing
- The safety, serviceability and environmental requirements in the execution and operation phases

An adequate geological-geotechnical exploration and a thorough description of the ground in the early planning stages are important, as the ground conditions may be decisive not only for the shape of the cross section and the method of construction but also for the tunnel system and the alignment.

2.2. DESIGN PHASES

The design of a tunnel project is often subdivided into different phases according to the project stages:

- Conceptual design
- Preliminary design
- Tender design
- Final design

2.2.1. Conceptual Design

The scope of the conceptual design is to select or confirm the alignment of the tunnel and to provide the client with information for the decision-making process. Aspects of tunnelling related to a particular alignment are highlighted and investigated in detail.

2.2.2. Preliminary Design

Based on the selected alignment, the conceptual design of the project is refined and an Environmental Impact Study is carried out. The priority of the preliminary design stage is focused on the legal aspects of water resources, forestry and environmental protection.
Different clients and authorities require individual substages for railway or road tunnels. The common target however is to receive the approval for construction of the project from the authorities.

2.2.3. Tender Design

The scope of the tender design is to detail the works in such a way that the exact pricing of each work item is feasible. Also contractual documents are elaborated.

2.2.4. Final Design

The scope of the final design is the detailing of the work described in the tender stages in such a way that they can be constructed in an economical way, to be structurally safe, dimension-ally accurate and functional.

2.3. INVESTIGATION AND DESCRIPTION OF THE GROUND CONDITIONS

2.3.1.General

The geological investigations form the basis for the description of the ground.
The description of the ground is required for the elaboration of a geological model that is adequate for the preparation of the geotechnical model, for the assessment of the ground, its subdivision into different geological units or homogeneous zones and the recognition and assessment of potential hazard scenarios. The characteristic properties of the ground must be reported in the geotechnical model.
Geological, hydrogeological and geotechnical investigations shall be carried out beforehand as well as supplementing during the design and construction phases and shall be geared to the construction and use of the underground structure.
The geological investigations are the owner's responsibility. The investigations should be planned and supervised by experienced engineering geologists in close cooperation with the design engineer and the owner. The elaboration of the geotechnical model is the responsibility of the engineering geologist.

2.3.2. Common exploration methods

The following well-known exploration methods are mainly employed to investigate the site conditions:

- Analysis of existing geological records (e. g. for structures already built in the same or similar geological formations)
- Field mapping
- Remote sensing
- Exploratory boreholes
- Field tests
- Laboratory tests
- Exploratory adits and galleries (pilot tunnels)
- Geophysical measurements

2.3.3. Evaluation and presentation of the results of the geological investigation

The origin of all data shall be documented in a clear and comprehensive way. It has to be stated whether the information derives from:

- Field or laboratory tests
- References to the technical literature
- Information in existing geological reports
- Empirical values
- Estimates or assumptions

Known gaps in the results presented shall be pointed out. The investigation and measurement methods shall be described. In the determination of the geotechnical properties of soil and rock using laboratory and field tests, standardised methods shall be employed if possible.

2.3.4. Extent of site investigations

The extent of the site investigations in the design phase shall be project-specific, executed in suitable steps, corresponding to the planning stage and to the complexity of the geology and taking into account economic criteria. In zones of predicted hazards (such as faults, discontinuities, cavities, etc.), in portal areas and in zones with small overburden the ground may have to be studied in greater detail.

The extent of the site investigations carried out during construction depends on the actual conditions encountered and the predicted hazards (discontinuities, cavities, occurrence of gas and water). The investigations serve to specify measures to reduce and manage the risks in accordance with the hazard scenarios.

2.3.5. Description of the geological conditions

The geological description shall be provided for each geological unit or homogeneous zone. The basis for this is given by the geological investigation. The qualitative description shall, as far as possible, be accompanied by quantitative information.

Geological units in soil are normally described as geological formations of the same origin (e.g. moraines, river gravels, weathered marl, and clay deposits). The description of the soil is based on standard classifications, combining information concerning the petrography of the components and their properties (shape, degree of roundness, degree of weathering, strength, swelling capacity etc.). The soil structure (layering, anisotropy) as well as any special features has to be described (e.g. the presence of blocks or organic constituents). The description shall be supplemented by further information, e.g. grain size distribution, permeability, density de-gree of saturation, behaviour when exposed to free water, etc.

In the case of rock, one must distinguish between rock description based on an intact specimen and the description of the rock mass as a whole. The rock specimen description in-cludes mineral content, structure and texture as well as the petrographic identification.

The description of the rock mass includes the following elements:

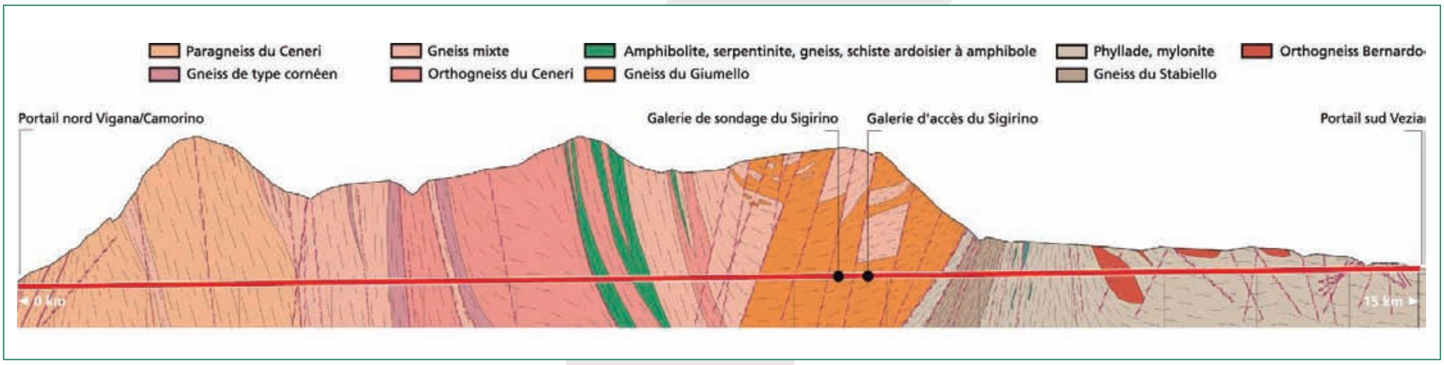
- General geological structure (homogeneous zones, sequence of different types of rock, stratification, foliation, density, fault zones etc.)
- Description of the discontinuities
- Degree of weathering, karst formation, hydrothermal transformations
- In situ stresses and assumed tectonic residual stresses
- Fault zones, such as zones of rock mechanically transformed by tectonic processes (kakirite, cataclasite), as well as karst formations must be specifically recorded. Such zones shall be described like homogeneous geological zones, depending on their extent and frequency. The geometrical data on the position in space of the discontinuities and fault zones shall be reported both as absolute in space as well as relative to the structure (e.g. with respect to the tunnel axis).

2.3.6. Description of the hydrogeological conditions

The local and regional hydrogeological conditions shall be described. In particular, aquifers, their possible interaction, groundwater build up and barriers as well as the regional flow conditions and the relationship to surface waters shall be summarized.

In particular the following items shall be described:

- The possible effects of the structure during its realisation and service life on the existing hydrogeological conditions (quantitative and qualitative effects)
- The possible effects of the groundwater on the facilities during construction (water inflow) and operation due to pressure effects, chemical aggressiveness, sintering etc.
- The type of circulation (pores, discontinuities, karst), the permeability parameters, the level of the groundwater, the flow direction of the water, etc., in each aquifer



Geology

2.3.7. Description of the geotechnical properties

The geotechnical properties of soil and rock shall be described. Measurements of geotechnical properties, such as the strength, deformability, swelling and permeability parameters, abrasivity shall indicate the number of specimens, range of values and spatial validity. Comparative values, empirical values and estimates shall be denoted as such. The sources of information shall be given.

