

RECOMMENDATIONS ON THE DEVELOPMENT PROCESS FOR MINED TUNNELS

Working Group 14
Mechanized Tunnelling

Working Group 19
Conventional Tunnelling

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ASSOCIATION
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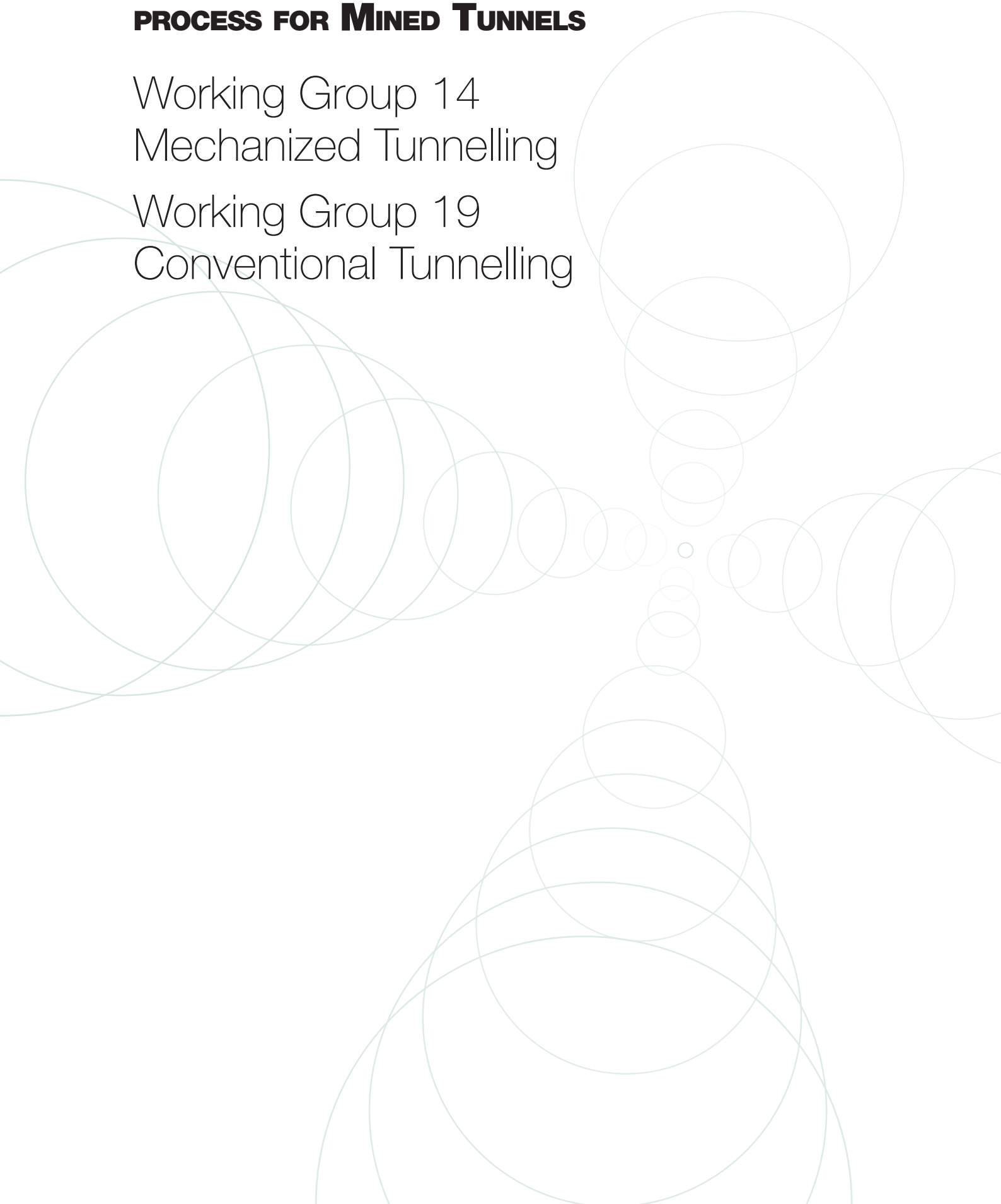
ITA

INTERNATIONAL TUNNELLING
AND UNDERGROUND SPACE
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This document has been elaborated by the members of the ITA Working Groups 14 (Mechanized Tunnelling) and 19 (Conventional Tunnelling). They represent various countries from three different continents.

The technical expressions used in this document take into account the ITA Glossary (<https://www.ita-aites.org/en/component/seoglossary/1-main-glossary>).

Nevertheless, most contractual terms are not part of the ITA Glossary. This document follows generally the design bid build procurement model (see also FIDIC Red book) [16].

The most important contractual terms will be defined additionally for this document.

Contractor :

Person or organisation appointed by the Owner as Contractor whose role is to build the project in accordance to the design and specifications of the Design Engineer and to the cost and time negotiated and agreed in the contract documents.

Design Engineer : Person or organisation appointed by the Owner responsible for the the elaboration of the design and the specifications of the project during all design stages.

Owner : Organisation, or individual, who commissions the activities necessary to implement and complete a project in order to satisfy their needs and the enters into contracts with the commissioned parties.

An Owner organisation can be categorized as follows:

1. Publicly or privately funded.
2. Level of knowledge and experience within the Owner organization in dealing with the construction industry and implementing building projects.
3. Owner acts as future operator or acts as project developer to pass the project on to others.
4. The degree of contribution that the Owner is making to the actual project management

Site Supervision : Owner's representative on site responsible for the construction management of the project during the execution stage.

Tunnelling Methods : Catalogue of construction methods for the excavation of underground structures, with a distinction between the mechanical drives (excavation by TBM) and conventional drives (excavation by drill and blast method or any other mechanical aid than TBM).

ITA's working groups on mechanized (WG 14) and on conventional tunnelling (WG 19) elaborated several documents regarding the specific tunnelling methods [1], [2], [8]. In many projects the ground conditions allow either conventional or mechanized tunnelling methods. Therefore, many Owner's organisations have to find an answer on the question which would be the most appropriate tunnelling method for their project.

Both working groups agreed during the WTC 2010 in Vancouver that recommendations on this topic shall be a joint work of both working groups. The answer on the question of the most appropriate tunnelling method depends on many factors for each individual project, not only on the ground conditions but also on many other factors as discussed herein this report. It also depends significantly on the knowledge gained during the project development and on other projects in the area. The complexity of the topic does not allow a simple approach.

The present document intends to highlight the influence of the main project requirements and the factors affecting the selection of the tunnelling method depending on the different project phases. This document does not include typical technical data, such as advance rates, penetrations rates depending on ground conditions, etc. Such aspects shall be treated in a future ITA-Report.

Each project is unique and requires independent project-specific assessment. However, these recommendations represent guidelines and suggestions for the project development with respect to the selection of the tunnelling method in general. The recommendations were developed on the "design – bid – build" procurement model. If other models, such as e.g. the "design – build" are chosen, the general approach will be the same, but with a different allocation of the responsibilities. The present report does not treat this topic in detail which shall be analysed in a future document. Also the list of typical documents is only a first collection of some examples. This list shall be developed in a next report of ITA.

These recommendations are intended to be used by Owner's representatives, tunnelling engineers (Design Engineers and Site Supervision), Contractors and Subcontractors.

3 >> INTRODUCTION

The increasing demands for infrastructure projects today require more underground construction in increasingly adverse ground conditions. It has been observed that in recent years' tunnels are being located in more challenging conditions, adverse tunnelling conditions, and remote locations. Concurrently, tunnelling methods shall be carefully considered in light of site conditions, geological setting, and end use objectives. The selection and implementation of the tunnelling methods is one of the key factors competing and conflicting in order to achieve all end-use objectives.

The selection process consists not only of the Contractor's final choice of equipment, but it is a process starting during early feasibility studies. Although at this early point the task may seem simplistic, the early feasibility studies limit or open the variety and choices of the means and methods of the tunnelling method during construction. As major infrastructure projects often have long preparation phases, (sometimes measured in decades), it is advisable to come back to the initial studies and question the early project decisions in light of technological developments and changes in project conditions.

In this process it is required to observe from the beginning, the different interests and task allocations of all involved parties. It is in the overall interest of all parties in this revolving process to select the tunnelling method which best fits the final purpose of the structure, permits safe construction, utilizing state-of-the-art methods and still achieving the most robust economical and sustainable solution. Figure 1 shows conceptually, the main parties involved in the selection of the tunnelling method.

3.1 INTENDED USE OF THE RECOMMENDATIONS

The aim of the working groups 14 and 19 with this report is to develop recommendations for Owners, Consultants and Contractors to promote the international understanding of the development of underground projects by unifying the terminology and by presenting an overview of a recommended structured approach for the project development.

The contents shall be valid for most parts of the world. Therefore, the recommendations highlight only the most important principles, but do not deal with the details, which are treated by many national codes, guidelines, and practices.

The report starts with a description of the main project requirements for an underground project independent from a specific project phases. In the following chapters, supplementary measures for the selection of the tunnelling method for each project phase specifically related to the individual project requirements are given.

Therefore, the specific recommendations in Chapters 4 to 7 shall always to be considered together with the general recommendations made in Chapter 3.

3.2 SUMMARY OF TUNNELLING METHODS

3.2.1 Mechanized Tunnelling

Mechanized Tunnelling in the context of this document utilizes Tunnel Boring Machines (TBM) and Shielded Machines. The excavation diameters for mechanized tunnelling range from approximately 400 mm for remote controlled utility tunnelling up to double-deck traffic tunnels with diameters beyond 17.5 m. Figures 2 and 3 show examples of tunnels constructed by mechanized tunnelling.

TBMs could be equipped with a full face cutter-head or with partial face excavation from within a shield.

Depending on the TBM design, mechanized tunnelling allows to maintain continuous active support onto the tunnel face during the excavation process if required such as the case for soft ground TBM. The tunnel face and excavation area can be completely isolated from the rear tunnel and working area, for example to maintain natural ground water levels, even higher than 10 bars, or to tunnel safely in contaminated or gassy ground.

Ground support can be installed simultaneously from within the advancing TBM. In hard rock the ground support can simply be rock bolting, with the possibility of applying sprayed concrete lining. Ground support by precast reinforced concrete segments build a watertight lining in both, hard rock excavations as well as in soft ground tunnelling. The segments are installed from within the TBM.

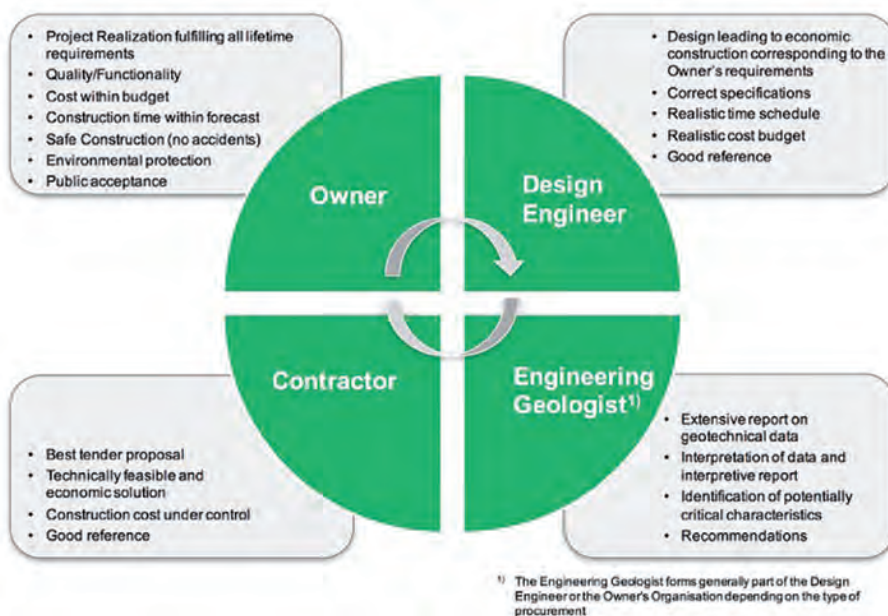


Figure 1: Parties involved in the selection process of the tunnelling method

⁽¹⁾ The Engineering Geologist forms generally part of the Design Engineer or the Owner's Organisation depending on the type of procurement

3 >> INTRODUCTION

The production quality of the precast segments has advanced to high standards permitting its use as an integral part of the



Figure 2 : Top left: Lowering a TBM into the start shaft
Lower left: TBM arrived at the portal with back-up still inside the tunnel © Babendererde Eng

final tunnel lining. On most applications the precast segmental lining is the final lining without any additional structural liner. This is called single-pass lining.

