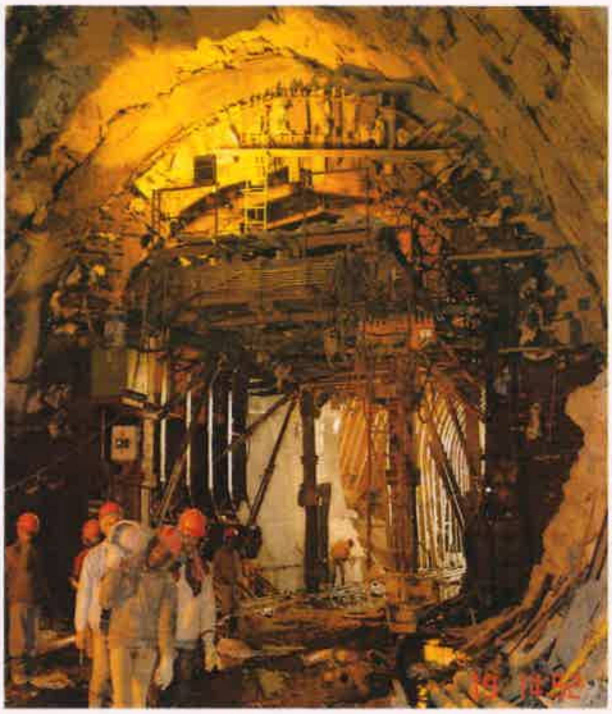
Workshop on

THE OBSERVATIONAL APPROACH IN TUNNELLING: EVOLVEMENT, ISSUES AND CHALLENGES

29 - 30 October 2018, New Delhi



COURSE MATERIAL

Organised by *In association with* *under the aegis of*

TAI

Tunnelling Association of India

ESTD. 1927
NEW DELHI

Central Board of Irrigation & Power

GC GEOCONSULT

International Tunnelling and Underground Space Asssociation

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CONTENTS

Austrian Society for Geomechanics

The Austrian Practice of NATM Tunnelling Contracts

2011

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1 PRELIMINARY REMARKS

1.1 General

Tunnelling stands out among the various engineering disciplines for its large measure of unpredictability. It is in particular the uncertainties of the ground which call for an approach that differs from many of the other engineering disciplines.

Its special feature is the need for intensive feedback between assumptions and reality. Information needs to be gathered constantly on actual ground conditions, characteristics, actual ground behaviour and the interaction between the ground and the selected tunnelling methods (supports and construction processes). This information will form the central basis for adjusting the design directly at the tunnel site. This in turn will enable optimum decision-making only where information of this kind is provided in "real time", that is, as tunnelling proceeds.

For optimum decision-making at the tunnel site, it is necessary to provide for the following conditions during the tendering phase preceding NATM (New Austrian Tunnelling Method) tunnelling:

- Adequate preparatory investigation and description of the ground,
- Interpretation of the forecast in terms of tunnel engineering and geomechanics,
- A design that covers the expected range of ground behaviours,
- Formulation of criteria and targets that should govern the selection of the various tunnelling methods.

If a tunnelling method is to be safe and economical, it needs adequate adjustment to changing ground conditions by use of flexible construction methods.

Construction contracts must thus answer the requirement of flexibility in order to enable the strengths of the NATM, which lie primarily in its adaptability, to be used to best advantage. **Austrian Standard ÖNORM B 2203-1"Underground works-Works contract" Part 1** Cyclic driving, which forms the basis for contracts in tunnel construction, addresses these requirements.

The construction contract needs to be drawn up in a manner that will serve as the best possible aid for optimal decision-making. The "flexible" construction contract in conformity with B 2203-1 thus meets the following principles:

- The ground-related risk, that is, the risk of differing ground properties and ground behaviour, is borne by the owner (risk allocation instead of risk sharing);
- The construction contract provides unit prices for all tunnelling items expected to be needed on the basis of the tender design;
- Payment is made for actual tunnelling work, rather than work items provided for in the design;
- The items of the bill of quantities and the payment models are formulated so that in the event of changes in the tunnelling process payment is adjusted largely without the necessity of a variation order;

- The construction contract provides for decision-making at the tunnel face, with a mutual agreement between owner and contractor. These decisions are based mainly on results of on-site inspection, geological and hydrogeological routine documentation, geotechnical measurements and the constant evaluation and interpretation of such information.
- In case agreement cannot be reached, the authoritative decision of an official tunnelling expert can be resorted to; this person is a mediator appointed by contract whose advice is sought in the case of difference of opinion in technical matters between owner and contractor.

1.2 Risks and responsibilities

Although Austrian Standard B2203-1 provides for no explicit allocation of risk, the following principle of risk sharing between owner and contractor is applied:

- **The risks and responsibilities of the owner include:**

  All information provided by the owner (such as preliminary work, tender documents, detailed construction documents) and the **ground**.

Thus, the ground is clearly the responsibility of the owner. Austrian Standard B2203-1 mentions "characterisation of ground (rock mass)" instead of a description. This should be prepared in conformity with the Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation issued by the Austrian Geomechanics Society (ÖGG). This guideline states that such characterisation should be made not only for the properties of the ground (rock mass), but also – and in particular so – for its behaviour. This clear allocation (also) of ground behaviour to the owner's sphere of risk is a special feature of the B2203-1, which goes beyond the international contractual practice laid down in the FIDIC Red Book of 1999. The B2203-1 stipulates the preparation of a Geotechnical Interpretative Report, which falls within the responsibility of the owner.

Note for the sake of comparison: Paragraph 4.10 "Site Data" of the FIDIC Red Book mentions "subsurface and hydrological conditions" and provides for the contractor to be responsible for their interpretation.

The following thus remains within the sphere of the contractor:

- **The risks and responsibilities of the contractor include:**

  All assumptions made by the contractor on the basis of the tender documents for price calculation and construction; all arrangements made by the contractor and by the suppliers and sub-contractors selected by him.

1.3 Fundamental structure of a bill of quantities

Unit price contracts usually provide two item categories:

- One-off pay items (flat-rate items such as site facilities, site clearance etc.) and

- Quantity-dependent pay items (items for payment according to pay quantities such as tunnel excavation, support elements etc.)
    - labour costs
    - material costs
    - costs of equipment operation and wear.

The intended flexible construction contract provides an additional item for

- Time-dependent pay items

  These are items that are only indirectly dependent on the quantities to be provided, while being directly dependent on the construction time.

    - costs for the site manager, engineers, surveyor, quantity surveyor etc. and for auxiliary site personnel (such as cleaning staff),
    - cost of site equipment, such as for implicit depreciation and interest as well as maintenance (repair) of equipment other than listed among the costs of individual pieces of equipment within a quantity-dependent item,
    - cost of operating special equipment (such as a workshop, warehouse, accommodation, canteens),
    - cost of operating site vehicles,
    - other continuing site overheads (such as rents, leases, communication, heating, lighting).

Payment for such items must be made even when due to unforeseen events either no or reduced quantity-dependent items are executed. The time-dependent pay items and consequently the time-dependent costs normally remain unchanged during such a phase.The time-dependent item category is thus also intended to ensure the realistic management of payment for the normal work which continues to be needed during such unforeseen phases.

In the case of a ground-related event or other unexpected incident (within the owner's sphere of risk and responsibility) affecting the normal tunnelling operations, the time-dependent items are paid for on the basis of the time elapsing until tunnelling is resumed. In addition, the contractor receives payment for all quantity-dependent and/or potential one-off items implemented during such a period.

The idea of time-dependent pay items is, among other things, to avoid the arising of any advantages or disadvantages for the contractor as the result of unexpected tunnelling scenarios. During such phases, the contractor receives payment for the greater part of the work to be performed by way of the regular settlement procedure (monthly progress payment). This minimises conflicts of interests, while supporting the desired optimal decision-making process.