For rock it is necessary to distinguish clearly between the geotechnical data for the intact rock itself and the discontinuities (rock boundaries, fracture surfaces, karst) as well as the filling in of the cavities.

2.3.8. Description of gas occurrences

The occurrence of rocks with a potential gas source or with gas reservoirs together with the corresponding migration paths as well as already known indications of gas in similar geological formations shall be investigated within the design framework. From this it must be clear, whether the possibility of gas deposits and flooding exists and what effects are to be expected due to the escape of gas in order to plan appropriate hazard mitigation measures.

2.3.9. Further Information

The descriptions shall include the following data, as applicable:

- In situ stresses
- Creep movements / areas with landslides
- Neotectonic movements
- Temperature of rock mass
- Seismic risk
- Substances that present a health hazard (quartz, asbestos etc.)
- Radioactivity (including radon)
- Zones of residual waste or contaminated ground
- Ground water contamination

2.3.10. Extent of the description of the ground conditions

Experience has shown that full disclosure of geotechnical information would reduce the risk to both the client and the contractor. Therefore full disclosure of geotechnical information (see 5.3.7) is recommended for Conventional Tunnelling.

2.4. LAYOUT OF UNDERGROUND STRUCTURES

2.4.1. Choice of tunnel system and of alignment

The tunnel system comprises all underground works that are necessary to achieve the planned use and ensure the safety of persons and material assets. Besides the main tunnel tube(s), the tunnel system may comprise, e.g. cross-passages, adits and shafts as escape routes or other ancillary structures such as ventilation shafts or caverns for technical equipment. The choice of the tunnel system is based mainly on operational, organisational and safety considerations. The ground conditions and the topography (layout of the access tunnels and shafts) may also have an influence on the selection of the tunnel system. For example, construction time and cost risks may be different for a twin tunnel than for a double-track tunnel.

The vertical and horizontal alignment of the tube(s) also depends on several factors such as:

- The use of the tunnel (maximum longitudinal gradient, minimum curvature)
- The drainage considerations during construction and operation
- The accessibility and natural hazards in the portal areas
- The ground conditions

If possible, the alignment should be adapted to the ground conditions in an early phase of the project, as hazards and the respective construction time and cost risks can be avoided or re-duced by the choice of a different alignment.

Aspects of execution or operation and safety (such as the necessity of intermediate adits, ventilation shafts or escape adits) may also influence the choice of the alignment. This is particularly true for long tunnels.

The ground conditions shall be taken into account when specifying the spacing between two adjacent tunnel tubes. In special cases (e.g. branching, portal region) other criteria may be decisive.

Similar considerations apply to the selection of the location and axis orientation of caverns.

Twin tube tunnel

2.4.2. Shape of the cross section

The shape and the dimensions of the cross section of underground openings are determined essentially by

- The serviceability requirements associated with the use of the underground works,
- The geological-geotechnical conditions and
- Construction aspects

The required clearance profile is a key factor in the determination of the cross section of the underground opening. The clearance profile is defined according to the scope of the structures, e.g. railways, metro, highways, utility lines, access, escape routes, storage, power plants, protective shelters or military installations. Besides the scope of the structure, further serviceability criteria required by the client can be decisive for the choice of cross section, e.g.:

- Additional space requirements for operating and safety equipment (cable installations, signalling systems, signage, lighting, ventilation, etc.)
- Aerodynamic requirements
- Required water-tightness with respect to water inflow from the ground or water losses from the opening (e.g., the requirement of a complete sealing against pres-surised groundwater necessitates an invert arch or even a circular cross section)
- Maintenance requirements
- Requirements arising from the safety and rescue concept (escape routes within the tunnel, availability of the facilities in emergencies)

The shape and the size of the cross section depend also on the ground conditions, as the latter determine the extent of the required support measures in the construction stage (tunnel support) and in the service stage (permanent lining). Inadmissible reduction in size of the opening due to ground convergence must be avoided by means of additional excavation to account for ground deformations and corresponding support measures.
Weak rock zones, squeezing or swelling rock and soft ground (soils) require a circular cross section or at least a horseshoe-shaped cross section including an invert arch.
Economic considerations and the availability of the necessary equipment may be decisive for the construction method and have, therefore, a considerable influence on the shape of the cross section. In contrast to TBM or shield tunnelling, the cross section of tunnels excavated by conventional methods can be freely chosen within the constraints of the geological conditions.
The main shapes are:

- Horseshoe cross section
- Horseshoe cross section with an invert arch
- Circular cross section

In the determination of the shape and dimensions of the cross section attention must be given to tolerances with respect to driving accuracy, construction tolerances and surveying tolerances.

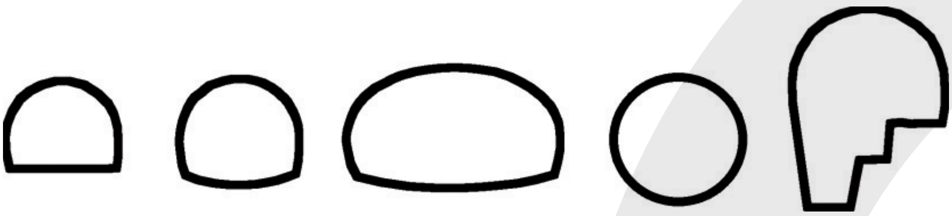


Fig. 1: Typical cross sections in conventional tunneling

2.5. EXCAVATION AND SUPPORT

2.5.1. General

The aim of the structural design is the determination of an economic final structure and a construction method fulfilling the safety, serviceability and environmental protection requirements for the given ground conditions. The design engineer is responsible for an accurate design.
The structural design serves as a basis for the approval procedures, the tender documents (determination of excavation and support classes and their distribution) and the determination of the excavation and support methods used on site.
The design work consists of the preparation of different structural alternatives taking into consideration the relevant boundary conditions, checking the feasibility and assessing the implementation possibilities with regard to fulfilling the design requirements.
The successful construction of underground works depends on the detailed consideration of all factors that are relevant for the structural behaviour. In underground works, the structure comprises the ground surrounding the opening and all temporary or permanent support ele-ments necessary for equilibrium or limitation of deformations. The factors governing struc-tural behaviour can therefore be summarised as follows:

- Ground structure and properties, hydrogeological conditions
- Initial stresses
- Dimension and shape, location and alignment of the opening
- Method of excavation (in the cross section and in the longitudinal direction)
- Support measures (temporary and permanent)

The information required for the structural design of underground openings is manifold and can be grouped according to the following sources:

- Geological explorations and field tests
- Laboratory investigations
- Structural analyses using ground-structure interaction models
- Field tests and measurements
- Engineer's own experience

2.5.2. Outline of the design process

The design is developed stepwise, beginning with the determination of zones with the same ground behaviour during construction (homogeneous zones) and ending with the definition of the excavation and support classes.

In a first step, the project area is subdivided into homogeneous zones having similar conditions with respect to:

- Geological and hydrogeological conditions (based upon the description of the ground, see Section 2.3).
- Topographical conditions (e.g. depth of cover, slopes in the vicinity, etc.).
- Environmental aspects (e.g., structures at the surface, nearby underground structures, groundwater resources to be protected, etc.)

The definition of the tunnel segments has to be based on the current knowledge in each project stage. The number of tunnel segments is project-specific and depends on the design stage, as well as on the complexity of the geological conditions in the project area. In general, a rough subdivision of the alignment will be sufficient in early planning stages, while the increased information in subsequent stages may necessitate a higher resolution.

In the following step, based upon experience and simplified calculations, a rough assessment of the project conditions, potential hazards and necessary measures is carried out and a preliminary decision is made concerning the cross section and the construction method for each section of the alignment.

The usual cross section in sufficiently firm rock and without any water pressure is often a horseshoe-shaped cross section. In this case the rock around the hollow space is part of the load-carrying structure and the final lining has to carry only small loads due to the ground. In less firm or more weathered rock the loads due to the ground increase so that the tunnel's cross section has to be closed at the base.