The excavated material will be removed through the TBM, depending as well on the type of face support. In Slurry-TBMs the material is pumped from the TBM to the tunnel portal in pipes together with the face support medium, normally bentonite suspension, to a separation plant. Open face rock TBM or Earth Pressure Balance (EPB) TBMs can as well use rail-bound transport or continuous conveyor belts for mucking. The material supply to the TBM is either rail-bound or rubber-wheeled vehicles.

TBMs, customized for each project, are travelling factories with specifically designed work areas for each work sequence. This way the efficiency is high, but it requires trained personnel for the different positions. Table 1 provides most common mechanized

equipment for rock or soft ground applications. Full face tunnelling using any of the above listed equipment will produce a circular



Figure 3 : Top right: Pipe-jacking tunnel as water sewer
Lower right: Backfilling the gaps aside of an invert gallery in a large tunnel parallel to tunnel excavation © Babendererde Engineers

cross-section tunnel; with both curved and tangent alignments. However, recently and in limited applications square, rectangular, double and triple - O tunnel cross-sections have been successfully excavated.

3.2.2 Conventional Tunnelling

Conventional tunnelling in the context of these recommendations means the construction of underground openings of any shape with a cyclic construction process of:

- Excavation of the full or the partial face, by using the drill and blast methods or mechanical excavators, except by full face TBM
- Mucking excavated material from the face to the shaft or portal for disposal
- 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

Conventional tunnelling generally allows a high flexibility of the shape of the excavation (Fig. 4 right) and the possibility of partial face excavation if needed.

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 (tunnellers), assisted by standard and/or special plant and equipment executes each individual cycle of tunnel construction.

Conventional tunnelling method encompasses the so called traditional Drill and Blast (D+B) and the so called New

FACE SUPPORT	FULL FACE EXCAVATION	PARTIAL FACE EXCAVATION
None or passive	Open Hard Rock TBM or Main Beam TBM	Digger shield
	Single Shield Hard Rock TBM	Auger or road header
	Double Shield Hard Rock TBM	
Active	Earth-Pressure Balanced TBM (EPB-TBM)	Digger shield with compressed air
	Slurry-TBMs	Auger or road header with compressed air
	Compressed Air Shields	
Combination	Dual- or Multimode-TBMs, combining for example hard rock excavation with EPB- and/or Slurry mode.	

Table 1. Most common equipment with or without active face support for hard rock or soft ground applications.

3 >> INTRODUCTION

Austrian Tunnelling Method (NATM) or sometimes referred to as the Sequential Excavation Method (SEM) or the Sprayed Concrete Method (SCM).

The conventional tunnelling method using standard equipment allows access to the tunnel excavation face at almost any time and is very flexible and adaptable for situations that require a change in the structural support system. Instrumentation and monitoring of the behaviour of the ground during excavation is essential for successful tunnelling. Supplementary support system, often referred to as tool box, can be implemented as required. A standard set of equipment for the execution of a conventional tunnel drive in rock may consist of the following items:

- Drilling jumbo to drill holes for blasting, rock bolting, water and pressure relief, grouting, etc. (Figure 4 left)
- Road-header or excavator in cases where the ground is suitable for road-header excavation or blasting is not possible or economical



Figure 4 :
- Top: Drilling jumbo working in a conventional tunnel drive.
- Below: Tunnel bifurcation excavated by conventional tunnelling
General description of the project development process © AlpTransit Gotthard Ltd.

- Lifting platform allowing the miners to reach each part of the tunnel crown and of the tunnel face
- Lifting equipment for steel sets or lattice girders
- Loader or excavator for loading excavated ground onto dump trucks
- Dump trucks for hauling excavated ground
- Set of sprayed concrete equipment for application of wet or dry sprayed concrete

3.3 General description of the project development process

Underground projects follow the same project development process as many other infrastructure projects. In many countries national codes or standard practices give clear definitions of the design and construction process and the related tasks to be taken by the Owner and its Consultant. Table 2 shows an example of the project development steps from the point of view of the ITA Working groups 14 & 19, as there is no international standard available for the definition of the Project Phases.

Owner's organizations shall be aware that the level of influence of the Owner's decisions regarding the means and methods of tunnelling method is most effective at

the earliest phases of the project, whereas the consequences (on the final cost and time schedule) increase mainly after the completion of the final design and the starting of the tendering process (Fig. 5). Under certain circumstances, Contractors may opt to change the construction method proposed by the Owner if determined that the Contractor proposed method will save time or money. The assessment of the risks and consequences shall be properly documented and clearly stated. Owners and their Consultant's shall pay highest attention to the project definition and design phase in general but also regarding the topic of the selection of the most appropriate tunnelling method. However, it is recommended that Owners provide performance specifications of the means and methods of construction allowing the Contractor to select the proper equipment.

Whereas the alignment of an underground structure can be shifted easily in the design phase, such a decision becomes more difficult after starting the procedure for obtaining the environmental clearance and the construction permit and it will be nearly not feasible after the contract award. Costs for such a decision will increase very much if such a decision is taken in the late design phases or much later.

GENERAL PROJECT DEVELOPMENT PHASES	CONSULTANT'S TASKS	GOAL
1. Project concept and definition	0- Analysis of the needs 1- Basic design criteria Environmental Process	Purpose of the projects Design criteria, corridors Environmental process, approvals and permitting, right of way acquisition
2. Design	2- Conceptual (basic) design 3- Preliminary design 4- Final (detailed) design ¹	General layout, feasibility Cross sections Detailed design, construction permit, third party approvals, interfacing design, coordination and project integration
3. Preparation of the construction (tender phase)	5- Tender documents 6- Tender process	Draft contract documents Most economic offer
4. Construction	7- Construction documents 8- Site Supervision	Execution of the work
5. Completion/ Commissioning	9- Documentation	As built documentation and collecting construction experiences

Table 2. General project development phases and consultant's tasks

3 >> INTRODUCTION

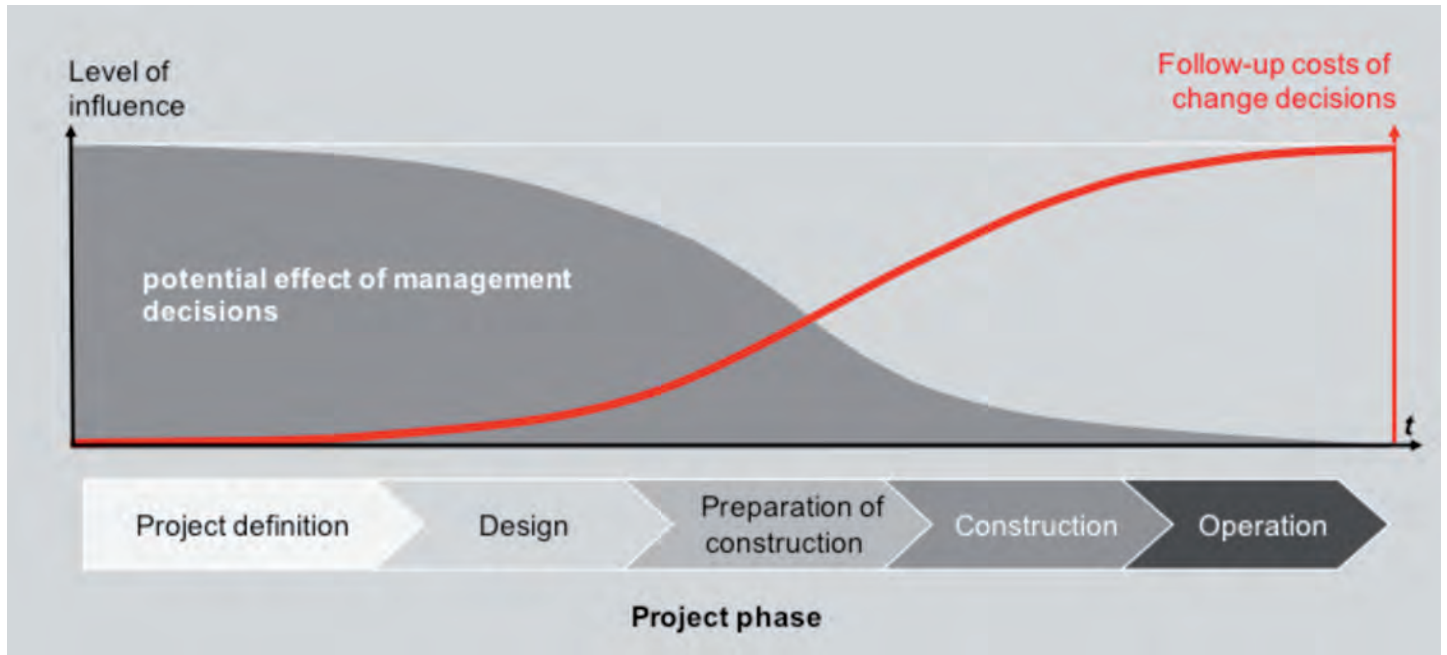


Figure 5 : Potential effects of management decisions and potential impact on costs

Regarding the topic of the selection of the tunnelling method, the costs will increase rapidly if the Owner asks for such a change after tendering the project.

Figure 5 shows that management decision can be taken during the earliest project phases without high follow-up costs. After receiving the construction permits and obtain required approvals and mainly after the contract award, the follow-up costs of management decisions increase significantly. Regarding the question of the selection of the tunnelling method, Figure 5 indicates that an unplanned change of the tunnelling method is very expensive and could lead to major cost increase and time delay after the award of the contract. The Owner's organisation

shall define the most appropriate way to ensure the selection of the most appropriate tunnelling method preferably no later than during the phase of the preparation of the tendering documents as defined in Table 2. If obtaining the construction license depends on the tunnelling method, the selection of the method has already been done in the design phase (e.g. projects where separation plants are needed).

Alternatively, if the selection of the tunnelling method is not strongly influenced and either of the two methods is viable; Owners may issue the tender documents with two options allowing the Contractors to bid on both methods.

4 >> DESCRIPTION OF THE MAIN PROJECT REQUIREMENTS

The main goal of the implementation of a tunnelling project is to meet its functionality of requirements within the commonly agreed upon level of quality, design life, and operational requirements. Other requirements are the realization of the project within the foreseen time limit and within the given cost target.