2 TENDERING AND COSTING

2.1 Time-dependent costs (B2203-1: 4.3.1)

2.1.1 Tendering procedure

Tender documents should provide special pay items for time-dependent costs. For underground work of major longitudinal extent, these items should be subdivided into phases in conformity with the sequence of works as shown below:

a. Commencement of the construction works to commencement of tunnelling (fixed time),
b. Tunnelling (variable time),
c. Extra charge on tunnelling for simultaneous installation of final lining (variable time),
d. Installation of final lining after the contractual end of tunnelling (variable or fixed time),
e. Work following the installation of the final lining (fixed time)

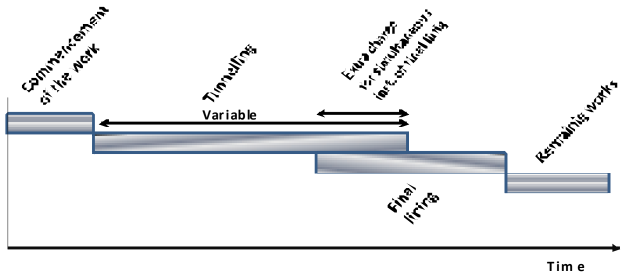


Figure: Simple work sequences for time - dependent cost

In the case of complex work sequences, in particular where several headings and above-ground work are implemented simultaneously, an allowance should be included for overlaps, mutual dependencies and the potential complications involved. The work sequence underlying the costing sheet should always be based on the critical path as follows from a construction schedule provided by the owner.

Whereas phases a., d. and e. are considered independent of the ground conditions actually encountered, phases b. and c. are directly dependent on the tunnelling conditions, such as ground behaviour, tunnelling classes (TC), supplementary measures and special measures.

It is thus necessary to agree by contract on advance rates for each predicted tunnelling class and also for potential supplementary and special measures as well as complications. These advance rates should be included in the offer submitted by the bidder.

2.1.2 Costing guidelines

Advance rates are calculated by the bidder. These are primarily based on:

- typical cross sections,
- tunnelling classes (TC) and their lengths, including typical support-element drawings,
- excavation method,
- multiple-drift tunnelling and criteria for longitudinal spacing of drifts, ring closure distance
- ground characterisation (rock mass behaviour, geotechnical longitudinal section).

A cycle period for one excavation round is calculated referring to all other tender information, in particular information on geology and rock-mass behaviour, as well as for the boundary conditions of the project, and serves as a basis for calculating an advance rate for each tunnelling class. The length of an excavation round is assumed as being the upper limit of the round-length range.

Example: Cycle diagram for tunnelling class 5/2.21 (see Annex 1):

Drilling, charging	90min
Blasting, ventilation	20min
Mucking	120min
Wire mesh and steel arch installation	40min
Shotcrete Spraying	90min
Anchor installation	40min
Other	10min
Total	410min / 60min/h = 6.8h per cycle

For a length of 1.7m per excavation round and a daily working time of 24h/d, the resulting advance rate is

24h/d / 6.8h/cycle x 1.7m/cycle = 6.0m/d

This method is applied for determining advance rates for all tendered tunnelling classes (TC), and for entering them in a construction-time calculation table. The predicted tunnelling time is calculated from the tendered tunnelling class lengths and the advance rates offered.

The pay items for time-dependent costs are tendered and offered as lump sums in order to permit cost comparison during bid evaluation.

Example: Conversion of time-dependent cost lump sum into pay units (see Annex):

The following example shows the method of converting one lump sum (1LS) related to the predicted tunnelling time into pay units (PU) at contract award to permit payment during the construction period.

Pay item in the offer:

Item xxx Time-dependent tunnelling cost 1 LS € 996,265.-

This lump sum relates to a predicted tunnelling time, calculated from the offered advance rates and predicted tunnelling-class lengths of 104.65 work days (WD).(see Annex, Page 23)

Item in the contract:

Item xxx Time-dependent tunnelling cost

104.65 PU of € 9,519.97 each WD = € 996,265.-

2.2 Tunnelling Classes (TC) (B2203-1 : 4.3.2)

2.2.1 Tender documents

The geotechnical design of underground structures is based on the Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation issued by the Austrian Geomechanics Society (ÖGG), which describes the individual design phases.

In the tender design phase, the final step in geotechnical design for typical support-element combinations and work sequences is determining tunnelling classes in conformity with B 2203-1. Tunnelling classes are best defined in the form of a matrix (tunnelling class matrix) considering the excavation methods required for technical reasons (such as blasting or mechanical excavation), subdivisions of the specified excavation cross section and the longitudinal development of the sequence of tunnelling activities. These boundary conditions should remain unchanged for each line in the matrix, or else a different matrix should be provided.

The matrix provides a separate box for each tunnelling class, defined by first and second organising numbers. The first organising number for top heading and bench or full face (no division into top heading and bench) results from the splitting of the tunnelling activities into round-length ranges, while the excavation of the invert is split up according to opening-length ranges.

Each typical support-element design (characteristic support-element combination) is based on the sum total of quantities of support elements and supplementary measures multiplied by the rating factors provided in B2203-1, Table 3. This sum is then divided by the corresponding "rating area". This gives the support number as the second organising number.

The rating factors for the individual support elements are dimensionless and mutually balanced factors that represent a relative measure for the time required for installing the support elements. The implementation of a rating area considers the more efficient installation of support elements in larger cross sections. The support on the tunnel shape increases linear with tunnel diameter, while rating area increases exponentially with the power of two.

No support number is determined for the invert. The second organising number results from the type of primary support, that is, open floor, invert slab, invert arch with or without longitudinal division.

The scope of application of the second organising number (the "width of the matrix box") is a function of the round length as shown in Standard ÖNORM B2203-1, Table 4.

The tender documents should provide an excavation pay item for each tunnelling class in m³.

2.2.2 Costing guidelines

- **Labour costs**

Computation of the advance rates for the individual tunnelling classes should include the entire tunnelling cycle, (i.e both the principle excavation work and the installation of support elements, should be weighted together). It is natural, therefore, that the overall labour costs calculated for the tunnelling crew should be considered in the excavation item so as to avoid burdening the support items with labour costs.

Minor changes in support quantities arising as tunnelling proceeds will not affect the advance rate in any appreciable degree. Should major changes in support quantities occur, however, the application of the rating factors will result in a new support number and, hence, a new second organising number. Then a different tunnelling class will apply in the matrix system and this will be based on a different contractual advance rate and thus involve different labour costs.

Within the area of a matrix-box there is no difference of advance rates and excavation item price. It is the contractor's risk where inside this area his calculation lies.

B2203-1 does not, however, provide for the entire tunnelling wages to be included in the excavation pay item. It is also permissible to allocate wages to individual support elements.

Where the matrix model is applied, the labour costs in the excavation items will normally be computed as follows:

- Workforce x working time (h/WD)* / advance rate (m/WD) **=**
  man hours / m (MH/m)

- MH/m / cross-sectional area (m^2) **= man hours / m^3 (MH/m^3)**

*WD = work day.

For the purposes of the above calculations, the cross-sectional area is understood to be the specified excavated face area, as this is the quantity for which payment will be made.

- **Other excavation costs**

The other costs of the excavation item include

- auxiliary materials such as explosives and blasting accessories (kg/m^3),
- secondary materials (€/m^3),
- working consumables such as power (kWh/m^3) and
- diesel (lt/m^3) and wear parts ((€/m^3) for equipment.

These are derived from empirical values obtained from back analysis of costing for previous projects and adjusted to meet the requirements or boundary conditions of the current project. The working consumables power and diesel can each be categorised as a work-related part (such as tunnelling equipment) and a time-related part (such as lighting, ventilation, pumps etc.). These must be designated as such in the cost calculation to enable the contractor to realise these costs adequately. In order to ensure fair payment, time-dependent other costs should be shown in the items for time-dependent costs, where they are paid per day or payment unit even through periods of tunnelling interruption.