As a first improvement a straight horizontal invert would be planned, becoming more and more vaulted with increasing weakness of the ground. In soft ground or under high water pressure the shape of the cross section has to become a circular ring.

In the next step excavation and support classes have to be developed for each alignment section. These are determined by the predicted ground and water conditions.

These classes describe the way to proceed with the excavation steps and the support measures, each within a certain and defined range. The classes vary according to the anticipated ground behaviour upon excavation.

The main features of the excavation and support classes are the period between excavating and supporting, the requirement of subdividing the cross section, the necessity of advanced support measures and the requirement of supporting the face. In poor ground conditions, for example, the cross section will be divided in several headings, which must be carefully excavated and supported in short steps. In another alignment section there may be medium firm rock, so that here an excavation and support class must be planned with two partitions of the cross section, with drill and blast excavation in long steps and with reduced support measures. For each alignment section the planned excavation and support classes should be adapted to the most likely ground conditions as well as to potential hazard conditions that can be deduced from the geotechnical conditions.

Subsequently, the potential hazards are described and analysed in detail by taking into account the selected preliminary technical solution. Depending on the results of this assessment, mitigation measures are planned. These may be modifications of the initial method, introduction of additional support elements

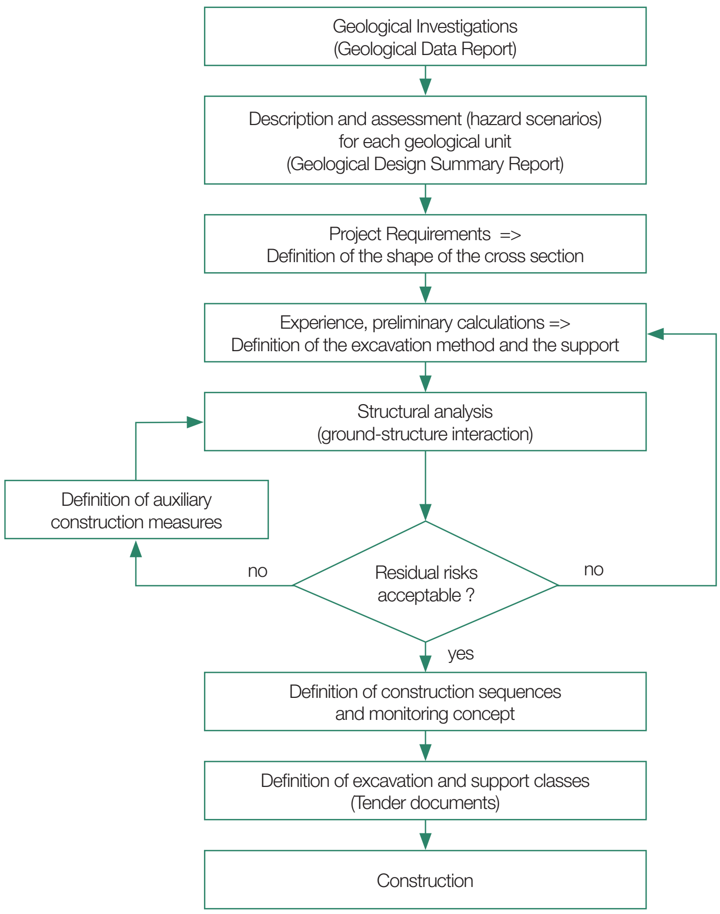


Fig. 2: Design steps for conventional tunnelling

or even the selection of another method. The assessment is carried out for each construction stage as well as for the operation phase.
As a rule all types of construction procedure have their own specific hazard scenarios that have to be evaluated in detail. Therefore, the technical solution is developed iteratively by repeating the procedure sketched above until a solution is determined that fulfils all safety and serviceability criteria for the alignment section under consideration.

It may be useful to work-out technically equivalent design alternatives for each alignment section and select the final solution in the next stage, where a synthesis over the different alignment sections is carried out by also taking into account construction time and cost considerations as well as aspects of the execution of the construction works. For example, frequently changing the excavation and support methods will, in many cases, be technically and economically unfeasible.
Based on the results of the previous steps the alignment is divided into regions with similar excavation and support requirements. Both excavation and support have to be determined to a large extent prior to the construction.
All possible geological conditions should be addressed with a defined range of excavation and support methods as well as the probability of occurrence.

In the final step, the design must be transformed into a cost and time estimate for the tendering process. Excavation and support classes are specified, based on the evaluation of the excavation and support measures. The excavation and support classes form the basis for compensation clauses in the tender documents. An excavation and support class may be assigned to more than one tunnel section, as the same measures can be appropriate for different conditions.
To establish the bill of quantities a prediction of the distribution of excavation and support classes is required. This distribution has to be established for the most probable conditions and should also include the likely variations of excavation classes resulting from the ground conditions. When establishing the distribution of excavation and support classes along the alignment the heterogeneity of the ground has to be considered.

2.5.3. Hazards and their mitigation
The recognition and the assessment of potential hazards as well as the planning of appropriate mitigation measures are fundamental to the design of underground structures.
In the present document, the term "hazards" means an event that has the potential to impact on matters relating to a project, which could give rise to consequences associated with:
a) Health and safety
b) The environment
c) The design
d) The design schedule
e) The costs for the design
f) The execution of the project
g) The construction schedule
h) The costs associated with construction
i) Third parties and existing facilities including buildings, bridges, tunnels, roads, surface and subsurface railways, pavements, waterways, flood protection works, surface and subsurface utilities and all other structures/infrastructure that can be affected by the execution of the works.

Hazards shall be identified and evaluated on a project-specific basis and their consequent risks must be identified and quantified by risk assessments through all stages of a project

Possible hazards in underground construction include, but are not limited to:
- Collapse of roof or of the ground above the opening up to the ground surface
- Rock fall
- Rock burst
- Failure of the working face
- Reduction of section (convergence)
- Heave of the tunnel floor due to swelling
- Deterioration of lining due to aggressive groundwater
- Ground surface settlement or heave causing damage (e.g. when tunnelling under traffic routes, buildings, bridges, dams, etc.)
- Inflow of water or mud
- Escape of gas (methane, radon, etc.) or release of dangerous substances into the atmosphere like dust affecting the lungs (quartz, asbestos)
- High temperatures in the rock mass or in the groundwater
- Seismic actions (e.g. at transition between underground construction and cut-and-cover construction)
- Effects on springs and surface waters

The hazards, individually or in combination, constitute possible hazard scenarios. The description of the hazards in the form of hazard scenarios is primarily qualitative and should, if possible, be augmented by quantitative data. Causes and mechanisms shall be reported.
The assessment of hazards should cover the different locations of the underground construction works and the surrounding rock mass as well as the different construction stages and the planned service life.
The assessment shall be carried out in close cooperation with the experts involved in the project (designer, engineering geologist and resident engineer).

In general, hazards can be counteracted by avoidance, prevention or hazard reduction hazard, for example:
- Choice of a different alignment
- Choice of a structure with less susceptibility with respect to the considered hazards
- Choice of a structure that is able to suffer local damage and the loss of an individ-ual structural element or a whole section of the structure without total failure
- Choice of a structure that does not fail without prior warning
- Choice of suitable geotechnical auxiliary measures
- Choice of suitable construction materials
- Appropriate structural analysis and dimensioning
- Careful detailing of the structural elements including waterproofing and drainage
- Execution as planned and carried out with proper care
- Suitable execution checks and warning systems (monitoring with instruments, see section 4)
- Special protective measures for neighbouring structures and plant
- Measures to deal with critical events
- Appropriate monitoring and maintenance

Both the assessment of the hazards and the design of the mitigation measures are based on an in-depth understanding of the underlying mechanisms, experience from previous similar projects, structural analysis and careful dimensioning (Section 2.5.4). The planned construction method must be evaluated with respect to safety and serviceability (i.e., that displacements are within acceptable limits) requirements for all construction stages. Furthermore, the compliance with environmental requirements (surface settlements, vibrations, ground water disturbance, etc.) should be checked. The variability of the influencing factors has to be considered in the assessment.