Owners shall be aware that the ground surrounding the excavation is the main supporting element and the stability of the tunnel depends on the factual ground behaviour in response to the excavation. The ground conditions often remain not completely known, and its behaviour not completely predicted even after extended ground investigation campaigns. Factual ground conditions may also change within a short distance as many experiences have shown. Owners shall be aware that risks related to ground conditions or ground behaviour are the responsibility of the Owner.

Other boundary conditions which have to be taken into consideration include:

- the Geology (ground conditions)
- Ground behaviour
- Ground water conditions
- Geometrical restrictions
- Location, Accessibility and Logistics

- Occupational health and safety
- Environmental conditions
- Nearby buildings and structures
- Noise and vibrations
- Public acceptance / Stakeholder interests
- Market conditions
- Experiences from comparable projects
- Organisation and processes
- Time schedule
- Length and cross section of the tunnel
- Contractor's preference
- Risk aspects
- Cost

All these requirements may have an influence on the selection of the tunnelling method and have to be considered during the different stages of the project development. The importance of a specific requirement may increase or decrease during the project development phases. For example, the geotechnical aspects are more critical during the conceptual and preliminary design phases while market conditions aspects are more critical during the tendering and construction phases.

Table 3 and the following section will give an indication how to deal with the different requirements in the different design phases.

4.1 GEOLOGY

The description of the geological, hydrogeological and geotechnical conditions is the basis for the interpretation of the ground conditions and its subdivision into different homogeneous zones as well as the definition of possible difficult and mixed ground conditions. A ground model (geological and geotechnical model, including shear and fault zones) is defined by the description of the ground conditions and the expected behaviour of the ground during tunnelling. The ground model must be the stable base for the development of the project in subsequent phases. The geotechnical model forms part of the ground model and bases on a thorough ground investigation and its evaluation. The geotechnical model is the base for the definition of the excavation method and required support to be established in the design documents and shall lead to the application of an excavation and support classes system.

When developing the ground model, a clear distinction between the description of the ground (factual data) and the Design Engineer's or Geologist's interpretation of the ground behaviour has to be made.

PROJECTS REQUIREMENTS	PROJECT DEFINITION PHASE	DESIGN PHASE		TENDER PHASE	CONSTRUCTION
Geology	set tunnel alignment	ground investigations	ground model	proving all geol. docs (GDR, GDSR, GBR)	monitoring, report and documentation
Logistics	analyse accessibility	develop logistic concept		transfer boundary conditions to future contractor	contractor's responsibility
Quality/functionality	requirements	quality level, general layout		definition of final quality/functionality	Owner : check of quality
Time Schedule	determine time restrictions	structured in detail		provide detailed time schedule	Owner : time management
Costs and financing	rough cost estimation	first cost calculation	financing secured	costs verification	Owner : cost control
Occupational health and safety		define level of work safety		requirements transferred to future contractor	Contractor : fulfill requirements
Environmental aspects	restrictions considered	define of protection		requirements transferred to future contractor	Contractor : fulfill requirements
Public acceptance	inform effected stakeholders	public discussion		includ public relations	public outreach program
Market conditions	estimate capacity	check availability		market force decides	
Experiences	lessons learned from former projects	experienced engineers, responsibilities		contractors experience	monitoring, report and documentation
Organisation and processes	established clear idea	construction permit		contract award	processes coordinated

Table 3. Project requirements and relevant general tasks for project development with respect to the tunnelling method

4 >> DESCRIPTION OF THE MAIN PROJECT REQUIREMENTS

Factual data are:

- Results from field borings and laboratory testing
- Key engineering properties of the ground samples with distinction for the different excavation techniques
- Ground water conditions (incl. chemistry of the ground water)
- Flow rates
- (known) gassy conditions
- Overburden height
- Measured pollutants and contamination in the ground and groundwater
- Detected obstacles and known underground structures; existing foundations
- Presence of boulders in soft ground matrix
- Presence of shear zones, faults, discontinuities, etc.
- Measured in-situ stresses
- Observed and expected mixed ground conditions

Interpreted data are:

- Geological units (Fig. 6) and their interpreted geotechnical properties
- Description of anticipated ground behaviour

- Description of anticipated ground water (flow rate, presence of artesian conditions, saturated sand lenses, etc.)
- Definition of the hazard scenarios (including geological hazards)
- Relevant experiences in the same or similar geological units
- Baseline values

Geological, hydrogeological and geotechnical investigations shall be carried out at an appropriate level depending on the project phase.

The origin of all geological data shall be documented in a clear and comprehensive way. It shall be stated whether the information derives from project related investigations and tests, references to technical literature, information in existing geological reports, empirical values, estimates or assumptions.

The accuracy of the descriptions or the relevant uncertainties shall be specified. Known gaps in the results presented shall be pointed out.

The type of investigation and the measurement methods shall be described. If possible, standardised methods shall be employed in the determination of the geotechnical properties of soil and rock using laboratory and field tests.

4.2 GEOMETRICAL RESTRICTIONS

Geometrical restrictions have a strong influence on the selection of the tunnelling method.

The largest diameter driven by a TBM is presently around 17.5 meters corresponding to an excavated area of 240 square meters. Apart from a few rather special cases TBM's excavate generally circular openings only.

Larger openings and openings with not circular geometry are usually constructed using the conventional tunnelling method.

Whereas conventional tunnelling can follow any curved design, tightly curved alignments with a radius of less than 15 dtunnel with lining and 10 dtunnel without lining pose a challenge to TBM's with long back-up installations.

The maximum length of a tunnel drive depends on the restrictions of logistics (supply chain) and the requirements of occupational health and safety (ventilation, rescue time). Both methods are suitable in this case. However, for short tunnels, the economical and time schedule requirements often favour the conventional tunnelling methods.

Both tunnelling methods are also applicable for inclined and vertical shafts. Although,

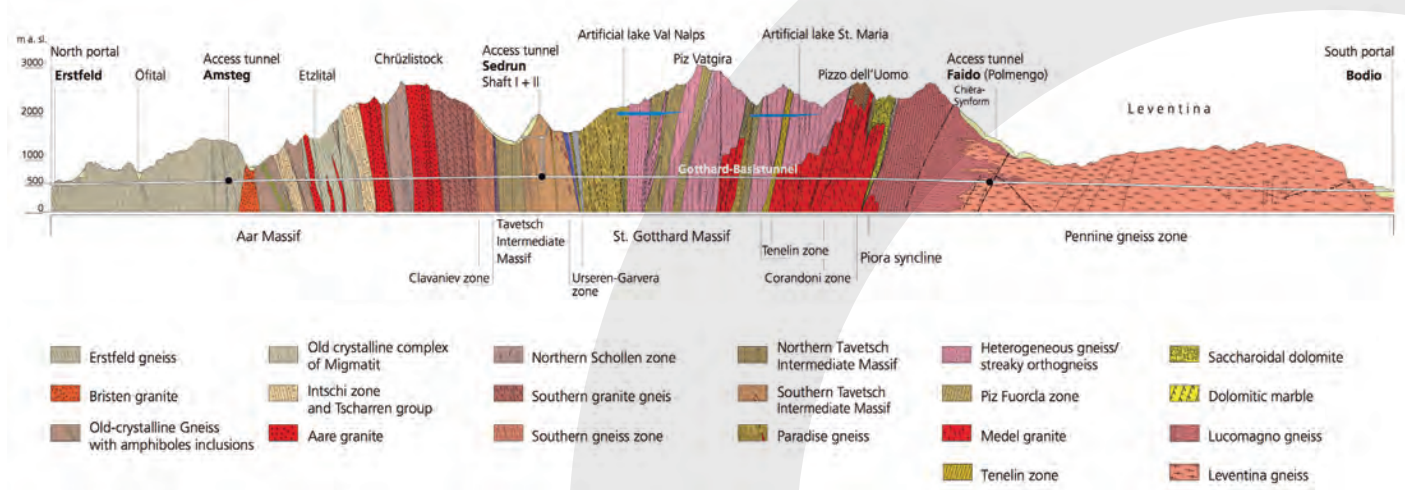


Figure 6 : Example of a geological longitudinal profile is part of the ground model © ATG

4 >> DESCRIPTION OF THE MAIN PROJECT REQUIREMENTS

there are limitations on the size of vertical and inclined shafts using mechanized excavation.

Many projects consist in a composition of longer linear structures (tunnels) and shorter structures with large, not circular cross sections (caverns). Both tunnelling methods may be used there in the same project. Fig. 7 shows such an example.

4.3 LOGISTICS

In addition to the ground conditions, the local logistical conditions define additional restrictive requirements which may influence the selection of tunnelling method of a project. The following topics have to be considered:

- Accessibility
- Availability and capacity of energy (power) and water supply
- Potential disposal areas
- Potential areas for site installations (e.g. area for a segment factory (Fig. 8)) and assembling areas for TBM's above or below ground
- Muck separation plant

- Availability of area for separation plant in case of slurry TBM
- Transportation requirements

Conventional tunnelling uses generally a standard set of equipment. The standard equipment is generally smaller than a TBM. Also the level of electric power consumption is generally lower for conventional drives. Conventional tunnelling is therefore more convenient for projects with a restricted accessibility or a limited power supply.



Figure 8 :Stored precast concrete segments ready for supply to the tunnelling work for a water supply project. The logistics and supply of this type of tunnel support are extensive and needs to be considered early in the tunnel planning phases. © Daetwyler

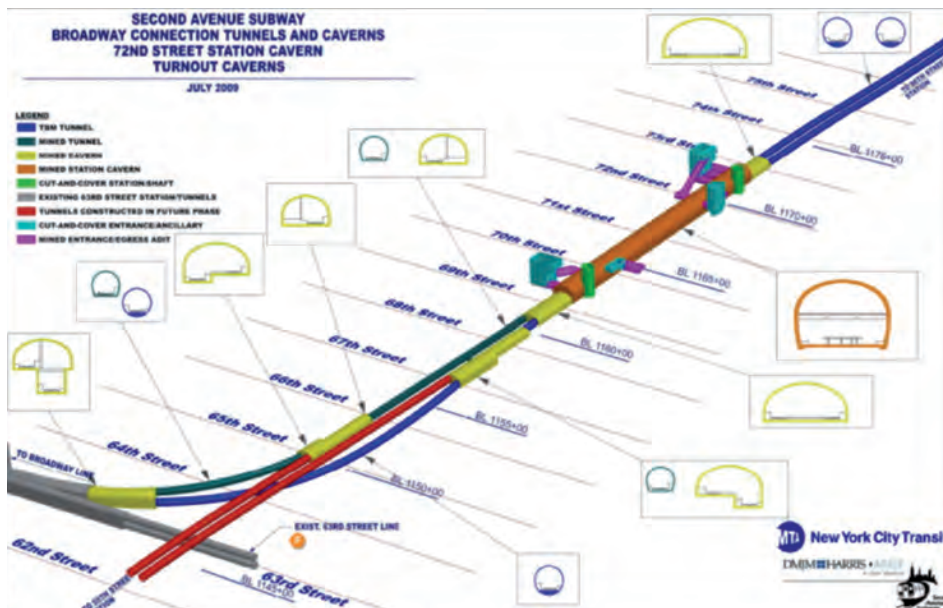


Figure 7 : Example of a project including TBM bored tunnels, caverns and tunnel enlargements, shafts in soil and rock conditions were built using the conventional tunnelling method. (Overall site plan for the Second Ave. Subway, 72nd Street Station and Tunnels Project for the MTA in New York City, USA).