2.3 Difficulties due to water ingress (B2203-1: 4.3.6.1 and 5.5.2.6.1)

2.3.1 Tender documents

The Standard B2203-1 distinguishes on principle between dewatering (pump sumps, pumps, piping etc.) and water complications incurred during the implementation of the tunnelling works. Dewatering and water complications form separate pay items.

Dewatering measures include works required for removing the water from the drive. Water complications are understood to be those complications which affect and thus delay tunnelling due to inrush of underground water in the face- working area. Payment for this delay is made through additional labour cost, time-dependent costs and additional construction time.

In the preparation of the tender, the owner estimates the number of days on which water complications are expected to occur, using the geological predictions, and specifies the following:

- contractual critical flows,
- predicted flows,
- up gradient or down gradient tunnelling,
- impact of water on the rock mass,
- partial drift in which the water complications occur (crown, bench, invert),
- location of water ingress within the partial drift (may be omitted where appropriate).

Allowance for difficulties is made by the owner in the construction-time calculation tables of the tender documents by specifying expected work days in a matrix on the basis of up to 6 different yield ranges for water inflow and in up to 4 different complication classes.

2.3.2 Costing guidelines

The bidder should list reduction factors for advance rates within certain limits for each water range and each complication class (from favourable to very unfavourable). If the yield of underground water is larger than the critical flow within the specified tunnelling face-working area, this reduction factor is applied to increase the corresponding contractual time (without water complication) by an additional tunnelling time (to allow for water difficulties).Pumps, pump sumps, pipes e.g. are paid with separate items.

2.4 Over-excavation and excess concrete (B2203-1 : 4.3.5 and Fig. 2 and Fig. 3)

Any excavation outside the specified excavation profile is termed over-excavation in B 2203. This is a generic term that includes deformation allowance ($ü_m$) and over-profile ($ü_p$).

2.4.1 Tender documents

- **Deformation allowance "$ü_m$"**

Deformation of the rock mass following excavation reduces the excavated underground space. In order to arrive at the specified tunnel size it is necessary to enlarge the excavation volume by an adequate allowance, the deformation allowance ("$ü_m$"). This enlargement is considered in computing excavation volumes and support quantities. Adjustment of the deformation allowance as the work proceeds is possible. This is the responsibility of the owner.

The actual deformation of the rock mass (v) is determined by measurement.

It is rarely possible to estimate in advance exactly what the deformation will be. The difference between the deformation allowance and the actual deformation volume ($ü_m$-v) must, therefore, be filled up with inner-lining concrete. This concrete quantity is paid for by the owner and the computation method to be used is specified in the tender documents.

- **Over-profile ($ü_p$)**

As a result of the natural properties of the rock mass and the excavation method used, the actual excavation contour will lie on the outer side of the specified excavation line.

The magnitude of the difference depends both on the working skill of the contractor and the properties of the rock mass, which are the responsibility of the owner. Accurate contractual separation of the spheres of responsibilities between owner and contractor is not possible.

The spheres of responsibility of owner and contractor are, therefore, defined by fixing a limit for the excavation work. This dimension is termed over-profile ($ü_p$). The excavation line displaced by the dimension $ü_p$ is termed boundary surface A. The dimension $ü_p$ is specified by the owner for each round-length range in the tender documents. By experience this will be between 0.2 and 0.4m, dependent on the magnitude of the cross-sectional area. It is well known that longer round lengths cause more over-profile.

No extra payment is made for over-excavation inside boundary surface A. This should be allowed for by the contractor when pricing the tunnelling classes specified in the tender documents. Over-excavation outside boundary surface A, unless caused by improper work, is paid for under separate items independent of tunnelling classes.

Separate pay items are provided for filling up over-excavation volumes with shotcrete or concrete. Boundary surface A moves into the cavity as a result of the actual deformations, so as to form a new boundary surface B. Payment for filling up accepted over-excavation volumes on the outer side of boundary surface B is based on cubic metres. Payment for over-excavation on the inner side of boundary surface B is per square metre of excavated surface, with filling of inner-lining.

2.4.2 Costing guidelines

Since no separate payment is made for over-excavation on the inner side of boundary surface A, the contractor needs to make a price allowance for such extra volumes. This not only concerns the excavation perimeter, because wire mesh, lattice girders / steel arches will also need to be installed later along a larger radius and a substantial proportion of this over-excavation volume will be filled up with shotcrete to comply with the specified excavation line.

Costing must naturally allow for these excess-quantity factors.

Example: It is accepted practice to assume, for a specified risk limit $ü_p$ of 0.3m, an extra shotcrete thickness of some 0.15m for the primary lining in order to meet the level-surface criteria for the subsequent installation of waterproofing and final lining.

Assuming a theoretical nominal thickness of 0.2m and a rebound of 15%, this would give a shotcrete excess consumption factor of (20+15)/20*1.15 = 2.0, for which allowance must be made in costing.

Filling-up of the remaining 0.15m – or possibly more or less as estimated by the contractor – with final-lining concrete should be tendered per square metre in a separate item. This pay item on a square-metre basis enables the contractor to allow in his costing for expected thickness increases or reductions on the basis of the limit $ü_p$. No payment is made for filling up gaps caused by attested improper work.

2.5 Support elements (B2203-1 : 4.3.7 and 5.3.3.3)

2.5.1 Tender documents

Adequate pay items should be provided for the individual support elements. The quantities should be calculated on the basis of the predicted distribution of tunnelling classes as seen from the tunnelling drawings. The computed quantities (for unforeseen events, supply of subsequent support elements etc.) should not be increased by more than 5-10% in the tender documents. Reserve quantities of more than 10% may have undesirable impacts on pricing and make bid comparison difficult.

2.5.2 Costing guidelines

The pay items for support elements should allow for the costs of support materials including excess consumption (overlap of wire mesh, overlap of steel arches, excess shotcrete consumption from over-excavation and rebound) in addition to the required operating costs and costs of auxiliary materials and wear. The wages for the corresponding installation works are normally (see 2.2.2 above) included in the labour cost for the entire tunnelling crew in the excavation item.

3 CONSTRUCTION AND PAYMENT

3.1 Time-dependent costs (B2203-1 : 5.5.2.1)

Payment for time-dependent tunnelling works is made on the basis of contractual tunnelling time rather than on actual tunnelling time.

Below is an example showing the method of determining contractual tunnelling time from tunnelling classes (TC).

Tunnelling Class	Predicted tunnel length	Actual tunnel length	Contractual rate of advance	Predicted tunnelling time	Contractual tunnelling time	Actual tunnelling time
1	2	3	4	5	6	7
TC 5/2.21	53,2	94.0m	6.00m/WD	8.9 WD	15.7 WD	18.0 WD
TC 5/3.53	80.0m	78.0m	5.20m/WD	15.4 WD	15.0 WD	12.0 WD
TC 5/4.93	66.8m	28.0m	4.00m/WD	16.7 WD	7.0 WD	9.0 WD
Tunnelling interruption				0.0 WD	1.0 WD	1.0 WD
Total	200.0m	200.0m		41.0 WD	38.7 WD	40.0 WD

In the example above for a tunnel length of 200m the predicted length of each tunnelling class is shown in column 2. The contractor gave contractual rates of advance (e.g. 6.00m/WD for TC 5/2.21 in column 4). The predicted tunnelling time, computed from predicted tunnel lengths and contractual rates of advance, is shown in column 5.

The tunnelling class lengths actually encountered during the works are shown in column 3. The contractual tunnelling time, shown in column 6, was calculated from the actual tunnel lengths and the contractual advance rates.

Column 7 reveals that the contractor took longer to do the TC 5/2.21 and 5/4.93 sections and less time for the TC 5/3.53 section (compare column 7 with column 6). With a tunnelling time of 40.0 WD, the contractor was slower by a total of 1.3 WD than stated in the contract.