As far as possible, the structural concept, the dimensioning and the construction methods shall be checked and assessed according to experience gained on comparable projects. Substantial divergences from normal construction practice shall be analysed and substantiated. In the assessment of the implementation possibilities special attention shall be paid to

- The simplicity of execution,
- The insensitivity to unavoidable execution inaccuracies or possible errors in execution,
- The ability to adapt to possible changes in ground behaviour, and
- The execution of the works

For the evaluation of the individual hazards (with and without remedial measures), a risk analysis should be carried out by means of a qualitative assessment of the probability of occurrence and by a quantification of the impact. Due to the fact that the different input data is normally quite inaccurate a simple qualitative method is recommended rather than complicated mathematical models. A simple and efficient method of risk evaluation is to determine the risk R as the product of the probability of occurrence P multiplied by the impact or loss of time I (Risk R = P x I). The probability of occurrence and the amount are estimated values.

The evaluation criterion and intervention strategy are project-dependent. The value of risk R after implementing planned remedial measures is the remaining, unavoidable risk.

2.5.4. Structural analysis and dimensioning
Design decisions should be made on the basis of a cautious qualitative and quantitative analysis of all relevant factors. Besides engineering judgement based upon the engineer's own fund of experience, modern methods of structural analysis (i.e. numerical methods) may be applied.

The quantitative verification of structural safety or serviceability may be dispensed with if the respective design requirements can be adequately ensured using well-proven design and/or execution measures. In fact, some actions can often be mitigated better using design measures or by eliminating the action than by dimensioning according to limit states. In order to judge the effectiveness of constructional and execution measures, reliable, comparable and transferable experience must be available.

The proper use of structural analysis requires a thorough understanding of and a "feel" for the complex processes involved in the construction of underground openings as well as a good background in geotechnical and structural engineering. Therefore structural analysis cannot make up for inadequate experience or intuitive insight into the problems. Thus the information provided by structural analysis supplements the basic knowledge that is expected of a tunnelling engineer. One is less likely to go wrong, therefore, when one starts from the wealth of knowledge already accumulated in tunnelling practice and then fits the information obtained by structural analyses into the framework of this basic knowledge.
The goal of the analysis is to investigate quantitatively the behaviour of the structure (described basically in terms of deformations and stresses) in the considered dimensioning situations taking into account the critical influence factors. The starting point of the structural analysis is the conceptual design.

A clear formulation of the particular problem facing the en-gineer is required before carrying out a structural analysis. On the basis of this formulation of the problem a suitable structural model can be established and the variations in the required input data can be defined by specifying of the upper and lower bounds.
The structural model idealises the complex reality with respect to the static system, the material behaviour and the loads. The structural model comprises the entire structure, i.e. the ground surrounding the opening and the temporary or final support elements. It connects actions, geometrical quantities and the properties of the construction materials and the ground for the purpose of structural analysis. The ground model is part of the structural model and comprises, in an idealised way, the geological structure and properties of the ground. The structural model must be suitable for predicting the structural behaviour in the dimensioning situations under consideration. It should, on the one hand, approximate as closely as possible the real situation and, on the other hand, be as simple as possible. The methods of structural analysis should be based on standard engineering practice or empirically proven theory.

Depending on the particular questions to be answered by the analysis, different structural models may be decisive. It is possible to assume different models for the same problem (behaviour hypotheses) and carry out a variation of parameters of each model. In this manner it is possible to single out the important factors and to compare the results corresponding to pessimistic and optimistic estimates.
Attention shall be given to parameters exerting a large influence. The results of the structural analysis shall be checked for plausibility, keeping in mind that they do not refer to the actual conditions but to the model considered. The validity of the computational results is conditioned by how well the model corresponds to reality. Since structural modelling also involves subjective assumptions, the final results are not beyond doubt. Structural analyses provide useful indications, but not proofs of the structural behaviour. Computations, therefore, cannot dictate important decisions but only provide a reason for these decisions.

The dimensioning situations, the assumptions made in the structural analysis, the analytical models and the verifications of structural safety and serviceability shall be clearly documented in the technical report. Computational results should be presented in the form of diagrams, which give a good summary of the results and allow various computed cases to be easily compared. For conclusions affecting constructional decisions the computed deformations in the ground and stresses in the lining are of especial value.

2.5.5. Modifications to construction method on site

Depending on the geological complexity, the extent of the geological pre-investigation and available experience from other projects in similar geological conditions, the information concerning the ground may be subject to uncertainties.
If the structural behaviour cannot be predicted with sufficient reliability based on site investigations, structural analysis and comparable experience, the design may permit or foresee construction method modifications during construction, provided that the relevant hazards can be detected and localised in time by observations and they do not lead to sudden or uncontrollable failure (s. Section 4 "Monitoring"). Otherwise, constructional measures and suitable types of supports must reduce the potential hazards in order to comply with the safety requirements.
For the purpose of construction method modifications on site, the information gained during execution both on the ground properties and on the structural behaviour shall be introduced into the current process of design and execution.

In particular, the design should specify:

- Relevant mechanisms endangering safety or impairing serviceability during construction
- The information to be collected on site during construction, for example geological records of the tunnel face, results of advance probing, qualitative observations (such as signs of excessive stress in the lining or failures of the face) or monitoring results (see Section 4 "Monitoring")
- Criteria for the selection of excavation, support or auxiliary measures
- That the criteria may be based upon qualitative observations or control values (in general the deformations of the opening and its surroundings) determined by structural analyses or experience
- The actions to be taken for every foreseeable significant deviation of the observational findings from the expected ones
- A management concept with all technical and organisational provisions to allow a timely decision-making process during construction

During construction, all relevant data, concepts, considerations and decisions shall be recorded in such a way that a review of the decision making process is possible.

2.6. FINAL LINING

An underground space ex cavated by the Conventional Tunnelling Method may need a final (secondary) lining in addition to the primary lining according to the requirements of the project to

- Cater for all the final load cases
- Fulfil the final safety margin
- Include the necessary protection measures (e.g. water tightness)
- Guarantee the required service life time

Generally two options exist to construct the final (secondary) lining:

- Installation of an independent secondary lining that is normally dimensioned to withstand all the final load cases.
  The secondary lining can consist of shotcrete or cast in situ concrete.
  According to the requirements of the project the final lining consists of unreinforced concrete or reinforced concrete (steel bars or fibres).
- Installation of additional layers of shotcrete to strengthen the primary lining for all the final load cases.

2.7. TENDER DESIGN DOCUMENTS

Based on the individual reports submitted by the various expert teams involved in the project, a technical report should be prepared documenting the decision-making process and summarising the results of the design.
Finally the tender design documents should contain:

- The contract documents
- A summary of the results of geological and geotechnical investigations, and the interpretation of the results
- A description of the ground and the associated key parameters
- A description of the possible hazards, the relevant influencing factors, the analyses performed, and the underlying geotechnical model
- The specification of excavation and support, relevant scenarios considered, analyses applied, and results
- A baseline construction plan
- Detailed specifications concerning the baseline construction plan (including measures to be determined on site if any)
- The determination of excavation and support classes, their distribution along the alignment
- The bill of quantities
- The technical specifications
- The drawings

The baseline construction plan in the tender design documents describes the expected ground conditions (geological model with distribution of ground types in the longitudinal section), the excavation and support types (round length, excavation sequence, overexcavation, invert distance, support quality and quantity, ground improvements, etc.) as well as zones, where specific construction requirements have to be observed. The baseline construction plan also has to contain clear statements describing which measures cannot be modified during construction, as well as the criteria and the actions for possible modifications and adjustments during construction.

3 >> Construction methods

3.1. EXCAVATION METHODS

The excavation methods for Conventional Tunnelling are:

- Drilling and blasting mainly applied in hard rock ground conditions
- Mechanically supported excavation mainly used in soft ground and in weak rock conditions (using roadheaders, excavators with shovels, rippers, hydraulic breakers etc.)