4.4 QUALITY / FUNCTIONALITY

Each project must fulfil the functionality requirements of its future use (Fig. 9) during its design life. These include the regular operation, maintenance requirements, and the operational requirements in the case of extraordinary events (e.g. natural disasters or accidents) during its operation.

The intended operational requirements define the internal cross sections and the internal geometrical requirements, whereas the ground conditions and the structural durability define the dimensions of the lining and therefore the excavated (outer) diameter. Expandability of the project (e.g. second tube for traffic single line traffic tunnels) shall also be considered in many cases during the planning phases.

The quality level of the construction shall be selected according to the expected design life of the facility and taking into considerations the costs for operation and maintenance. For example, a mine access tunnel life span may be 10 to 15 years, while the life span of a road tunnel is a 100 to 150 years. The quality requirements and the predefined design life shall be established early in the project basic design criteria during the project definition phase and preferably shall remain unchanged. A late change of the quality level will lead to major consequences in later project phases and during the entire project life cycle. The quality level has a major influence on the cost of the project.

Quality and functionality must be achieved regardless to the selected tunnelling method.



Figure 9 : Functionality and required design life must be defined in the basic design criteria © Raimond Spekking/de.wikipedia.org

4 >> DESCRIPTION OF THE MAIN PROJECT REQUIREMENTS

4.5 TIME SCHEDULE

The duration of the project is also a key factor for the total project cost. The time schedule indicates whether and how the target schedule can be achieved.

The overall time schedule of a project shall include not only the design and construction processes, but the time required for the following activities:

- Site investigations (geotechnical and environmental)
- Archaeological investigations
- Proceedings for the construction permit
- Land acquisition
- Negotiation of the funding commitments
- Environmental process and approvals
- Agreements with other agencies affected by the construction
- Coordination with third party stakeholders and the public
- Procurement and project delivery method (i.e. design-bid-build; design-build, public-private partnership, etc.)
- Utility and traffic relocations
- Construction access points and logistics
- Construction activities, including
 - Mobilisation and set up time
 - TBM and power delivery
 - Excavation and lining
 - Finishing
 - Testing and commissioning
 - Time contingencies

The construction time depends on the tunnelling method, due to different mobilisation times and generally different daily advance rates for both methods. Not only the excavation cycle determines the overall advance rate, but also the logistics of the entire supply chain and the type of maintenance requirement of the equipment are key factors, which must be considered, when calculating the overall advance rate (Fig.10). Furthermore, tunnels being linear structures, the availability of multiple access points and headings would influence the time schedule for excavation and lining.

TBM drives are generally faster for long tunnel drives in homogeneous ground conditions

and therefore often more economic than conventional drives.

For projects with special boundary conditions, logistical issues or with a certain geological setting, the construction of a short tunnel using a TBM or of a long tunnel using conventional tunnelling can be more economical or less risky as several examples have shown.

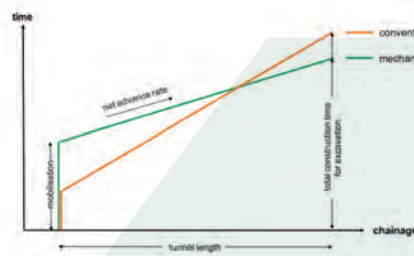


Figure 10 : key factors for the calculation of the construction time for the excavation

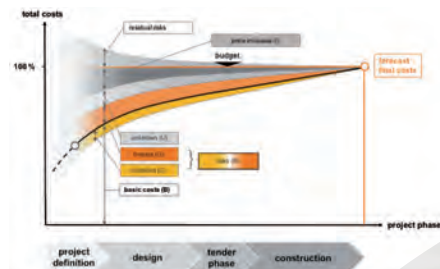


Figure 11 : General cost development during design and construction of a project [14]

4.6 COSTS AND FINANCING

Costs of a tunnelling project depend mainly on the required quality level of the final construction, on the construction schedule (including all aspects of the ground conditions, logistics etc.), or risk factors, and on the market conditions.

Cost objectives and the funding limits are often critical requirements for the execution of a project. An absolute cost transparency is therefore a must during all phases of the project.

According to the well-known experience that no construction is risk free, it is of highest importance that not only the basic costs are calculated. Also the costs for risks, unknown conditions and the future price escalation have to be included in order to get a reliable forecast of the final costs (cf. Fig. 11), a stable budget and to minimise the risk of a budget overrun.

Each design step has its own level of cost evaluation using the appropriate methods (see Table 4). Proper contingencies comparable with the level of the design development shall be included.

During the project definition phase a cost framework is established. The cost framework is defined by the general data of the project (length, volume) multiplied by specific cost values which are based on the experience from completed projects under comparable boundary conditions. The tunnelling method

PROJECT PHASES	PROJECT DEFINITION	DESIGN			TENDER PHASE	CONSTRUCTION
		conceptual design	preliminary design	final design		
Design phases	Basic design criteria	conceptual design	preliminary design	final design	tender design	construction drawings
Project knowledge	not consolidated	planning	planning	planning	planning / contract	contractually
Level of cost evaluation	cost framework	pre-consolidated	consolidated	consolidated	consolidated	consolidated
Method for cost evaluation	Characteristic values	intermediate	preliminary cost estimate	final	verification of the final	contract

Table 4. Design steps and corresponding level and methods for the cost evaluation

4 >> DESCRIPTION OF THE MAIN PROJECT REQUIREMENTS

is at this early stage of the project often of secondary influence, but shall be considered as a parameter in the database of specific experience values.

The intermediate cost estimate in the phase of the conceptual design is still not based on a consolidated project knowledge. It is generally calculated on specific costs on the main construction elements. The specific costs for the excavation shall take the various tunnelling methods into account.

The preliminary and the final cost estimates are based on a single, consolidated project. A detailed calculation of the basic costs, based on quantities material costs, labour costs, equipment costs, cost of consumables, indirect costs, costs of logistics, overhead cost and anticipated profit shall be included. The construction cost shall reflect the selected tunnelling methods.

Risk management is the base for the definition of additional costs for potential risks. A surcharge for unforeseeable aspects shall be added as also the costs for the price increase within the period of the project design and execution, if the final costs at the project end are required. Risk management plan shall be established including a risk register to allocate mitigation measures during design and/or construction. The cost of the mitigation measures shall be included. Residual risks shall be priced and a suitable contingency be established and included in the project overall budget.

The procurement model and the payment method may have an influence on the estimated final costs, due to the fact that procurement models with payment methods with asymmetric risk allocations generally lead to higher costs due to the fact, that higher risk contingencies are often included by the Contractor or the Owner (Fig. 12).

Furthermore, projects that are delivered using public-private partnership, build-operate-transfer or other similar arrangements, the cost of funding the project shall also be included.

As financial risks may become crucial for the success of a project an independent review of risk analysis and the budgets by experienced experts is highly recommended after each project phase.

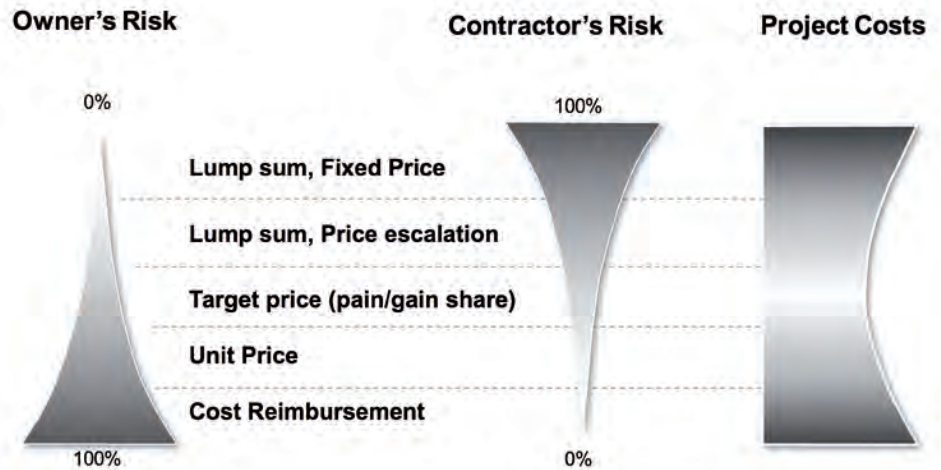


Figure 12 : Total costs in function of the payment method (for underground construction)

The Owner shall also consider the lifecycle costs including the costs for maintenance and operation. The analysis of lifecycle costs may have an influence on the selection of the tunnelling method.

Early and stable funding sources and a financially sound and technical competent Contractor help to achieve the financial goals of a project.

4.7 OCCUPATIONAL HEALTH AND SAFETY

Each worker has the right to leave the site after his working shift as healthy and safe as he started his work. Health and safety requirements are therefore of highest importance for underground construction.

The general layout (accesses, escape ways, etc.), the selection of the construction materials and the availability and the quality of the working space define the general level of work safety already in the early design phases. Occupational health and safety requirements in conjunction with the geology and other factors may impact the selection of the tunnelling method.

Important aspects to be considered are:

- Working place conditions
- Occurrence of gas
- Fire hazards
- Water inflows (high pressure, hot water)
- Ground water table (e.g. compressed air environment)
- Equipment selection
- Proximity to other nearby structures
- Availability of rescue teams
- TBM intervention requirements

Many international and national regulations define the requirements on health and safety. It is recommended to follow ITA's "Guidelines for good occupational health and safety practice in tunnel construction" [3] already in the earliest design phases.

Up to now no internationally recognized studies are available, which show significant differences on the level of occupational health and safety related to the tunnelling method.

Regardless of method of construction, occupational health and safety measures shall be implemented consistent with the selected tunnelling method.

4 >> DESCRIPTION OF THE MAIN PROJECT REQUIREMENTS

4.8 ENVIRONMENTAL ASPECTS

Environmental aspects are critical in order to make an underground project feasible.

The following topics have to be taken into consideration

- Consideration of nature reserves
- Consideration of historical preservation
- Consideration ground water protection zones
- Investigation on the occurrence of contaminated ground and groundwater
- Concept for re-use of muck and muck disposal
- Protection of neighbouring buildings and structures
- Minimising vibrations
- Minimising surface deformations
- Minimising dust
- Minimising noise
- Prevention of odours
- Prevention of lighting
- Prevention of toxic substances
- Minimising impact on aquifers
- Wastewater treatment
- Slurry treatment
- Ground treatment according to weather seasons
- Use of biodegradable liquids

Many international and national regulations define the requirements on environmental aspects. It is recommended in the earliest design phases to follow the checklist of appendix A in ITA's report on "Underground works and the environment" [4].

Tab. 4 shows a list of environmental topics directly related to the tunnelling method

As TBM drives produce generally lower vibrations and less noise impact than a drill a blast drive, environmental aspects may be decisive for the selection of the tunnelling method in certain cases, mainly in densely populated urban areas with shallow overburden.

4.9 PUBLIC ACCEPTANCE

Many infrastructure projects encounter objection by the public. This is often due to lack of understanding the project benefits, the impact on the community and the environment, or the financing aspects. A lack of public acceptance may complicate the realisation of a project, delay it or even result in cancelling the project.

It is therefore of highest importance to secure the public support of a project from the earliest phases by early engagement of the public and the project stakeholders and continue throughout the project phases.