Payment for this time-dependent cost item is not based on the actual tunnelling time of 40.0 WD, but on the contractual tunnelling time of 38.7 WD. This comes from the fact that the increased tunnelling time of 1.3 WD falls within the sphere of the contractor. This model thus commits the contractor to make up for excess tunnelling time in another tunnel section. At the same time, this model provides an incentive for the contractor to speed up the work and thus to acquire some advance over the contractual tunnelling time, which he may use as a cushion for the works ahead. (An additional example is given in the Annex)

The following demonstrates the separation of risk and responsibility:

The change in TC distribution, which in this case has caused the tunnelling time to be reduced from 41.0 WD to 38.7 WD, falls within the owner's sphere of risk and responsibility. This reduction "belongs" to the owner since it is a result of the ground conditions.

The contractor's risk and responsibility is the non-realisation of the contractual advance rates in TC 5/2.21 and 5/4.93, a delay which was not entirely made up for by the increased advance rate in TC 5/3.53. The excess tunnelling time of 40.0 – 38.7 = 1.3 WD must be made up for the works ahead. If this involves extra expenses, these are borne by the contractor.

3.2 Tunnelling interruptions

In case the sequence of works (tunnelling, concrete pouring etc.) is interrupted for reasons not within the contractor's responsibility, payment for the time-dependent costs occurring during this period is continued on the basis of the relevant items of the bill of quantities. The labour cost for the crews must also be reimbursed unless these cannot perform other works at the site for which proceeds may be generated. Such reimbursement usually calls for an amendment to the contract to be agreed on.

3.3 Selection of supporting measures and classifying tunnelling (B2203-1 : 5.5.2.3)

The information obtained from the geotechnical measurements, the geological documentation and visual inspection of the tunnel and the ground forms the basis for deciding, by mutual agreement between owner and contractor, on the action to be taken for the tunnelling work ahead. The results are documented in primary-support stipulations. This kind of on-site decision-making takes place on a daily basis. The primary-support stipulation has the status of a working drawing.

Where no agreement is reached on site between owner and contractor, advice is sought from a independent tunnel expert so as to avoid tunnelling interruptions due to contractual disputes.

The primary-support stipulation can omit specification of quantities for the individual support elements or can specify ranges. The works actually implemented are documented in an excavation-round report jointly by owner and contractor. The support number or 2nd organising number is determined, for each round, from the quantities of support elements installed, on the example of the tender documents. The round is thus assigned a certain tunnelling class.

3.4 Over-excavation (B2203-1 : 5.5.2.4)

3.4.1 Over-excavation on the inner side of boundary surface A

This volume does not need to be measured during implementation of the work as this is allowed for in the excavation unit price.

3.4.2 Over-excavation outside of boundary surface A

In case over-excavation occurs outside of boundary surface A despite proper work, this should be measured jointly by owner and contractor prior to shotcreting. Payment for excavations of this kind includes the loading, hauling and disposal of the material.

3.4.3 Over-excavation to provide for the deformation allowance ($\ddot{u}_m$)

In determining excavation volume, this over-excavation should be understood to be excavation as designed.

3.5 Excess concrete

3.5.1 Excess concrete on the inside of boundary surface B ($\ddot{u}_p$)

The additional concrete requirements are not measured. The excess concrete for "$\ddot{u}_p$" item in m² is calculated according to round-length range along pay line "1b".

3.5.2 Excess concrete on the outside of boundary surface B ($\ddot{u}_p$)

Concrete or shotcrete, according to expediency, for filling up over-excavation (m³) as jointly measured by owner and contractor is paid for up to the boundary surface.

3.5.3 Excess concrete for non-occurrence of the deformations (v)

When the deformations (v) have ceased, "$\ddot{u}_m$-v" is measured and the volume is determined using the computation model stated in the bill of quantities.

4 FINAL REMARKS

A great help in optimising decision-making for on-site design adjustments is the fact that the price structure of a flexible construction contract holds little potential for a conflict of interests.

The goal is to arrive at a situation where the contractor will face neither advantages nor disadvantages from whatever changes arise from the project. Any profit or loss should mainly result from the contractor's performance within his own range of risk and responsibility. This goal can be attained provided the bill of quantities, payment models and pricing conform to the principles defined in **Austrian Standard ÖNORM B2203-1**. This avoids contradicting interests and motivation conflicts.

ÖNORM B 2203-1 provides incentives for adequate pricing through:

- quality requirements for tender design and tender documentation,
- realistic values for the bill of quantities,
- clear and well-defined separation of spheres of risk,
- detailed description of payment models,
- comprehensible final invoice.

The NATM views the tunnelling process as a complex system of interaction between man and nature, or in other terms, between tunnelling measures and the ground. Systems of such complexity are impossible to control by previously defined "if – then" solutions. The control of a NATM tunnelling project thus calls for a continual feedback system. The main feedback processes are:

- implementation of geotechnical measurements and interpretation of the results,
- ongoing documentation and updating of predictions of ground conditions,
- inspections at the tunnel face,
- tunnel stability considerations and back analyses where required,
- holistic interpretation of all information gathered.

"Real-time" use of all this cumulative information gathered requires for a high level of competence mainly for the following staff:

- tunnelling crews at the tunnel face,
- tunnelling design staff,
- geologists on site,
- geotechnical engineers on site,
- contractor's site management,
- local site supervision,
- project management.

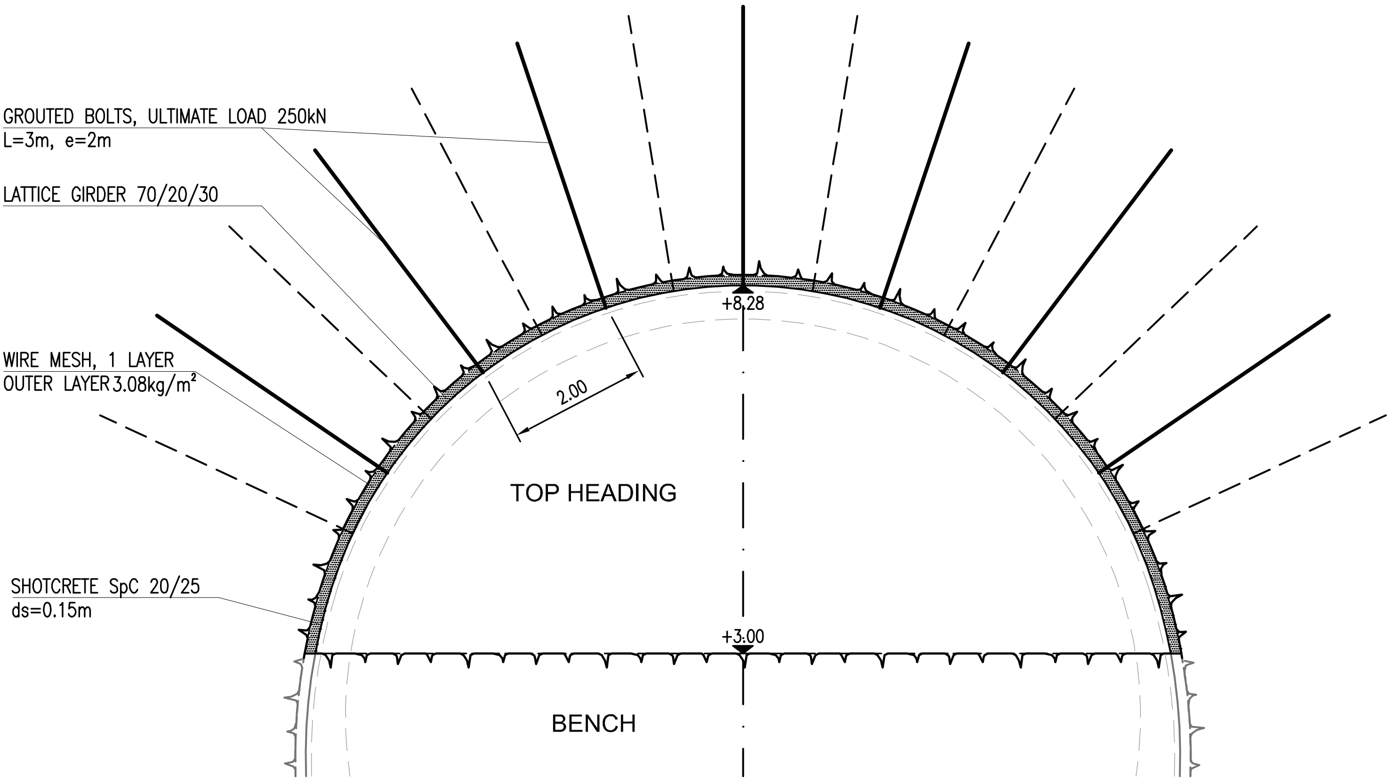
Competence in this context is understood as meaning experience, teamwork capacity, critical faculty (in respect to the selected tunnelling measures), and creativity and communication skills.