Both excavation methods can be used in the same project in cases with a broad variation of ground conditions. In both excavation methods the excavation is carried out step by step in rounds. The round length generally varies from 4 m in good conditions to 1 m or less in soil and poor ground conditions (e.g. squeezing rock). The round length is the most important factor for the determination of the advance speed.

The design engineer shall prescribe or limit the choice of the method of excavation only if there are compelling reasons based on project restrictions. The responsibility of the selection of the excavation method should be left to the contractor, based on the owner's description of the ground conditions and the limits set by the design engineer.

Drilling and blasting, full face

Mechanical excavation, top heading bench

Excavation with shovel

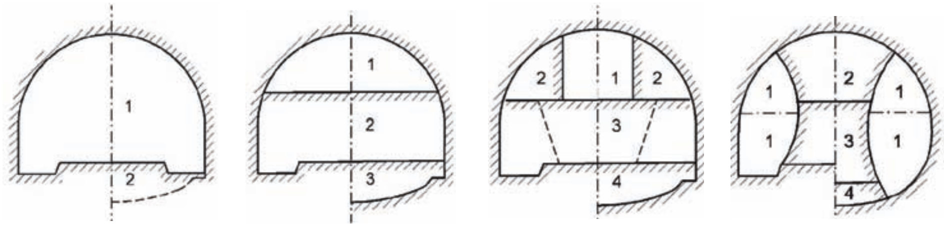
Face support with shotcrete

Road header excavation

Conventional tunnelling in squeezing ground (full face)

3.2. EXCAVATION SEQUENCE

Conventional Tunnelling allows full-face and the partial excavation of the tunnel cross sec-tion. Besides the structural analysis an important criterion for selecting the adequate excava-tion sequence is the length of the individual excavation-steps/rounds, which depends on the stand-up time of the ground without support. In good ground conditions the maximum round length is limited by the acceptable tolerance for overbreak, which is mainly an economic criterion when overbreak has to be filled up to the design line of the tunnel circumference.



Full face — *Partial excavation top heading/benching/invert* — *Partial excavation (caverns)* — *Partial excavation with side drifts*

Fig. 3: Typical excavation sequences in conventional tunneling

Re profiling

Re profiling

Both excavation types (full-face and the partial excavation) allow exploratory drillings from the face at any time.

Full-face excavation is used for smaller cross sections and in good ground conditions with long stand-up times. Since a high degree of mechanisation of the work and the use of large, high performance equipment has become common, also bigger cross sections (70 to 100 m^2 and more), even in difficult rock conditions (e.g. squeezing rock) are excavated with the full-face method. In any case, face stability shall be given serious consideration and often face support - bolting, shotcrete etc. - becomes necessary.

Full-face excavation allows the immediate closure of the primary support ring, close to the excavation face.

Partial excavation is mainly used for big cross sections in soils and unfavourable ground conditions. There are several types of partial excavation such as top heading, bench- and invert-excavation, side drifts, pilot tunnel, etc. Partial excavation, allows the combination of the different excavation methods in the same cross section, e.g. blasting in the top heading and excavating the bench by using a mechanical excavator e.g. a roadheader.`

The choice whether full-face or partial excavation is preferable depends on ground properties but also on environmental aspects, on the magnitude of settlements at the surface and economic considerations. In special cases both excavation sequences can be used. However, frequent changes in the type of excavation are uneconomical.
Today full-face excavation is also becoming possible in difficult ground conditions.

Partial excavation

Top heading

3.3. PRIMARY SUPPORT

The purpose of the primary support is to stabilize the underground opening until the final lining is installed.
Thus the support placement is primarily a question of occupational health and safety but it is also a question of the usability of the tunnel itself as well as of the protection of the envi-ronment (neighbouring buildings, lines of communication in or above ground facilities, etc.).
In many cases it may become necessary to apply the support system in combination with auxiliary constructional measures.

The most common elements for the primary support are

- Rock bolts
- Shotcrete (not reinforced and reinforced with fibres or wire mesh)
- Steel ribs and lattice girders
- Meshes
- Lagging

These elements are applied individually or in combination in different types of support depending on the assessment of ground conditions by the responsible site engineers and by taking into account the corresponding design. In each round, elements of the primary support have to be placed up to the excavation face for reasons of safety and health and according to the structural analysis and the assessment of the actual ground conditions. The selection of the support elements has to consider the onset of effect and the support pressure of each element.
Additional elements for the primary support can be placed in the rearward area according to the requirements of the structural analysis, the ground conditions and the construction sequence.
The baseline construction plan indicates the support types available for each homogenous zone in the geotechnical model and contains limits and criteria for possible variations or modifications on site. The baseline construction plan also contains warning criteria and remedial measures for the case when acceptable limits of behaviour are exceeded.

Rockbolts

3.4. AUXILIARY CONSTRUCTION MEASURES

In special cases, the excavation work can only be carried out by means of additional auxiliary construction measures. The auxiliary construction measures can be classified in the following categories:
- Ground improvement
- Ground reinforcement
- Dewatering

3.4.1. Ground improvement

Ground improvement means the application of methods that improve the mechanical or hydraulic properties of the ground.
The main methods are
- Grouting
- Jet grouting
- Ground freezing

Ground improvement has normally to be carried out alternately to the excavation and leads to interruptions of the excavation work. In special cases ground improvement can be carried out from the surface or pilot tunnels outside the future tunnel cross section.

Grouting

The different techniques for grouting are consolidation grouting, fissure grouting, pressure grouting and compensation grouting.
Grouting can be carried out in the tunnel excavation as face grouting or as radial grouting from the excavated tunnel or from a pilot tunnel. The most commonly used grout material is cement. In special cases chemical products such as resins or foams are also applied. In these cases the environmental and safety restrictions have to be considered specially.

Face grouting

Jet Grouting

Jet grouting is applied mainly horizontally or at a slightly upward or downward angle from within the face of the tunnel. An improvement of the roof arching behaviour is achieved by applying one or more layers of jet grouting columns in stages corresponding to the excavation operations.

An improvement of the stability of the face is achieved by placing individual jet columns parallel to the direction of advance in the working face.

Less common in tunnelling is vertical or steeply inclined jet grouting, except in shallow tunnels where it is applied from the surface. From within the tunnel vertical or steeply inclined jet grouting is mainly applied to underpin the bottom of the roof arch.

Jet grouting

Jet grouting

Ground Freezing

The following ground freezing techniques are known to waterproof or stabilize temporarily the ground:
- Continuous frozen bodies which provide long-term load-bearing
- Short-term, immediately effective local freezing of damp zones close to the face or in the immediate vicinity outside the excavated cross section

Short-term, immediately effective freezing is achieved by means of injection lances with liquid nitrogen cooling.

A long-term frozen body is produced along the top and side boundaries of the excavated cross section, and in some cases in the invert region. The freezing is achieved by a drilled tube system, through which coolant is pumped. The frozen bodies can be installed alternately to the excavation work from the extended tunnel face in an overlapping way or in advance from separate adits and from the ground surface in cases of small overburden.

Ground freezing

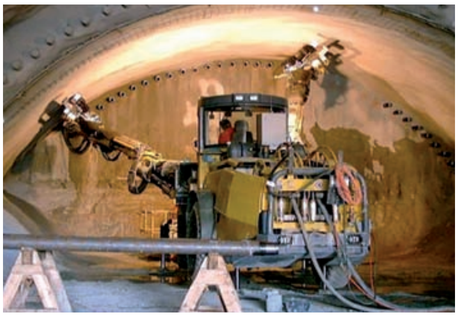
3.4.2. Ground reinforcement

Ground reinforcement involves the application of methods that use the insertion of structural elements with one predominant dimension. Bolts, anchors, micro piles and spiles are such elements. The main methods of application are pipe umbrellas; face bolting or radial bolting from a pilot bore.

Pipe umbrella

Pipe umbrellas are specified to supplement the arch structure in the roof and springline regions as well as stabilization of the face and in advance of the face immediately after the excavation.