The following elements may help to gain the

public acceptance:

- Clear communication of the needs and benefits of the project
- Early and clear communication of the project risks
- Minimising the impacts on the environment and on third party assets
- Professional stakeholder management (involve affected stakeholders in a direct cooperation or by continuous information)

Public acceptance is generally driven by environmental aspects (noise, dust, vibrations), impact during construction (traffic, impact on businesses, utilities, etc.) and economical aspects but not directly by the selection of the tunnelling method. However, the impacts of the tunnelling method on the environmental aspects, time schedule and costs are important for public acceptance. The public acceptance is often influenced by experiences from similar other projects.

4.10 MARKET CONDITIONS

The local market conditions have to be considered in the selection of the tunnelling method of an underground project, regarding the following aspects:

- Local labour skills and availability
- Local industry experience and preference
- Local Owner's experience and preference
- Availability of suppliers
- Tax liabilities
- Material and labour costs
- Trade barriers
- Union and labour laws
- Local occupational health and safety requirements

Market conditions are related to the local boundary conditions. In some countries the experience with TBMs is rather small, such an implementation of this equipment would initially ask for more international specialists to initiate a TBM operation and maintenance which often they continue throughout the construction in expertise and advisory capacity. Conventional tunnelling works with standard equipment and is generally applicable in all markets.

REQUIREMENT	MECHANIZED	CONVENTIONAL
Dust emissions	X (open TBM only)	x
Diesel emissions	(x)	x
Noise reduction	-	x
Vibrations	x	x
Pollution of muck	-	x
- Nitrite	x	x
- Hydrocarbons	x	-
- Conditioners	x	-
Pollution of slurries	-	x
- Nitrite	x	x
- Hydrocarbons	x	-
- Conditioners	x	-

Legend :

X impact to the environment

(x) impact to the environment may occur, depending on secondary installations

- not relevant

4 >> DESCRIPTION OF THE MAIN PROJECT REQUIREMENTS

4.11 EXPERIENCES

Experience is of highest importance in underground construction. Personal experiences of the Owner's decision makers and their consultants may facilitate the decision making of selecting the tunnelling method. Comparison with other projects can give helpful information.

When carrying out comparative studies it is highly recommended to consider also the boundary conditions of the comparable projects in order to understand the decisions taken.

Wrong conclusions may be taken if the selection process is not fully vetted and all issues are not fully addressed for the project specifics.

It is important to recognise that experiences cannot replace the regular engineering process by the Design Engineer or the advancement in the technologies of both mechanized excavation and conventional tunnelling.

There is a world-wide broad experience on conventional and on mechanized tunnelling available to assist in regions with less experience.

4.12 ORGANISATION AND PROCESSES

The realisation of a project is a sequence of many processes. Each project needs a clear process map (Fig. 13) with a clear allocation of the responsibility for:

- The core processes (design, tendering, construction)
- The management processes (financial funding; cost control, scheduling, risk management; environmental management; health and safety management; management of change requests, stakeholder management, procurement model, project insurance, etc.)
- The support processes (legal and code compliance, real estate, human resources, controlling, reporting, IT-support, etc.)

The general processes are not directly related to the tunnelling method, whereas the time required for individual process steps

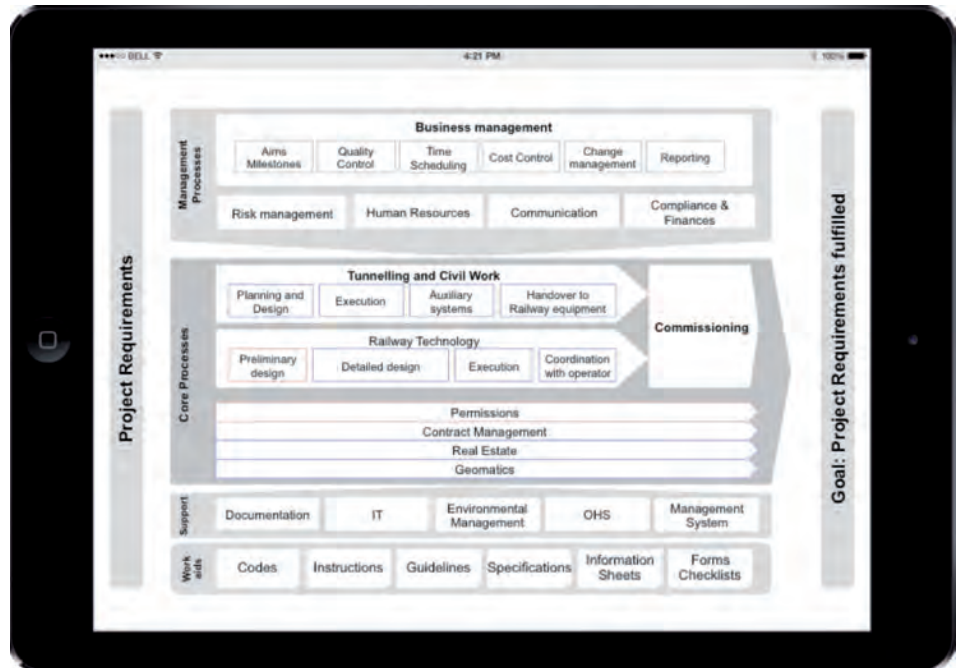


Figure 13 : Example of a process portal for a railway tunnel project on a tablet computer

may vary significantly from one tunnelling method to the other.

The organisational structure is generally not depending on the selection of the tunnelling method. However, the resources may be different from one tunnelling method to the other.

It is highly recommended that the project management plan or handbook reflects the processes required for the selection of the tunnelling method.

4.13 RISK MANAGEMENT

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.

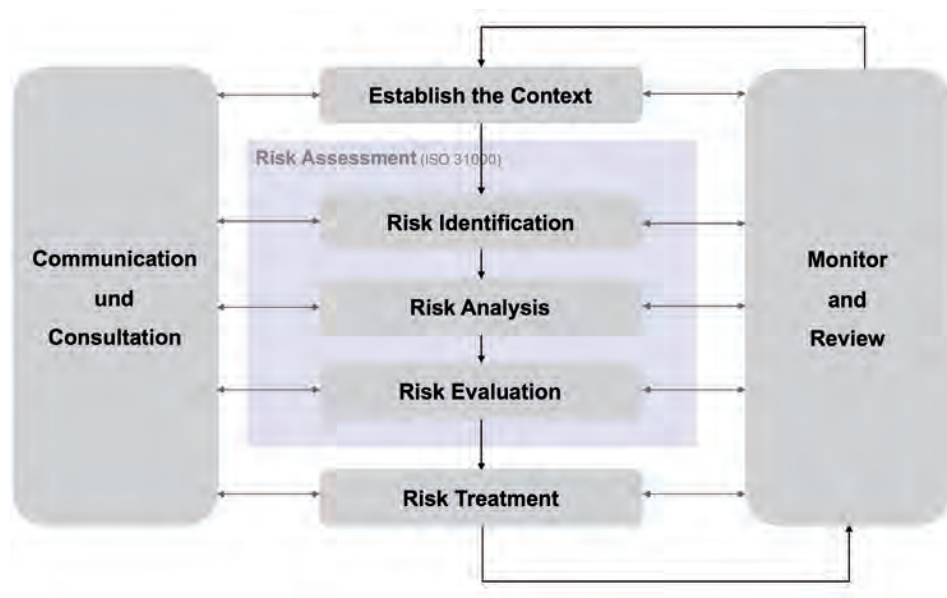
Therefore, the recognition and the assessment of potential hazards as well as the planning of appropriate mitigation measures are fundamental to the design of underground structures.

Hazard identification and the management of risk to ensure their reduction to a level 'as low as reasonably practicable' (ALARP) shall be integral considerations in the planning, design, procurement and construction of Tunnel Works. So far as it is reasonably practicable, risk shall be reduced through appropriate design and construction procedures in any case.

Responsibility for risk management shall be explicitly allocated to relevant parties to a contract so that they are addressed adequately and appropriately in the planning and management of a project and that appropriate financial allowances can be made.

The use of a formalised Risk Management procedure, such as ISO 31000 (Fig. 14), shall be employed as a mean of documenting formally the identification, evaluation and allocation of risks [15]. Risk Management shall start at the the initial stage of the project definition and shall be treated as a continuous cyclic process during the entire period of the project design and construction.

4 >> DESCRIPTION OF THE MAIN PROJECT REQUIREMENTS



The specific hazards shall be considered for each part of the project with the related tunnelling method, whereas the general hazards may be considered generally for each contract. The qualitative risk assessment shall include (independently from the tunnelling method):

- Hazard identification
- Classification of the identified hazards, assessment and evaluation the risks
- Identification of risk mitigation measures
- Details of the risks in the project risk register indicating risk class and risk mitigation measures for each hazard.

It is recommended to follow ITA's "Guidelines for tunnelling risk management" [5].

Figure 14: Risk Management process according to ISO 31000

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
- ii) 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.
- jj) The reputation of a project and the involved organisations

It is important to identify the potential hazards in a structured process. The following suggestion for the grouping of the the potential hazards is proposed in ITA's "Guidelines for tunnelling risk management" [5].

General hazards:

1. Contractual disputes
2. Insolvency and institutional problems
3. Authorities interference
4. Third party interference
5. Labour disputes.

Specific hazards:

6. Accidental occurrences
7. Unforeseen adverse conditions
8. Inadequate designs, specifications and programmes
9. Failure of major equipment, and
10. Substandard, slow or out-of-tolerance works.

5 >> PROJECT DEFINITION PHASE

5.1 GEOLOGY

The exact alignment of the future project is often not exactly known in the phase of the conceptual design rather various corridors are usually being considered. The project is developed at this stage within the boundaries of predefined corridors. In order to reduce risks, it is of high importance to know the zones of unfavourable ground conditions within the design corridors at this early stage (see example Fig. 15).



Figure 15 : Alignment of the Gotthard Base Tunnel (Switzerland) in relation to unfavourable ground conditions

First ground investigations shall be done. Commonly used methods at this phase are:

- Analysis of existing geological records (e.g. for structures already built in the same or similar geological formations)
- Historical records of adjoining projects
- Geological maps
- Technical literature
- Field mapping
- Remote sensing
- Limited exploratory boring

Usually the Design Engineer tries to find an alignment of the project, where the unfavourable zones will be crossed in the shortest possible distance while meeting the project functional requirements. For example, unfavourable zones for urban tunnelling include known manmade or natural underground obstacles or limitations in the right of way. Avoiding crossing active faults in seismic area, or difficult ground conditions are other examples.

Difficult geologic and hydro geologic conditions can be dealt with ground improvement methods. These consist of the various forms of grouting such as permeation grouting, jet grouting, compaction grouting, compensation grouting or drainage and ground freezing to name the most common methods. With improved ground, tunnelling conditions become more favourable and are available for both mechanized and conventional tunnelling.

In urban tunnelling where the alignment conditions may be shallow and the ground friable, ground improvement may allow for conventional tunnelling within tolerable surface deformation limits. Ground improvement in combination with the various pre-support methods in conventional tunnelling including for example pipe arch canopy methods will lead to a robust design and thereby enhance management of risk associated with characteristics of ground strength, stability and deformations.

5.2 LOGISTICS

Accessibility, transportation, access, potential laydown areas, areas for muck deposits and disposal, etc. shall be analysed in this phase. Under certain circumstances,

these conditions may be decisive on the selection of the tunnelling method at this initial stage of the project.

5.3 QUALITY / FUNCTIONALITY

At this stage the Owner shall decide on the functionality (e.g. design speed, number of trains running through a tunnel, allowed breaks of operation for maintenance, etc.) of the project and the required quality level (e.g. life time). It is important to define these parameters early and maintain them throughout the various design phases.