A flexible construction contract combined with staff competence combines forms a firm basis for successful NATM tunnelling.

ANNEX
TUNNELLING CLASSES
EXAMPLE

Tunnel "Example"

Standard support type: 5/1 (top heading)
Round length: >1.30m & ≤ 1.70m
Multiple-drift tunnelling: Top Heading / Bench / Invert
Ring closure distance < 120m behind face of top heading excavation
⇨ Tunnelling Class 5/2.21



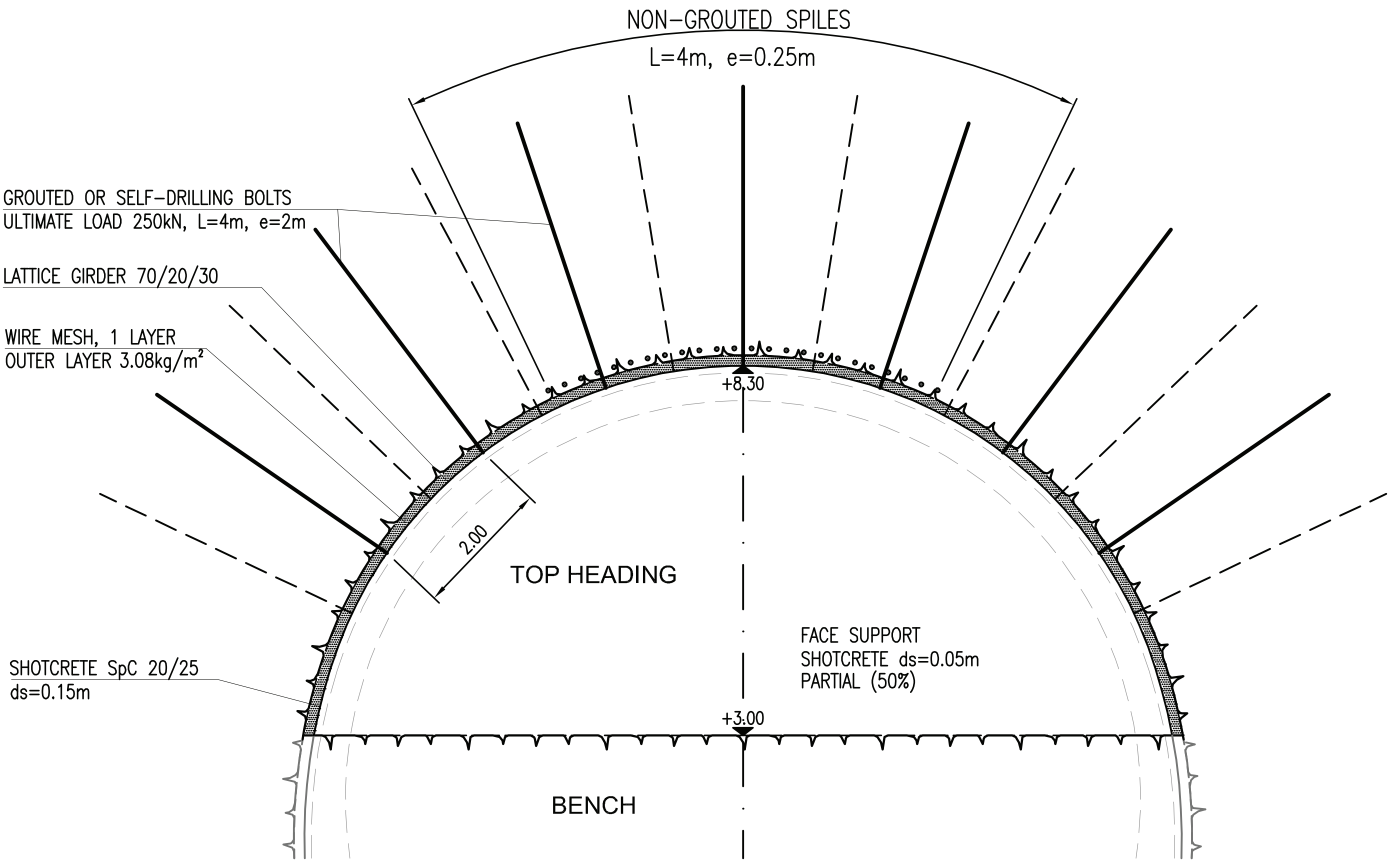
Tunneling Class Top Heading		Round Length up to / üm			
TC 5/2.21		Top Heading	1.7m / 0.03 m		
Installation site **Top heading**	**installation time**	**Support elements (for 1 m of Tunnel)**		**Volume/ round**	**Volume/ m of tunnel**
T	Immediately after excavation round	Shotcrete SpC 20/25	ds= 0.15m	4.49 m³	2.64 m³
T	Immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 outer Layer	29.95 m²	17.62 m²
T	Immediately after excavation round	Lattice girder	YES	17.62 m	10.36 m
T	max. 2 excavation rounds behind top-heading face	Grouted bolts	Ultimate Load 250 kN, 0 m	21.00 m	12.35 m
			Excavation volume	**87.72 m³**	**51.60 m³**

Tunnel "Example"
calculating Tunnelling Class 5/2.21
Top heading

Top heading		üm=0.03 m	5/2.21		
Excavation profile	51.60 m²	Round length	up to 1.7 m		
Support elements (for 1 m of Tunnel)		Unit	quantily	Rating factor per unit of quantity	Ratio
Bolts	Friction bolts (Swellex or equivalent)	m		0.8	
	Grouted bolts	m	12.35	1.1	13.59
	Self- drilling bolts	m		1.7	
	Tube bolts	m		2.0	
	Prestressed grouted bolts	m		2.5	
Face Bolts	Number of bolts in the face	ST		8.0	
	Installation of face plates	ST		1.7	
	Installation of face plates plus prestressing	ST		5.0	
Spiles	Driven spiles	m		0.5	
	Non-grouted spiles	m		0.6	
	Friction spiles	m		0.8	
	Grouted spiles	m		0.9	
	Self drilling spiles	m		1.3	
	Grouted hollow bar spiles	m		1.6	
Grouting in excess of 10kg per m of bolt, spile, footing micropile		kg		0.1	
Wire mesh	Outside with steel arch	m²	17.62	1.0	17.62
	inside with steel arch	m²		1.5	
	Outside without steel arch	m²		2.0	
	Top heading invert	m²		0.8	
	Additional reinforcement, face wire mesh	m²		2.0	
Arches and wall beams		m	10.36	2.0	20.73
Shotcrete	Top heading and bench headings	m³	2.64	20.0	52.86
	Top heading invert, top heading footing (elephant footing)	m³		12.0	
	Face	m³		14.0	
	Filling spandrels and over excavation	m³		14.0	
Deformation gaps	withoute ductile elements	m		3.5	
	with ductile elements	m		5.0	
Steel-Sheet forepoling		m²		5.5	
Footing micro piles	micropiles dia. ≤ 38mm	m		4.5	
	micropiles dia. > 38mm	m		5.0	
Partial face excavation		ST		22.0	
Top heading footing (elephant's foot)		m		50.0	
Demolition of top-heading invert arch during bench excavation		m		50.0	
Summation					**104.80**
Rating area					**47.52 m²**
Support number					**2.21**