Portal pipe shields are drilled at the portal wall along the cross section parallel the direction of advance and serve to bridge zones of disturbance behind the walls. Fan-like, overlapping pipe shields are installed in stages alternately with the excavation for the tunnel driving. The pipe umbrella shall extend at least 30% beyond the face of the next excavation.



Pipe umbrella

Spiles

Spiles are steel rods left in the ground for the local short-term stabilisation of the roof section and at the working face on the boundary of the excavation.

The spiles rest on the first steel arch in front and should be at least 1.5 times as long as the subsequent advance in the excavation. Depending on the type of soil, the spiles can be jacked, rammed or inserted in drillholes. To improve the ground conditions spiles can be used with a central borehole and lateral es-cape openings (cf. bored bolts). After grouting, this creates an optimum bond with the sur-rounding material. Spiles are placed during the excavation cycle in predefined steps.

Face bolts

Face bolts are often necessary to stabilize or reinforce the face. Depending on the relevant hazard scenario, the relevant bolt type and length have to be determined in the design. Practically any bolt type or length is possible. As a protection against rock fall, spot bolts may be sufficient whereas in difficult ground conditions (e.g. squeezing rock and soils) systematic anchoring with a high number of long, overlapping steel or fibreglass bolts may be necessary. Face bolts are placed during the exca-vation sequence, if necessary in each round or in predefined steps

Face anchors

3.4.3. Dewatering and drainage

In some cases the tunnel construction is only possible with the application of special dewatering measures. According to the ground conditions and other boundary conditions conventional vertical or horizontal wells or vacuum drains can be used.
In the design of the dewatering measures environmental aspects have to be considered, such as limits on lowering the ground water table, settlements, etc.

In the case of low overburden, dewatering measures can be carried out from the ground surface. In the other cases, dewatering has to be done from the tunnel cross section or from pilot tunnels.

4 >> MONITORING

4.1. OBJECTIVES OF MONITORING

Field monitoring is an indispensable element of modern tunnelling. The purpose of the instrumentation may be:

- Checking the structural behaviour with respect to safety and/or serviceability criteria, mainly during construction and in some cases during service life.
- The quantification of structural response to a specific method of construction and checking the effectiveness of specific support measures.
- The comparison of theoretical predictions with the actual structural behaviour and the assessment of the material parameters of the ground.
- Checking adjacent structures and facilities for their safety and serviceability as a result of the construction of the tunnel.

Due to its quality, monitoring data can also be used for clearing disputes between contractual partners or between the client and third parties. Therefore a further objective is:

- Documentation of evidence related to the tunnel construction and the effects on adjacent facilities.

Instrumentation can also help to advance the state-of-the-art in technology in a particular geotechnical context (e.g. urban subway construction). The monitoring results often provide a very valuable insight into the ground deformation pattern and failure mechanisms, contribut-ing thus to the project optimisation in terms of safety, construction time or cost.

The results of field measurements can be used to assess structural behaviour with respect to safety and/or serviceability requirements. In such cases, the determination of acceptable behaviour should include threshold values of key indicator parameters. The monitoring results should be evaluated in combination with other observations in order to decide whether corrective measures are necessary or not.

Deviations from past deformational behaviour, such as an unexpected acceleration over several readings without ongoing construction activities in the vicinity of the monitoring section, must be analysed immediately. Such procedures can obviously be applied only for the case of ductile structural behaviour.

Decision-making based on measurements is impossible when the structural behaviour is brittle (e.g. rock bursts or tunnel face instabilities), as the predictions of deformation values close to collapse are highly unreliable.

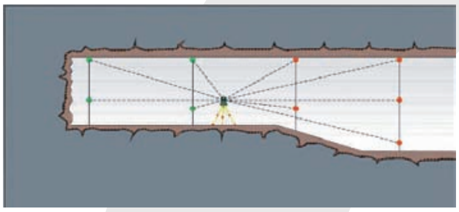
The planning of a monitoring program should include the following steps:

- Prediction of the mechanisms that control behaviour
- Selection of parameters to be monitored
- Prediction of the magnitude of change
- Selection of instrumentation and its accuracy
- Instrument location plan
- Redundancy of instrumentation
- Data collection plan
- Data processing,
- Interpretation and report plan

4.2. PHYSICAL QUANTITIES AND INSTRUMENT SELECTION

The most important physical quantities to be monitored can be subdivided in following groups:

- Deformations (displacements, strains, changes in inclination or curvature)
- Stresses (contact stresses, boundary stress on a beam, state of stress) and forces on structural elements (bolt force, normal load on a compression element or steel arch)
- Piezometric levels
- Temperatures



Monitoring

The most common monitoring method is the measurement of displacements, for example convergence of the underground opening or ground surface settlements.

Displacements have the advantage that in a mathematical sense they represent integrated quantities and are basically not subjected to local effects. Stresses, strains or changes in curvature, on the other hand, are differential quantities, whose validity is limited to local regions (scale effect). Therefore the observation at several successive points will be necessary to obtain a distribution over a sufficiently large area.

In some cases, for example the construction of underground openings in swelling rock or in the presence of difficult groundwater conditions, measurements of contact stresses or groundwater pressure can be a very relevant and sensitive measurement. With the selection of the parameters to be monitored the instrument types are also selected. The instrument resolution and required range are given by the predicted maximum of the magnitude change.

However, the accuracy depends not only on the resolution, but also on the measuring principle used for the instrument. Additionally, instruments with a large range often have a lower resolution and accuracy. Finally, in selecting the instrument, availability, durability, maintenance and calibration requirements as well as costs also have to be considered.

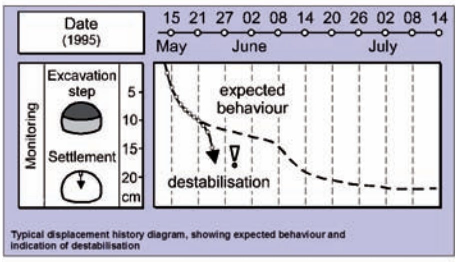
Monitoring

4.3. MONITORING LAYOUT AND PLAN

The monitoring layout is determined by the predicted mechanism or behaviour of the structure. For example, it must be established if pointwise measurement is adequate or if measurements along profiles or over surfaces are necessary. For the definite location of the instruments the zones of primary concern and critical areas, in which additional instrumentation may be required to get meaningful results, should be identified. The layout and spacing between instrumentation arrays will depend on factors such as the stratigraphy, level of detail and degree of redundancy required as well as the location of the tunnel in relation to nearby existing structures.

The plan of data collection includes details about frequency of readings, data transmission and data storage. Readings may be taken at intervals, continuously (real time), depending on specific construction stages or time events.

In addition, the plan shall include data reduction, analysis, interpretation and assessment of the response of the structure.



Monitoring

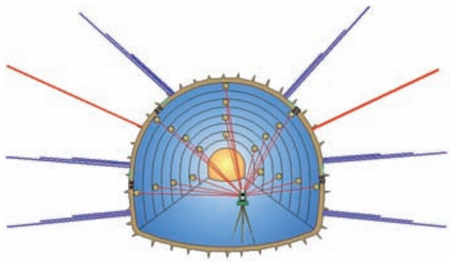
4.4. ORGANISATIONAL ISSUES

In contract documentation, responsibilities for installation and commissioning, calibration, provision of baseline data, monitoring, information flow, data interpretation and reporting must be clearly defined.

For the owner it may be advantageous to appoint an independent monitoring contractor who carries out the monitoring work and, on a real-time basis, delivers the results to all par-ties involved in the execution of the tunnel project (client, designer, construction manager if present, contractor, etc). The evaluation of the monitoring results should also be carried out on a real-time basis by a suitably experienced third party (either the client with his consultant or the design engineer responsible for the detailed design of the tunnel). The contract conditions should provide the necessary empowerment to persons to implement immediate stabilizing works according to the results of the monitoring.