Although generally the functionality and quality requirements do not directly affect the selection of the tunnelling method, certain functional or quality requirements could impact the selection of the tunnelling method. For example, the functional requirements in a underground railway station may favour using conventional tunnelling in a system executed by TBM (cf. Fig. 7)

5.4 TIME SCHEDULE

Due to the lack of information at this phase, the time schedule cannot be evaluated in detail.

However, it is important to start assessing the time schedule at the early stages taking into consideration the two tunnelling methods. Also for the time schedule a certain range of uncertainty must be communicated and assumptions shall be clearly indicated. Linear schedule consisting of time-distance-diagrams are useful tools for linear structures, such as tunnels.

The time schedule will be different according to the tunnelling method and the boundary conditions. In many projects both tunnelling methods can fulfil the time restrictions of the project at this design phase and therefore, shall be assessed carefully to identify certain milestones that can favour one method versus another.

5.5 COSTS AND FINANCING

During the project definition stage no consolidated information on the project is available.

Therefore, no detailed bottom-up cost estimate can be calculated; however, cost estimates shall be prepared for both tunnelling

5 >> PROJECT DEFINITION PHASE

options using historical data and unit prices. Costs can be estimated only very roughly based on the experience from costs of comparable projects.

Adequate contingencies for risks and the unknown have to be added.

The range of uncertainty and the assumptions for each tunnelling method of the cost estimate shall be documented and communicated.

5.6 OCCUPATIONAL HEALTH AND SAFETY

All requirements of the local legislation have to be fulfilled by both tunnelling methods. The impact from possible polluted areas, gas etc. shall be considered in this phase.

5.7 ENVIRONMENTAL ASPECTS

All environmental restrictions have to be considered already in this early project phase, as they may be decisive for the alignment of the underground structure and the selection of the tunnelling method (see Section 3.8). Environmental aspects may be decisive on the selection of the tunnelling method at the project definition stage, such as e.g. noise protection, protection against vibrations.

5.8 PUBLIC ACCEPTANCE

Comprehensive stakeholder management is difficult to carry out in the project definition phase as there does not yet exist an exactly defined project. Nevertheless, the project requirements, the risks of the project and the main mitigation measures shall be communicated in an appropriate way. Affected stakeholders shall be involved in the project at this phase in order to make them participants of the project future development process.

Issues related to noise, dust, disturbance, traffic, etc. shall be communicated as they relate to the tunnelling methods.

5.9 MARKET CONDITIONS

The capacity of the market shall be estimated in this phase as it may have an important impact the future decision on the selection of

the tunnelling method. The market conditions usually vary with time; therefore, this issue shall be re-assessed at every phase of the project.

5.10 EXPERIENCES

Experiences from similar projects shall be collected and interpreted. In the project definition phase, the design and the lessons learned during the construction from other projects shall rather be analysed as they relate to the specific requirements and issues of the current project.

It is important to know the specific boundary conditions and project requirements of similar projects in comparison of the current project in order to understand the decisions taken in other projects and how they relate to the current project. Other conditions or requirements may lead to different technical solutions for the selection of the tunnelling method.

5.11 ORGANISATION AND PROCESSES

At the end of the project definition phase a clear idea about the project organization and the processes shall be established. The continuous risk management process must be implemented at the end of this phase, independent from the tunnelling method. The risk management shall address the two potential tunnelling methods.

The Owner's organisation shall take the decision on the procurement model, as there are:

• the design-bid-build - model (DBB)

This model follows the approach of a design and construction by different contractual partners of the Owner. The Owner commissions a Consultant (Design Engineer) with the preparation of the project documents, mainly the contractual documents, consisting of drawings, detailed specifications and further contractual documents such as bill of quantities, technical reports etc. The Contractors submit their offers on the basis of the tender documents prepared by the Owner's Engineer. The award of contract by the Owner will be given to the Contractor with the economically most advantageous bid (including price and quality).

• the design-build - model (DB)

This procurement model follows the approach of a combined order for the detailed design and the construction. The Owner develops a conceptual (basic) design for his project and tenders the design and construction of his project in a single contract. The Owner signs the contract with a single partner who acts as a general Contractor for the design and the construction. Usually specialized Contractors with the ability to organise the design and construction work act as a provider. The engineering-procurement-construction model EPC is a particular expression of the design-build model with limited influence of the Owner during the construction phase (turn-key contract).

• the design-build-operate-maintain - model (DBOM)

This model follows also the approach of a single contract for the design and the construction of a project. The Owner follows the design-build procurement model. In relation to the design, the DBOM model goes still one step further. The Contractor will also ensure the future operation and the maintenance during a predefined period.

• the build-operate-transfer – Model (BOT)

The BOT model is the procurement model with the highest integration of the Contractor in the project implementation. The BOT- agreement governs the design, construction, operation and maintenance as well as the financing of the project. The Owner issues a long-term concession to a project company in order to construct and operate the infrastructure. The infrastructure is passed back to the Owner after the expiry of the contractually agreed concession period. The BOT-model is often used for purely private projects or for projects based on public and private partnership financing (PPP - Model).

The risk policy of the Owner, the expected integration of the Contractor in the project and the financial capabilities of the Owner are the main criteria for the selection of the procurement model. The tunnelling method is of secondary importance in relation to the decision on the procurement model.

6 >> DESIGN PHASE

ITA's General Report on Conventional Tunnelling Method [2] gives a brief overview on the design procedures in underground construction in general and specifically for conventional tunnelling, whereas ITA's recommendation and guideline for tunnel boring machines (TBMs) [6] gives general information on the selection of the appropriate TBM.

As shown in Table 2, the design phase includes conceptual, preliminary, and final design phases. It is recommended that the selection of the tunnelling method be selected as early as possible, preferably at the end of the conceptual design, if clear differentiators can be identified. However, if the selection cannot be clearly made early in the design phase, the two methods shall be advanced through the preliminary design and if needed through the final design. Sometimes, it may not be possible to have a clear decision of the preferred method in the design phase and both methods are equally applicable, then the Owner may tender the contract with both methods allowing the selected Contractor to choose his preferred method. Obviously, all technical and environmental aspects shall be completely vetted for both methods.

6.1 GEOLOGY

The assessment of the ground conditions in the design phases is essential for the project definition and the construction methodology. The geological investigations are the Owner's responsibility. The investigations shall be planned and supervised by experienced engineering Geologists in close cooperation of both, the Design Engineer and the Owner. Detailed ground investigations shall be started at the beginning of the design phase, when the general horizontal and vertical alignments of the future project are determined.

Nevertheless, also the determination of the alignment requires already a certain level of ground investigations (cf. 4.1).

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

- Analysis of existing geological records, desk study (e. g. for structures already built in the same or similar geological formations)
- Engineering geological field mapping
- Exploratory drillings, galleries or shafts
- Field tests
- Laboratory tests

- Remote sensing
- Exploratory adits and galleries (pilot tunnels)
- Geophysical investigations

Based on this information a ground model (geological and geotechnical model) is established as the basis for the development of the future project. The ground model shows all factual data and the interpretation of the boundaries of the various strata. Ground behaviour in the various geological zones are determined in geotechnical interpretive report and/or baseline report by the Geologist and the Design Engineer.

As long as the ground conditions do not exclude one tunnelling method, the ground model and the geological/geotechnical reports shall describe the ground behaviour (incl. hazard scenarios) for both, mechanised and conventional tunnelling. The anticipated ground behaviour for mechanised tunnelling and/or for conventional tunnelling has a major influence on the selection of the tunnelling method.

As applicable the ground model implements the selected ground improvement methods and displays those for the various sections of the alignment. Ground classes and support classes for conventional tunnelling take the effects of ground improvement into account.

6.2 LOGISTICS

The boundary conditions on logistics have to be studied in detail in the design phase.

Whenever possible the Design Engineer shall develop logistic concepts (accessibility, transportation, laydown area, TBM assembly, installation areas, power supply, water supply, ventilation systems, etc.), which allow the application of mechanized or conventional tunnelling.

If compelling reasons of logistics exclude one or the other method, these reasons have to be clearly documented or provisions shall be made to overcome the difficulties of the logistics of one of the two methods. Cost of accommodating the logistics shall be taken into considerations.

6.3 QUALITY / FUNCTIONALITY

The required design life of the underground infrastructure defines the quality level needed.

Underground structures for transportation or water conveyance have often a required design

life of 100 to 150 years.

The criterion of the functionality describes the restrictions of the future operation of the infrastructure as e.g. the required operation time and the allowed maximum time for maintenance and repair.

The quality/functionality criterion has a big influence on the general layout of an underground structure (e.g. double track tunnel vs. two single track tunnels for railway systems), the standard profiles (e.g. single lined tunnel vs. double lined tunnel) and therefore also influence the selection of the tunnelling methods.

6.4 TIME SCHEDULE

A time schedule is elaborated in each step of the design phase showing the overall design and construction time as well as the critical path for each of the two tunnelling methods. The time schedule is structured following the project breakdown structure and shows the details according to the requirements of each design stage.

It is recommended to show and to communicate the range of the forecast of the construction time for each tunnelling method as the result of the risk analysis, taking into account the uncertainties of the ground conditions.

The total construction time may become decisive for the selection of the tunnelling method based on the preliminary design.

6.5 COSTS AND FINANCING

The costs can be calculated for the first time on the base of a consolidated planning during the design phase. The accuracy of the estimate is directly related to the design level (preliminary design, final design).

Costs are usually calculated based on the main construction elements during the conceptual and preliminary design phase using bottom up approach by calculating the material quantities, labour requirements, productivity rates, equipment usage, cost of consumables, soft costs, profit, and suitable contingencies based on the risk profile. During the final design the costs are calculated based the detailed tasks of the construction and unit prices on the level of working positions.

Not only the basic cost for construction but also charges for planning, land acquisition, third party cost, etc. shall be considered.

6 >> DESIGN PHASE

Adequate contingencies for risks and the unknown have to be added also during the design phase.

The range of uncertainty of the cost estimate must be communicated.

Stable financing shall be established preferably at the end of the design phase defining the funding sources, the cash flow, and secured commitment for completion of the project.

Without a stable financing the tendering shall not be started.

Costs and financing can be decisive on the selection of the tunnelling method at this phase from the Owner's point of view. Nevertheless, it shall be highlighted that a tender process with all options might produce quite surprising results as the potential Contractors may evaluate risks differently than the Design Engineer.

6.6 OCCUPATIONAL HEALTH AND SAFETY

The level of work safety is defined in the design phase by the conceptual design (layout), the construction procedures, by the selection of the quality of the construction materials and by the definition of the required health and safety standards.

Both tunnelling methods have to fulfil the required national or international OHS-standards.

6.7 ENVIRONMENTAL ASPECTS

Similar to the aspects of safety at work, the aspects of environmental protection shall be defined within the design phase and shall be assessed for both tunnelling methods. The sustainability aspects of the two tunnelling methods shall be evaluated. Decisions shall be taken such as the reuse of the excavated materials for gravel production in order to reduce the need of the use of natural, alluvial resources and the standard of environmental protection during the construction phase.

It is recommended to follow the checklist of key topics to consider when managing an underground or tunnel project as published in the ITA report No. 3, "Underground Works and the Environment [4]". The main categories of the checklist are as follows:

- Management and Organisation Considerations
- Architectural and Landscaping

Considerations

- Water Issues
- Air Issues
- Ground Contamination
- Noise and Vibrations
- Natural Biotopes
- Natural Resources

Both tunnelling methods shall fulfil the required environmental standards. Based on the selected alignment, the conceptual design of the project is refined and an Environmental Impact Study is performed taking into consideration the tunnelling methods, showing the impact of the project on the environment but also the proposed mitigation measures. The proposed mitigation measures will have an impact on the cost and time schedule.