Tunnel "Example"

Standard support type: 5/2 (top heading)
Round length: >1.30m & ≤ 1.70m
Multiple-drift tunnelling: Top Heading / Bench / Invert
Ring closure distance < 120m behind face of top heading excavation
⇨ Tunnelling Class 5/3.53



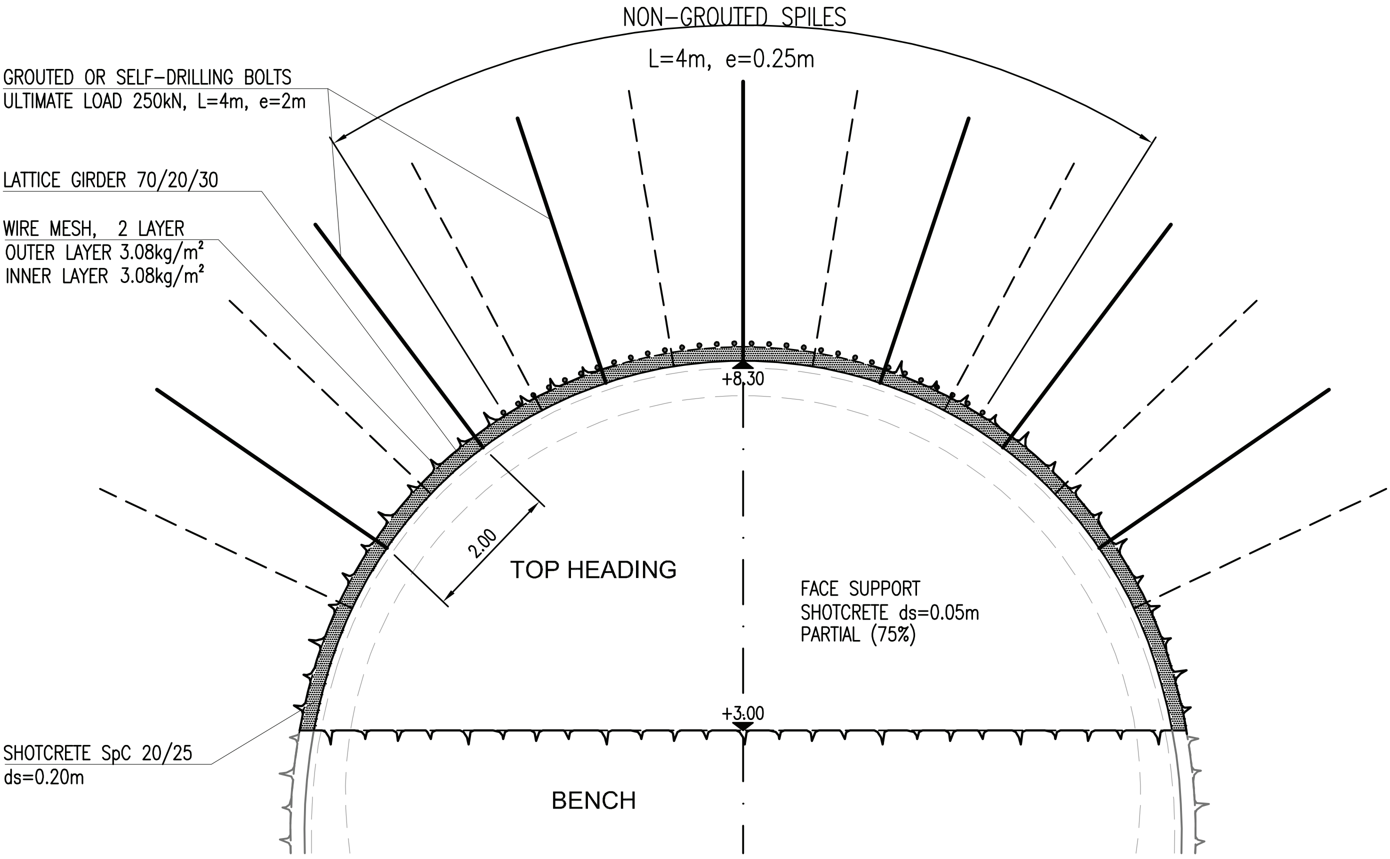
Tunneling Class Top Heading		**Round Length up to / üm**			
TC 5/3.53		Top Heading	1.7m / 0.05 m		
Installation site / **Top heading**	**installation time**	**Support elements (for 1 m of Tunnel)**		**Volume/ round**	**Volume/ m of tunnel**
T	before excavation round	Non-grouted spiles	L= 4 m	100.00 m	58.82 m
T	Immediately after excavation round	Filling spandrels		0.70 m³	0.41 m³
F	Immediately after excavation round	Shotcrete SpC 20/25	ds= 0.05m (50%)	0.01 m³	0.01 m³
T	Immediately after excavation round	Shotcrete SpC 20/25	ds= 0.15m	4.51 m³	2.65 m³
T	Immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 outer Layer	30.06 m²	17.68 m²
T	Immediately after excavation round	Lattice girder	YES	17.68 m	10.40 m
T	max. 2 excavation rounds behind top-heading face	Self-drilling bolts	Ultimate Load 250 kN, 0 m	15.00 m	8.82 m
T	max. 2 excavation rounds behind top-heading face	Grouted bolts	Ultimate Load 250 kN, 0 m	15.00 m	8.82 m
			Excavation volume	**88.33 m³**	**51.96 m³**

Tunnel "Example"
calculating Tunnelling Class 5/3.53
Top heading

Top heading		üm=0.05 m	5/3.53		
Excavation profile	51.96 m²	Round length	up to 1.7 m		
Support elements (for 1 m of Tunnel)		Unit	quantily	Rating factor per unit of quantity	Ratio
Bolts	Friction bolts (Swellex or equivalent)	m		0.8	
	Grouted bolts	m	8.82	1.1	9.71
	Self-drilling bolts	m	8.82	1.7	15.00
	Tube bolts	m		2.0	
	Prestressed grouted bolts	m		2.5	
Face Bolts	Number of bolts in the face	ST		8.0	
	Installation of face plates	ST		1.7	
	Installation of face plates plus prestressing	ST		5.0	
Spiles	Driven spiles	m		0.5	
	Non-grouted spiles	m	58.82	0.6	35.29
	Friction spiles	m		0.8	
	Grouted spiles	m		0.9	
	Self drilling spiles	m		1.3	
	Grouted hollow bar spiles	m		1.6	
Grouting in excess of 10kg per m of bolt, spile, footing micropile		kg		0.1	
Wire mesh	Outside with steel arch	m²	17.68	1.0	17.68
	inside with steel arch	m²		1.5	
	Outside without steel arch	m²		2.0	
	Top heading invert	m²		0.8	
	Additional reinforcement, face wire mesh	m²		2.0	
Arches and wall beams		m	10.40	2.0	20.80
Shotcrete	Top heading and bench headings	m³	2.65	20.0	53.04
	Top heading invert, top heading footing (elephant footing)	m³		12.0	
	Face	m³	0.76	14.0	10.70
	Filling spandrels and over excavation	m³	0.41	14.0	5.76
Deformation gaps	withoute ductile elements	m		3.5	
	with ductile elements	m		5.0	
Steel-Sheet forepoling		m²		5.5	
Footing micro piles	micropiles dia. ≤ 38mm	m		4.5	
	micropiles dia. > 38mm	m		5.0	
Partial face excavation		ST		22.0	
Top heading footing (elephant's foot)		m		50.0	
Demolition of top-heading invert arch during bench excavation		m		50.0	
Summation					**167.98**
Rating area					**47.52 m²**
Support number					**3.53**