4.5. OTHER OBSERVATIONS AND MEASUREMENTS

- Geotechnical observation of the rock mass (type of rock mass, weathering, geotechnical classification, the strength of the rock mass, zones of weakness, foliation, etc.)
- Hydrogeological observation (changes of the water table level, changes of the water level in wells, verification of the connection between ground water in the zone near the surface and at depth, quality of the water, chemical composition)
- Quantity of the water (inflow to the tunnel)
- Geophysical measurements (indicates failure in homogeneous rock mass)
- Seismic and acoustic measurements (in case of drill and blast excavation)



Monitoring

5 >> CONSTRUCTION CONTRACT

5.1. INTRODUCTION

Underground construction is clearly different from any other type of construction because of its inherent nature: uncertainties in the ground conditions, unforeseen conditions, dependency on the means and methods, and the high construction risk associated with this type of construction. It is very important to deal with contracting practices in tunnels and underground construction differently from other types of construction.

The contract conditions for Conventional Tunnelling shall allow for approval and certification for these changed and/or varied works within a short time. With reference to the possibility of encountering changed conditions the contract should be based on a measurement version. This will help to respond to changed conditions even if relevant provisions for all possible consequences could not be already included at the time of contract award.

There is a need for a creative, progressive and fair contracting form in underground con-struction and especially in Conventional Tunnelling. The advantages of the high flexibility of Conventional Tunnelling can only be realised with corresponding contracts with a fair risk sharing between the client and the contractor. The processes for improving underground contracting practices (see 5.3) is highly recommended for contracts dealing with Conventional Tunnelling.

The main issue that overrides all aspects of underground construction is risk. Risk can be related to construction means and methods, to ground type and behaviour, to unforeseen conditions, or to external factors such as third party approvals or imposed limitations.

The level of risk sharing is a major factor in deciding the type of procurement practice to be implemented. Other issues that influence the type of procurement include the size and the complexity of the project, the definition of its scope, and the identification of imposed constraints. Clients need to weigh various factors in reaching a decision regarding the procurement system. They have to weigh quality vs. costs vs. schedule. These factors are often mutually exclusive.

5.2. RISK MANAGEMENT

Many claims in tunnel construction are often related to unforeseen conditions. Therefore, it is recommended to provide a viable trigger by means of the Differing Site Condition (DSC) clause, culminating in the use of the Geotechnical Baseline Report (GBR) and Geotechnical Data Report (GDR) (see 5.3.7).

It is important from a risk-sharing perspective that the contractual language for the DSC, GBR, and GDR are harmonized.

5.2.1. Risk allocation/sharing

The allocation of risk between the client and the contractor will have a direct relationship to the contractor contingency as part of the contractor's bid. Therefore, it is important to identify a risk-sharing mechanism that is fair and equitable and that will result in a reasonable contingency by the contractor and a sufficient reserve fund to be provided by the client to address unforeseen conditions.

It is customary, for example, because the ground belongs to the client, that unforeseen conditions due to ground conditions are paid for by the client if certain tests are met, while means and methods are generally the contractor's responsibility and their inability to perform under prescribed conditions are risks to be absorbed by the contractor.

5.2.2. Contractor's contingency/client's reserve

With a proper contracting form and an equitable allocation of risks between the client and the contractor, the contractor contingency, which is part of the bid price, will be reduced. Similarly, the client's reserve will be used only if certain conditions are encountered, resulting overall in smaller costs for the client.

5.3. PROCESSES FOR IMPROVING UNDERGROUND CONTRACTING PRACTICES

The following processes aim at improving underground contracting practices. They include prequalification of contractors, geotechnical disclosure, Dispute Review Board (DRB) and amicable settlement process, the use of differing site condition clauses, escrow bid documents, unit prices and contingent bid items, value engineering, client-controlled insurance program, and partnering.

5.3.1. Pre-qualification of contractors

This involves technical and financial qualifications of the potential bidders to ensure their ability to perform the work effectively, economically, and to a high quality. The pre-qualification would include the company's or the joint venture's technical ability to perform the work. Items to be evaluated include: approach, experience with similar projects, with similar ground and similar proposed methodology.
Pre-qualification of the key staff, such as the contractor project manager, the field manager or superintendent, etc., is critical for a successful project.
In addition to the bidder's financial ability to obtain bonding, and his solvency, his history of completing projects on time and within the budget is a factor in the bidder's financial qualifications.
Pre-qualification should extend to major subcontractors and major suppliers.

5.3.2. Dispute Review Board (DRB)

The dispute review board process has been used in the tunnelling industry in certain areas for many years. In this process a board of independent, experienced, and impartial members is selected to hear and address disputes. Generally, the board consists of three members, one representing the client, one representing the contractor, and the third who acts as the chairperson of the board, selected by the other two members. The board provides recommendations to resolve disputes that participants are unable to solve. It is found that this process results in lower bids, better communication and less acrimony at the job site, fewer claims, and more timely and cost-effective resolutions.

5.3.3. Differing Site Condition clause

The Differing Site Condition (DSC) clause was established as a measure of allocation of risk between the client and the contractor relative to the ground condition. In exchange for lower initial bids, the client bears some portion or all of the risk regarding subsurface conditions.

In the case of low bids, bid contingencies are paid by the client, regardless whether adverse conditions are encountered or not. On the other hand, DSCs are paid only if they are encountered.

There are two categories of DSCs:

- Category 1 governs when subsurface conditions differ from those indicated in the contract. This is based solely on what is stated in the contract, including geotechnical data or geotechnical interpretation included in the contract documents.
- Category 2 applies when conditions, which were not known to the contractor at the time of contracting, differ from those normally encountered in the area. It is generally related to unusual conditions and not based on contract documents.

It is important to note that to recover on the DSC clause the contractor must demonstrate the impact on costs and time and must show causality.

5.3.4. Escrow bid documents

In this process the selected contractor's bid documents are placed in an escrow, that is, held in trust by a third party and turned over to the grantee only upon fulfilment of a condition. These documents would then be utilised if needed to assess a fair entitlement and adjustment for additional work, differing site condition issues and claims. However, in this process clients fear that the contractor could condition the bids while contractors fear that they could lose confidentiality of means and methods. This process has not been used extensively.

5.3.5. Partnering

In the last few years partnering clauses have been included in tunnelling contracts. The goal of this process is to minimise disputes and to prevent them from escalating in time and value by resolving them at the lowest possible level in the project organization. It attempts to establish a win-win attitude between the project participants, including the client, the contractor, the engineer, and the construction manager. This process encourages dialogue among the various participants and relies on reasonable people to resolve disagreements reasonably. It seeks to eliminate adversarial posturing and positioning that often develop when disputes and claims arise. Through this process a series of dialogues and interactions are developed whereby the team members are encouraged to work out differences in the best interests of the project. When an issue is not resolved at the lowest level, it is brought up to a higher level for resolution.

5.3.6. Value Engineering

To stimulate innovative approaches within the limitations of the contractual requirements, cli-ents opt to include a value engineering clause in the contract. Relaxing the design criteria where not critical or meeting the intent of the design more efficiently via creative approaches achieves efficiency. The savings achieved by value engineering are shared between the client and the contractor. It is important to assess the potential effects of differing site conditions on the design as modified by the value engineering.

5.3.7. Full geotechnical disclosure

Experience has shown that full disclosure of geotechnical information would reduce the risk to both the client and the contractor and thus the project costs. Therefore it is important for clients to invest in a comprehensive geotechnical program.

The information should be included in the contract documents. The intent of the disclosure of geotechnical information is to share and allocate construction risk between the client and the contractor.

The Geotechnical Data Report (GDR) contains all the raw data, including boring logs, records of measurements, and field and laboratory tests and their results. It is recommended that the Geotechnical Data Report be made a contract document in order to provide to the potential bidders with the same information that the design engineer used in the design.

In the Geotechnical Design Summary Report (GDSR) the design engineer's interpretation of the data, anticipated ground behaviour, and the identification of the conditions which affect the design and which may impact on construction should be shown.