6.8 PUBLIC ACCEPTANCE

Public discussions shall be initiated as early as possible to obtain the public and local authorities and elected officials support. It is intensified during the end of the design phase and especially during the legal proceedings for the construction permit and start of actual construction works. It shall also continue through the construction process to maintain the public support.

Environmental, construction impact, political and financial aspects are often the main subjects of discussion with various points of views depending on the stakeholders.

Compromises are often found before the initiation of the legal process to obtain the construction permit if long lasting legal processes or construction interruption is to be avoided. The early implementation of project-related public outreach panels, representing the interests of the various stakeholders is highly recommended. The lack of public acceptance



Figure 16 : Open site event attract all generations
(© AlpTransit Gotthard Ltd.)

may hinder the realization of underground structures.

Once under construction, underground constructions attract the interest of many people (Fig. 16), who are generally fascinated when they have the opportunity to visit the often unknown world of underground construction. Open minded relations to the different stakeholders may help to get the acceptance of the majority of affected people.

6.9 MARKET CONDITIONS

The Owner shall check, whether the market applicable to the selected design is able to support the selected tunnelling method. The Owner shall prepare the design for a TBM-drive and a conventional drive if both solutions are equivalent and the market is able to deliver both solutions. The Owner may tender both methods and allow the Contractors to choose their preferred method. However, if this approach is to be undertaken, all issues shall be vetted out thoroughly from the technical aspects as well as environmental issues and public acceptance.

6.10 EXPERIENCES

Experienced tunnel engineers shall be responsible for the design of underground projects.

Specific experience related to the tunnelling method is required. It is recommended to the Owner to carry out a design check of the project after each design phase by independent, experienced design checkers (expert design checking). The independent design checking engineers (Design Checkers) shall be highly experienced with the selected tunnelling methods and could be assigned from foreign countries if needed.

6.11 PROCESSES

The construction permit shall be obtained according to the local requirements of the project area. As long as the Owner has no mandatory reasons to prefer one or the other method, he shall also ask for a construction permit for both methods (e.g. rig area for segment factory, management of the muck, explosive handling or noise emissions) as long as the local legislation allows such a procedure.

7 >> PREPARATION FOR CONSTRUCTION (TENDER PHASE)

The tender phase is generally crucial for the selection of the tunnelling method. It is recommended to follow the various ITA recommendations during this phase, mainly the ITA

Contractual Framework Checklist for Subsurface Construction Contracts [7] and the Guidelines on contractual aspects of conventional tunnelling [8]. At this stage, if the Design Engineer was able to determine the preferred tunnelling method, the tender documents shall be prepared in accordance with the selected method. Otherwise, if no clear preferred method can be identified, the Owner may opt to tender both methods leaving the selection of the tunnelling method to the winning Contractor. In this case, the tender documents shall address issues related to both methods.

7.1 GEOLOGY

The Owner transfers his knowledge of the ground conditions to the future Contractor in the tender phase. The tender design documents shall contain among other documents [1] the following documents related to the ground conditions:

- a summary of the results of geological and geotechnical investigations, the Owner's interpretation of the results and all raw data from the exploration programme for the bidders' own evaluation.
- a description of the ground and the associated key parameters
- a description of the possible hazards, the relevant influencing factors, the risk analyses performed, and the underlying geotechnical model
- a description and anticipated performance of any improved ground and reasoning for the selection of the specific ground improvement methods (dewatering, grouting, ground freezing)
- a description of any additional methods for the use of controlling surface, subsurface and structure (mainly buildings and utilities) deformations including specialty tunnel presupport methods, compensation grouting, and underpinning
- 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
- baseline geotechnical and interpretive reports

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 (e.g. adaptation of the excavation sequence, the support types or round lengths in conventional tunnelling). Experience has shown that full disclosure of geotechnical information would reduce the risk to both the Owner and the Contractor and thus the project costs. Therefore, it is important for Owners to invest in a comprehensive geotechnical program during the early design phases, independent from the type of procurement.

The information on the ground conditions shall be included in the contract documents. The intent of the disclosure of geotechnical information is to share and allocate construction risks between the Owner and the Contractor properly.

A geotechnical data report 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 the potential

bidders with the same information that the Design Engineer used in the design.

In an interpretive geotechnical report, 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 would be shown. The interpretive report shall be provided to the potential bidders. The contractual status of the interpretive geotechnical report depends on the procurement model (contractual document in the case of DBB, for information in DB-contracts).

A separate geotechnical baseline report establishes a baseline on the 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 between the Owner and the Contractor. 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 the Owner and the Contractor. If baseline values are defined optimally, this can result in minimising contingency of the bidders while limiting the Owner's risk to a reasonable level.

The tender documents have to show the geological and geotechnical data on the same level for both tunnelling methods if both tunnelling methods are equally feasible and if the Owner allows both methods.

7.2 LOGISTICS

The boundary conditions and prior agreements reached on logistics shall be transferred to the future Contractor in the tender documents.

If compelling reasons (e.g. restriction in the construction permit) exclude one or the other method, these reasons have to be documented in the tender documents in order to exclude Contractor's alternatives.

The Contractor has to prove his ability to organise his supply chain in such a way, that he is able to reach his offered performance. The Contractor's ability to fulfil the offered contractual performance shall be an award criterion.

7 >> PREPARATION FOR CONSTRUCTION (TENDER PHASE)

7.3 QUALITY/FUNCTIONALITY

The Owner defines the requirements of final quality/functionality, the target values and the required quality control system in the tender documents.

Quality/Functionality is not related to the tunnelling method at this stage, but the more the Owner departs from the design process (for design-build contract or PPP procurement models) the more detailed the performance specifications of the final product must be defined at the time of tender.

The Contractor shall prove his ability to fulfil the required quality standards, the target values and the required control system with his offer.

The Contractor's ability to fulfil the required quality standards shall be an award criterion.

7.4 TIME SCHEDULE

The Contractor calculates his contractual advance rates according to the Owner's information on the ground conditions (see 6.1) and his working cycle. The excavation rate makes part of the entire performance offered by Contractor to meet the time schedule. The Contractor's ability to fulfil the offered contractual performance and to reach the milestones fixed by the Owner shall be an award criterion (see 6.2). However, advance rates, and the working cycles are part of the Contractor's means and methods and shall be solely his responsibilities.

7.5 COSTS AND FINANCING

Costs can be verified at stage of the final design by pricing of the bill of quantities from experiences of the Owner or his Design Engineer. This calculation creates the Owner's benchmark in the tender process. If the award is based on a lump sum price, the Owner shall request the cost breakdown and the quantities to verify that all issues have been included and that the cost breakdown structure is properly structured to meet the Owner's goals and quality standards.

Adequate contingencies for risks and the unknown have to be added also at this phase of the project. Based on the contractual structure, contingencies could be controlled by the Owner or the Contractor or a combination manner in which a structured formula for access the set aside contingency. The range of uncertainty of the cost estimate shall be also communicated to the sponsor or the funding agency at this stage of the project.

The financing of the project shall be fixed at this stage of the project. Tendering without a stable financing is not recommended.

7.6 OCCUPATIONAL HEALTH AND SAFETY

The Owner's requirements on occupational health and safety are transferred to the future Contractor with the tender documents. The Owner has to define the required standards, the target values and the required control system.

It is recommended to require the Contractor to provide the occupational health and safety plan in his offer and measures in the bill of quantities [10]. In addition, if special requirements by Owner are needed, they shall be included in the tender documents.

The Contractor shall also prove his ability to fulfil the required standards, the target values and the required control system in his offer.

Occupational health and safety is not related to the tunnelling method at this stage.

7.7 ENVIRONMENTAL ASPECTS

The Owner's requirements on environmental aspects and commitments made during the design phase shall be transferred to the future Contractor with the tender documents. The Contractor shall prove his ability to fulfil the required standards, the target values and the required control system in his offer.

Environmental aspects shall be an award criterion and may decide on the tunnelling method at this stage.

7.8 PUBLIC ACCEPTANCE

Measures for public relations during construction shall be included in the tender documents (facilities for visitor centres, information points, open site visits) shall be included in the tender documents regardless of the tunnelling method.

7.9 MARKET CONDITIONS

The market forces decide on the future tunnelling method during this phase. The Owner shall tender or at least allow offers for both methods as long as no compelling reasons favour one of the two methods in advance.

If both methods are of equal ability and no one method is favoured over the other, then the tender documents shall describe both methods in an equivalent level.

7.10 EXPERIENCES

If both tunnelling methods are technically feasible, experience with the tunnelling method offered by the Contractor shall be considered in the award process. The best experiences may become decisive. An experienced contractor with experienced work force is required for a successful construction of underground structures. The Contractor's experience (and his staff) shall be an award criterion.

7.11 PROCESSES

Costs can become the decisive criterion on the selection of the tunnelling method if both methods are technically feasible. The most economic or best value offer (best combination of quality and price) shall get the contract award. Quality in this context means Contractor's measures to ensure the completion of the project milestones, the type and quality of the site organisation, measures to ensure the project functionality, type of the quality assurance, mitigation measure for environmental protection, risk management and mitigation measures etc. (see 6.2 ff.).

8 >> TASKS DURING THE CONSTRUCTION

8.1 GEOLOGY

The primary support measures for conventional tunnelling and tunnel drives with open TBMs are chosen on site out of the provisions of the detailed (final) design after the thorough recognition of the ground conditions. It is advisable that the recognition and the relevant assessment of the ground conditions are carried out by experienced Geologists, the Contractor's and the Owner's representative (in the case of DBB procurement).

It shall be noted that traditionally, the ground conditions and the anticipated ground behaviour during construction is the responsibility of the Owner; the Owner owns the ground.

In this regard, if the actual ground conditions are different than anticipated requiring additional measures or changes in the construction method, the Owner shall be responsible and the Contractor shall be compensated for additional costs or time delay in accordance with the contractual conditions.

The ground conditions are one of the key factors for the daily advance rate and shall be taken into consideration from the design through the construction phases.

In the case of unforeseen ground conditions (Fig. 17), supplementary construction measures shall be applied. Conventional tunnelling allows generally more flexible reaction on changed ground conditions, as the excavated cross section can be changed and the tunnel face is normally accessible in the case of necessity.



Figure 17 : Unforeseen ground conditions due to rock burst phenomena® ATG

TBMs again must be designed to tackle the worst expected ground conditions. Recent progress in technology application provided the mechanised excavation method with increased flexibility and efficiency to be able to handle different ground conditions, difficult ground conditions, and mixed face ground conditions. Still, in case of unforeseen worse ground conditions conventional tunnelling is often used as a supplementary measure for TBM drives in the case of difficult ground conditions (using by-passes or auxiliary shafts).

Only in very rare cases the tunnelling method has been switched totally.

8.2 LOGISTICS

The Contractor is responsible for the logistics on site (Fig. 18), regardless the tunnelling method selected. TBM drives, due to their often high advance rates, will cause a comparable higher demand on logistics for transportation, whereas conventional tunnelling has high requirements on the logistics of the various steps in each round (drilling, blasting, mucking, primary support).



Figure 18 : Rig area of a major tunnel project - the heart of logistics® ATG

8.3 QUALITY/FUNCTIONALITY

The excavation is the prerequisite for the placement of the final lining and therefore the achievement of the lifetime requirements of the underground structure.