Tunnel "Example"

Standard support type: 5/3 (top heading)
Round length: >1.30m & ≤ 1.70m
Multiple-drift tunnelling: Top Heading / Bench / Invert
Ring closure distance < 120m behind face of top heading excavation
⇨ Tunnelling Class 5/4.93



Tunneling Class Top Heading		Round Length up to / üm			
TC 5/4.93		Top Heading	1.7m / 0.05 m		
Installation site **Top heading**	**installation time**	**Support elements (for 1 m of Tunnel)**		**Volume/ round**	**Volume/ m of tunnel**
T	before excavation round	Non-grouted spiles	L= 4 m	128.00 m	75.29 m
T	immediately excavation round	Filling spandrels		0.85 m³	0.50 m³
F	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.05m (100%)	0.03 m³	0.02 m³
T	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.2m	6.01 m³	3.54 m³
T	immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 outer Layer	30.06 m²	17.68 m²
T	immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 inner Layer	30.06 m²	17.68 m²
T	immediately after excavation round	Lattice girder	YES	17.68 m	10.40 m
T	max. 2 excavation rounds behind top-heading face	Self-drilling bolts	Ultimate Load 250 kN, 0 m	15.00 m	8.82 m
T	max. 2 excavation rounds behind top-heading face	Grouted bolts	Ultimate Load 250 kN, 0 m	15.00 m	8.82 m
			Excavation volume	**89.88 m³**	**52.87 m³**

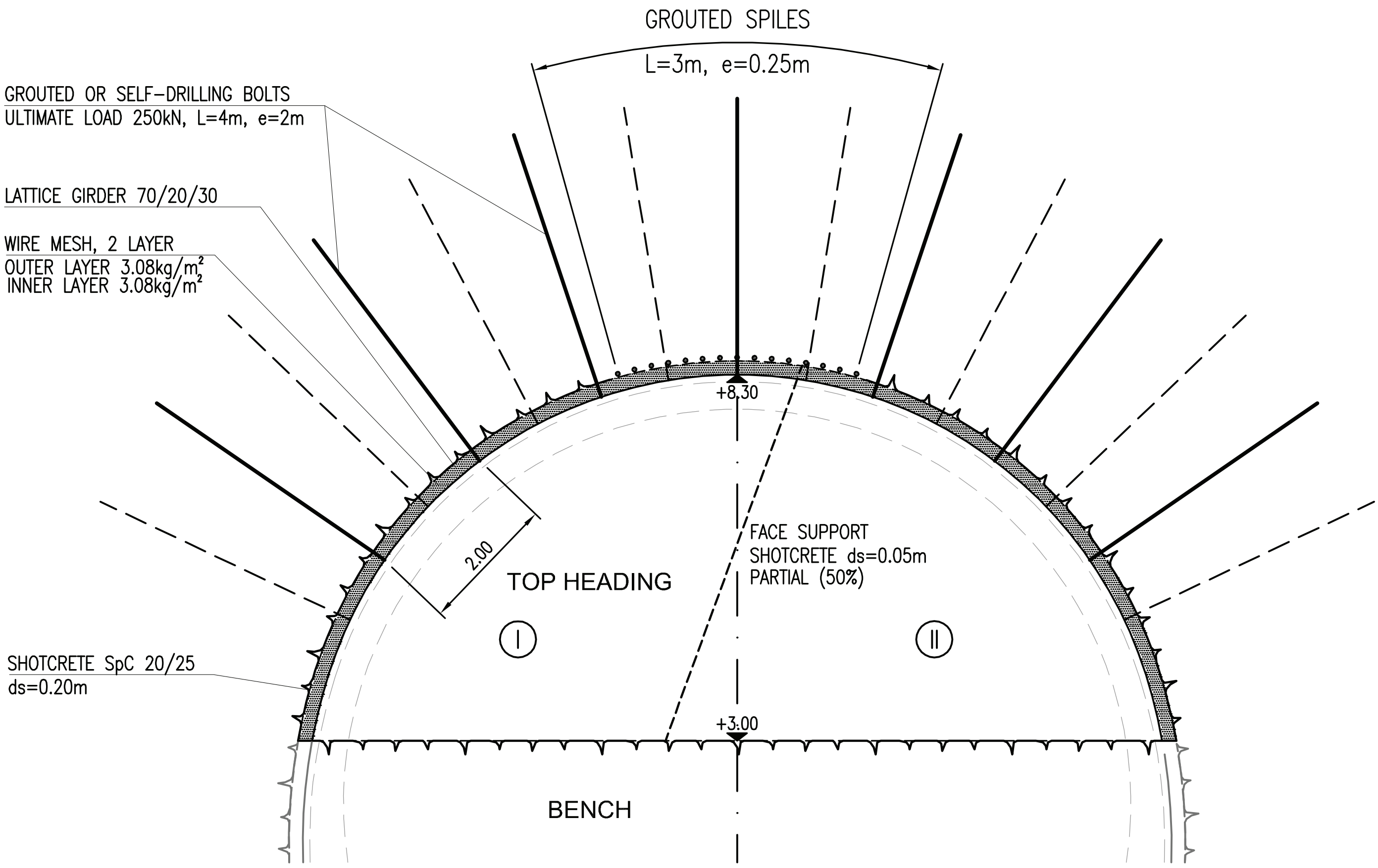
Tunnel "Example"
calculating Tunnelling Class 5/4.93
Top heading

Top heading		üm=0.05 m	5/4.93		
Excavation profile	52.87 m²	Round length	up to 1.7 m		
Support elements (for 1 m of Tunnel)		Unit	quantily	Rating factor per unit of quantity	Ratio
Bolts	Friction bolts (Swellex or equivalent)	m		0.8	
	Grouted bolts	m	8.82	1.1	9.71
	Self-drilling bolts	m	8.82	1.7	15.00
	Tube bolts	m		2.0	
	Prestressed grouted bolts	m		2.5	
Face Bolts	Number of bolts in the face	ST		8.0	
	Installation of face plates	ST		1.7	
	Installation of face plates plus prestressing	ST		5.0	
Spiles	Driven spiles	m		0.5	
	Non-grouted spiles	m	75.29	0.6	45.18
	Friction spiles	m		0.8	
	Grouted spiles	m		0.9	
	Self drilling spiles	m		1.3	
	Grouted hollow bar spiles	m		1.6	
Grouting in excess of 10kg per m of bolt, spile, footing micropile		kg		0.1	
Wire mesh	Outside with steel arch	m²	17.68	1.0	17.68
	inside with steel arch	m²	17.68	1.5	26.52
	Outside without steel arch	m²		2.0	
	Top heading invert	m²		0.8	
	Additional reinforcement, face wire mesh	m²		2.0	
Arches and wall beams		m	10.40	2.0	20.80
Shotcrete	Top heading and bench headings	m³	3.54	20.0	70.72
	Top heading invert, top heading footing (elephant footing)	m³		12.0	
	Face	m³	1.56	14.0	21.77
	Filling spandrels and over excavation	m³	0.50	14.0	7.00
Deformation gaps	withoute ductile elements	m		3.5	
	with ductile elements	m		5.0	
Steel-Sheet forepoling		m²		5.5	
Footing micro piles	micropiles dia. ≤ 38mm	m		4.5	
	micropiles dia. > 38mm	m		5.0	
Partial face excavation		ST		22.0	
Top heading footing (elephant's foot)		m		50.0	
Demolition of top-heading invert arch during bench excavation		m		50.0	
Summation					**234.37**
Rating area					**47.52 m²**
Support number					**4.93**

Tunnel "Example"