The Geotechnical Baseline Report (GBR) establishes quantitative values for selected conditions anticipated to have great impact on construction. These values are established through technical interpretation of the data and financial considerations of risk allocation and sharing. The advantages of this report are ease of administration of contractual clauses, unambiguous determination of entitlement, clear basis of contractor's bid, and clear allocation of risk between client and contractor. If baseline values are defined optimally, this can result in minimising contingency of the bidders while limiting the client's risk to a reasonable level.

6 >> Organisation of project execution

The organisation of the project execution is highly dependent on the selected contract model. Nevertheless the organisation of a project is decisive for its success.
For design bid build-contracts the following model is often used in Conventional Tunnelling:

6.1. Client
The overall project management is primarily the responsibility of the client and comprises the general supervision of the construction work, basic decision-making, determining which measures to adopt in the case of technical supervision, financial or schedule variations and deciding upon remedial measures to correct defects.

The ground belongs to the client. Therefore unforeseen ground conditions are the client's risk.

In certain circumstances the client may augment his staff by hiring a project manager and/or a construction manager. The project management team will act as an extension of the client's staff and will oversee the project performance technically, financially and in accordance with the project schedule. The construction manager oversees the implementation of the project during construction.

6.2. Design engineer
The client commissions a design engineer to perform the tasks of planning and design of the project during the different project stages.
After obtaining the corresponding construction and design approval the tendering is carried out. The design engineer prepares the tender documents, evaluates the tenders and formulates the contract award document on behalf of the client.

During construction the design engineer prepares the detailed design. If the design engi-neer is not the same consultant as for the site supervision a close relation to the site shall be established and the roles and responsibilities clearly defined. It is recommended that for conventional tunnelling, the design engineer is also the site supervision consultant for the tunnel excavation.

The design engineer and site supervision accompany the structure into service after com-pletion of the work. They prepare the asbuilt documents and maintenance plans.

6.3. Site supervision
The client commissions a consulting engineer with the overall supervision of the construction work (site construction manager). In many cases the site engineer is the same consultant as the design engineer in order to ensure an unshared engineering responsibility towards the client.
The site supervision safeguards the interests of the client and carries out the agreed work observing the recognized rules in that field while optimising costs and schedules.

The site construction manager is responsible for the general management and supervision on the construction site with regard to quality and costs. This involves checking the proper use and handling of construction materials, helping to implement the integral occupational health and safety concept, establishing measurement schedules and checking the contractor's bills.
Finally the site engineer supervises the rectification of defects.

6.4. Specialists and experts
In addition, as needed, the client uses specialists and consultants, who are usually commissioned directly by the client. These are, e.g., geologist, geotechnical engineer, hydrogeologist, environmental specialist, architect, building physicist, surveyor, safety officer, gas engineer, independent checking engineer, etc. The work of the specialists includes, among other things, giving expert advice to the design engineer and the client.

6.5. Contractor
The selected contractor carries out the work according to the contract documents. Means and methods are generally the contractor's responsibility and the inability to perform under the prescribed conditions is the risk to be absorbed by the contractor.

6.6. Dispute review board
The commitment of a dispute review board (see 5.3.2) is highly recommended.

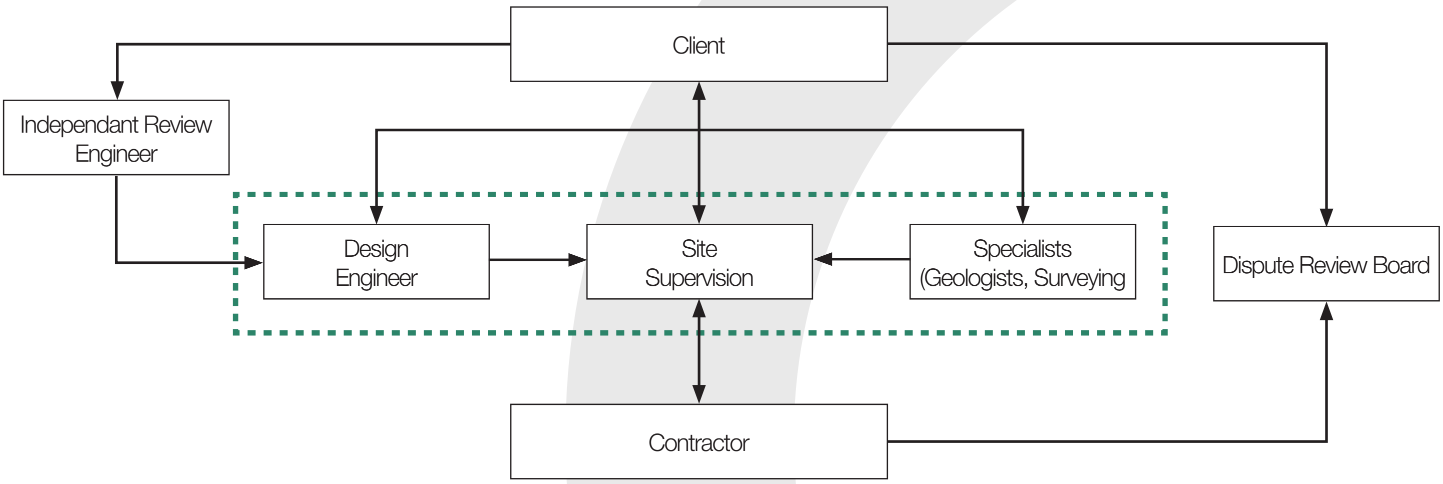


Fig. 4: Example of a Project Organisation

ITA WG 2, Research; ITA Guidelines for tunnelling risk management, Tunnelling and Underground Space Technology, Vol.19 (2004), No. 3, pp 217 – 237

ITA WG 3, Contractual Practices; ITA Recommendations on Contractual Sharing of Risks, Tunnelling and Un-derground Space Technology, Vol.7 (1992), No. 1, pp 5 – 7

ITA WG 3, Contractual Practices; ITA Position Paper on Types of Contract, Tunnelling and Underground Space Technology, Vol. 11 (1996), No. 4, pp 411 – 429

ITA WG 7, General approaches to design; Guideline for the Design of Tunnels, Tunnelling and Underground Space Technology, Vol. 3 (1988), No. 3, pp 237 – 249

ITA WG 12, Shotcrete use; Guideline for the Design of Tunnels, Tunnelling and Underground Space Technology, Vol. 3 (1988), No. 3, pp 237 – 249

ANNEX A1: SELECTED NATIONAL CODES AND GUIDELINES

Country	Code			Languages
Austria	Ö-Norm B2203:	"Werkvertragsnorm für Untertagbauarbei-ten mit zyklischem Vortrieb"	2001	German
	ÖGG-Richtlinie:	„Richtlinie für die geomechanische Planung von Untertagbauarbeiten mit zyklischem Vortrieb"	2001	
	ÖGG-Richtlinie:	„Richtlinie für die Kostenermittlung für Projekte der Verkehrsinfrastruktur unter Berücksichtigung relevanter Projektrisiken"	2005	
Japan	Japanese Society of Civil Engineers, Japanese Standard for Mountain Tunnelling		1996	English
Switzerland	Swiss Society of Engineers and Architects (SIA)			French English German
	Code SIA 118:	General conditions for construction	1993	
	Code SIA 198/118:	General conditions for underground construction	2004	
	Code SIA 197:	Design of Tunnels	2004	
	Code SIA 197/1:	Design of Railway Tunnels	2004	
	Code SIA 197/2:	Design of Road Tunnels	2004	
	Code SIA 198:	Underground structures, Execution	2004	
UK	British Tunnelling Society: 'The Joint Code of Practice for Risk Management of Tunnel Works in the UK',		2003	

ANNEX A2: MEMBERS OF THE ITA WORKING GROUP 19

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	HASIK, Otakar	Metroprojekt a.s., Prague
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	PIRAUD, Jean	ANTEA, Orléans
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	PESCARA, Moreno	GEODATA SpA , Turin
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	ITO, Fumio	Taisei Corporation, Tokyo
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