There are no indications on a generally different level of quality/functionality in relation to the tunnelling method. However, over-excavation associated with conventional tunnelling would often require filling the over-excavation with concrete or sprayed concrete which may impact (negatively or positively) the long term performance of the facility.

8.4 TIME SCHEDULE

Time management is of crucial importance for the success of the project.

Many contracts follow the principle that the ground belongs to the Owner. Accordingly, the Owner is responsible for time schedule delays if the ground conditions deviate from the contractual conditions.

On the other hand, the Contractor is responsible for the achievement of the contractually agreed performances as long as the ground conditions remain within the contractually defined conditions.

There are no indications on generally different development of the time schedules in relation to the tunnelling method. However, the time schedule and meeting Owner defined milestones will be different for the different tunnelling methods.

8.5 COSTS AND FINANCING

The cost changes during construction is mainly driven by the following parameters:

- Changes of the project requirements (e.g. higher standard of safety, environmental protection or compromises with stakeholders)
- Change orders from the Owner
- Ground conditions outside the contractually agreed limits
- Unexpected changes in the market
- Progress rates slower than planned

8 >> TASKS DURING THE CONSTRUCTION

Changes of the project requirements and change orders require a decision of the Owner's organisation. The cost changes due to these factors can be influenced by the Owner.

Changed ground conditions outside the contractual limits and unexpected changes in the market remain outside the influence of the Owner. However, it is the Owner's responsibilities for the ground conditions, while it is the Contractor's responsibilities for changes in the market conditions such as unavailability of locally qualified workers, or changes in cost of energy or fuel, etc.

8.6 OCCUPATIONAL HEALTH AND SAFETY

The requirements of occupational health and safety (example Fig. 19) have to be fulfilled each day independently of the selected tunnelling method. There are no indications for a systematically different level of the occupational health and safety standards in relation to the tunnelling method, though the conditions within the TBM back-ups are more factory-like and fully designed workplaces at every work position while in the conventional tunnelling the workers are more exposed to the ground at the tunnel face.



Figure 19 : Modern refuge chamber[®] ATG

The national standards regarding occupational health and safety shall be fulfilled in any case.

ITA Working group 5 has published several documents on the actual state of the art in the occupational health and safety. It is highly recommended to apply ITA's reports such as:

- Safe working in tunnelling [9]

- Guidelines for good occupational health and safety practice in tunnel construction [10]
- Guidance on the safe use of temporary ventilation ducting in tunnels [11]
- Guidelines for good working practice in high pressure compressed air [12]
- Guidelines for the provision of refuge chambers in tunnels under construction [13]

8.7 ENVIRONMENTAL ASPECTS

The environmental requirements (Fig. 20) shall be fulfilled each day independently from the selected tunnelling method. Nitrite and rests of explosives are the main issues for conventional tunnelling. Conditioners and hydrocarbons are the main items for TBM drives.

There are no indications for a systematically different level in the fulfilment of the environmental requirements in relation to the tunnelling method.



Figure 20 : Use of particle filters is part of the concept for environmental protection (© AlpTransit Gotthard Ltd)

8.8 PUBLIC ACCEPTANCE

Tunnel construction generally attracts high public interest independently from the tunnelling method. Public acceptance can be achieved with organized site visits (public days of the "open site" (Fig. 21)), visitor centres, information points, webpages etc.

8.9 MARKET CONDITIONS

Market conditions are relevant for the Contractor in this phase (suppliers, workers, engineers) and depend on the local conditions and the capabilities of the

resources for the tunnelling method. The selection of the tunnelling method shall take into consideration the market condition at the time of the selection and the future trend of the market conditions such as competing projects or potential changes in supply chains.



Figure 21 : Stakeholder management with the youngest in UK[®] A3 Hindhead Tunnel

8.10 EXPERIENCES

The experiences for future projects are gained with each underground project under construction. Monitoring, reporting and documentation are of highest importance during the construction phase. TBM data can be collected and evaluated by sophisticated monitoring systems and used for improvement of the technology.

Conventional tunnelling data can also be collected for further analysis. For example, similar systems as on TBMs exist also for modern drilling jumbos.

The Owner shall organize the evaluation strategy of the collected data during the tender phase independent from the selected tunnelling method. There is generally no difference in gaining further experiences in relation to selection of the tunnelling method.

8.11 ORGANISATION AND PROCESSES

Both tunnelling methods require highly sophisticated processes on the Owner's and the Contractor's side which shall be coordinated in a project specific quality management system. The requirements on processes and organisation are needed regardless to the tunnelling method selected.

The selection of the tunnelling method depends on the fulfilment of many requirements. The various requirements shall be analysed according to their relevance in each design phase.

Each project shall be evaluated on a case by case basis taking into considerations the project specific conditions and evaluation criteria.

It is preferred that the selection process of the tunnelling method be made during the design phases; however, often there is no obvious favourable method for the specific project. In this case it is recommended that the bidders be allowed to bid either of the two methods. If this approach is selected, the owner's engineer shall develop the tender documents allowing both methods and providing equal relevant information to allow the bidders to make informed decision on the selection of the tunnelling method.

Generally, there is no quick solution for the decision on the selection of the tunnelling method. As shown in the earlier chapters of this document, the Owner can leave this decision to the market conditions, as long as he has no compelling reasons to prefer one or the other method. There are two options:

- a. The Owner tenders both methods to the same level of information in the tender documents
- b. The Owner tenders only his preferred method but allows Contractor's alternatives for the second method

In both cases the tender documents have to contain all information related to the selection of the tunnelling method on the same level for both methods. Tab. 3 shows the various tasks which shall be considered in order to select the most suitable tunnelling method in relation to the main project requirements.

10 >> REFERENCES

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11 >> LIST OF TYPICAL AND EXCEPTIONAL PROJECTS

This report contains contributions by the various Members of Working Group 14 and Working Group 19 over the period 2013 – 2015. The animators Lars Babenderde (WG 14) and Heinz Ehrbar (WG 19) coordinated the work. Alexandre Gomes was the Tutor of WG 19 and Rick Lovat was the tutor of WG 14.

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11 >> LIST OF TYPICAL AND EXCEPTIONAL PROJECTS

CATEGORY	PROJECT			DIMENSION				CHARACTERISTICS			YEAR OF COMPLETION	TUNNELING METHOD		COUNTRY		
	ID	name	section	purpose	excavated diameter [m]	excavated cross-section [m2]	cross-section final tunnel [m2]	length [km]	water	geology		other	tendered		executed	
	1	Wienerwald Tunnel		Railway	10.7		48	2 + 11		rock		2012	Conv & TBM	Conv & TBM	Austria	
	2	Lainzer Tunnel		Railway	- 13 m	80 to 140	75	12.8		rock		2012	Conv	Conv		
	3	Unteres Intall		Railway	13.0					rock		2012	Conv & TBM	Conv & TBM		
	4	Koraim Tunnel	Lot KAT 1	Railway		82	43	2.0		rock		2022	Conv	Conv		
			Lot KAT 2 TBM	Railway	9.9	78	43	17.2	yes	hard rock		2022	TBM	TBM		
			Lot KAT 2 Conv	Railway		82	43	2.1			rock		2022	Conv		Conv
			Lot KAT 3 TBM	Railway	9.9	78	43	10.5	yes	hard rock		2022	TBM	TBM		
		Lot KAT 3 Conv	Railway			43	0.7			rock		2022	Conv	Conv		
	5	Semmering Base Tunnel		Railway			43	19 + 8	yes	rock		2025	Conv & TBM	Conv & TBM		
	7	Albvorland Tunnel		Railway	11.3	100	58	8.2		rock	karst	2021	Conv	TBM	Germany	
	8	Bosslar Tunnel		Railway	11.4	102	58	5 + 3		rock	karst	2021	Conv & TBM	Conv & TBM		
	9	Steinbühl Tunnel		Railway	11.3	100	58			rock	karst	2021	Conv	Conv		
	10	Filder Tunnel		Railway	10.8	92	58	9.0	minor	rock	swelling	2021	Conv & TBM	Conv & TBM		
	11	Albabstiegl Tunnel		Railway	11.3	100	58	5.9								
	12	Herrentunnel		Road	11.2	99	n.a.	2 x 0.9	3,5 bar	softground		2005	PPP (free)	TBM		
	13	Lötschberg Base Tunnel	Lot Steg / Raron	Railway	9.4	69	47	10,2		hard rock		2007	Conv & TBM	Conv & TBM	Switzerland	
	14		Lot Ferden	Railway		65 to 69	47	7.4	110 bar	hard rock	natural asbestos		Conv	Conv		
	15		Lot Mitholz	Railway		65 to 69	47	17.0	70 bar	hard rock	karst		Conv	Conv		
	16	Gotthard Base Tunnel	Lot Erstfeld	Railway	9.5	72	41	7.8	40 bar	hard rock		2016	TBM	TBM		
	17		Lot Amsteg	Railway	9.5	72	41	11.3	100 to 200 bar (initial)	hard rock			Conv & TBM	TBM		
	18		Lot Sedrun	Railway	9.5 to 12	85 (35 to 320)	41	8.6	100 to 200 bar (initial)	soft & hard rock	squeezing		Conv	Conv		
	19		Lot Faido	Railway	9.4	69 (17 to 328)	41	13.4	100 to 200 bar (initial)	hard rock	squeezing		Conv & TBM	Conv & TBM		
	20		Lot Bodio	Railway	8.9		41	16.0	minor	hard rock			TBM	TBM		
	21	Ceneri Base Tunnel	Vigana	Railway		90 to 350	41	0.8		softground/rock		2020	Conv	Conv		
	22		Sigirino	Railway		48 to 87	41	14.1		rock			Conv & TBM	Conv		
	23		Vezia	Railway		81	41	0.3		rock			Conv	Conv		
	24	Bypass Tunnel Flims	Flimsterstein	Road		90 to 120	70	2.9 + 0.5	200 to 700 Vs	rock	karst	2009	Conv	Conv		
	25	Cross City Line Zurich	Weinberg Tunnel	Railway	11.3	100	65	4.8		rock	river undercrossing	2014	TBM	TBM		
	26	Bypass Tunnel Kueblis		Road		99 to 120	70	3.4		rock		2016	Conv	Conv		
	27	Bypass Tunnel Saas		Road		80 to 110	70	2.6		rock		2011	Conv	Conv		
	28	Bypass Tunnel Roveredo	Tunnel San Fedele	Road		100 to 158	70	2.1 + 2.5		rock	softground in portal zone	2016	Conv & TBM	Conv & TBM		
	29	TRunnel Visp		Road						rock		2019	Conv	Conv		
	30	HEPP Machu Pichu	Tailrace River Crossing	Water	3.2			2 x 0.120	5 bar	softground		2000	TBM	TBM	Peru	
	31	Tunnel Weighbridge	Watertunnel	Water	3.2			0.7	2 bar	rock	fractured	2002	TBM	TBM	Jersey Isld	
	32	Lake Mead Intake N°3		Water	7.8			4.8	13 bar	various		2015	TBM	TBM	USA	
	33	Tuen Mun to Chek Lap Kok	Junction section East	Road	17.6			0.8	5 bar	softground		20xx	TBM	TBM	Hong-Kong	
	34	Almieti Madhava Reddy Project		Water	10.0			43.5	to 300 MPa	hard rock		20xx	TBM	TBM	India	

typical

exceptional

This list will be extended in future reports.