Standard support type: 6/1 (top heading)
Round length: >1.00m & $\leq$ 1.30m
Multiple-drift tunnelling: Top Heading / Bench / Invert
Excavation method: drill and blast
Ring closure distance: < 120m behind face of top heading excavation

⇨ Tunnelling Class 6/4.96



Tunneling Class Top Heading		**Round Length up to / üm**			
TC 6/4.96		Top Heading	1.3m / 0.05 m		
Installation site **Top heading**	**installation time**	**Support elements (for 1 m of Tunnel)**		**Volume/ round**	**Volume/ m of tunnel**
T	before excavation round	Grouted spiles	L= 3 m	36.00 m	27.69 m
T	immediately excavation round	Filling spandrels		0.50 m³	0.38 m³
F	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.05m (50%)	0.01 m³	0.01 m³
T	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.2m	4.60 m³	3.54 m³
T	immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 outer Layer	22.98 m²	17.68 m²
T	immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 inner Layer	22.98 m²	17.68 m²
T	immediately after excavation round	Lattice girder	YES	17.68 m	13.60 m
T	max. 2 excavation rounds behind top-heading face	Self-drilling bolts	Ultimate Load 250 kN, 0 m	15.00 m	11.54 m
T	max. 2 excavation rounds behind top-heading face	Grouted bolts	Ultimate Load 250 kN, 0 m	15.00 m	11.54 m
			Excavation volume	**68.73 m³**	**52.87 m³**

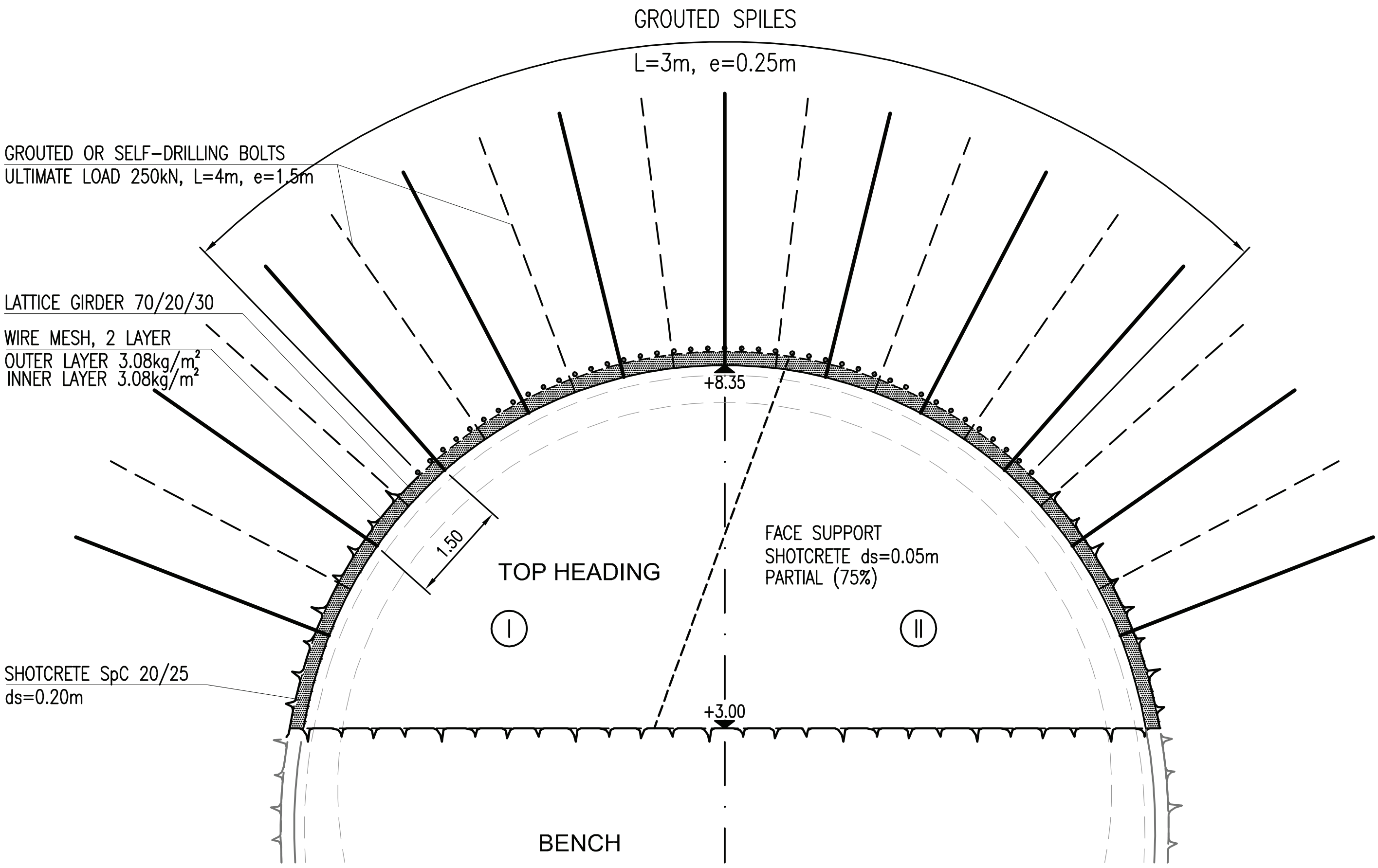
Tunnel "Example"
calculating Tunnelling Class 6/4.96
Top heading

Top heading		üm=0.05 m	6/4.96		
Excavation profile	52.87 m^2	Round length	up to 1.3 m		
Support elements (for 1 m of Tunnel)		Unit	quantily	Rating factor per unit of quantity	Ratio
Bolts	Friction bolts (Swellex or equivalent)	m		0.8	
	Grouted bolts	m	11.54	1.1	12.69
	Self-drilling bolts	m	11.54	1.7	19.62
	Tube bolts	m		2.0	
	Prestressed grouted bolts	m		2.5	
Face Bolts	Number of bolts in the face	ST		8.0	
	Installation of face plates	ST		1.7	
	Installation of face plates plus prestressing	ST		5.0	
Spiles	Driven spiles	m		0.5	
	Non-grouted spiles	m		0.6	
	Friction spiles	m		0.8	
	Grouted spiles	m	27.69	0.9	24.92
	Self drilling spiles	m		1.3	
	Grouted hollow bar spiles	m		1.6	
Grouting in excess of 10kg per m of bolt, spile, footing micropile		kg		0.1	
Wire mesh	Outside with steel arch	m^2	17.68	1.0	17.68
	inside with steel arch	m^2	17.68	1.5	26.52
	Outside without steel arch	m^2		2.0	
	Top heading invert	m^2		0.8	
	Additional reinforcement, face wire mesh	m^2		2.0	
Arches and wall beams		m	13.60	2.0	27.20
Shotcrete	Top heading and bench headings	m^3	3.54	20.0	70.72
	Top heading invert, top heading footing (elephant footing)	m^3		12.0	
	Face	m^3	1.02	14.0	14.23
	Filling spandrels and over excavation	m^3	0.38	14.0	5.38
Deformation gaps	withoute ductile elements	m		3.5	
	with ductile elements	m		5.0	
Steel-Sheet forepoling		m^2		5.5	
Footing micro piles	micropiles dia. $\leq$ 38mm	m		4.5	
	micropiles dia. > 38mm	m		5.0	
Partial face excavation		ST	0.77	22.0	16.92
Top heading footing (elephant's foot)		m		50.0	
Demolition of top-heading invert arch during bench excavation		m		50.0	
Summation					**235.89**
Rating area					**47.52 m^2**
Support number					**4.96**

Tunnel "Example"

Standard support type: 6/2 (top heading)
Round length: >1.00m & ≤ 1.30m
Multiple-drift tunnelling: Top Heading / Bench / Invert
Excavation method: drill and blast
Ringclosure distance: < 120m behind face of top heading excavation

⇨ Tunnelling Class 6/6.45

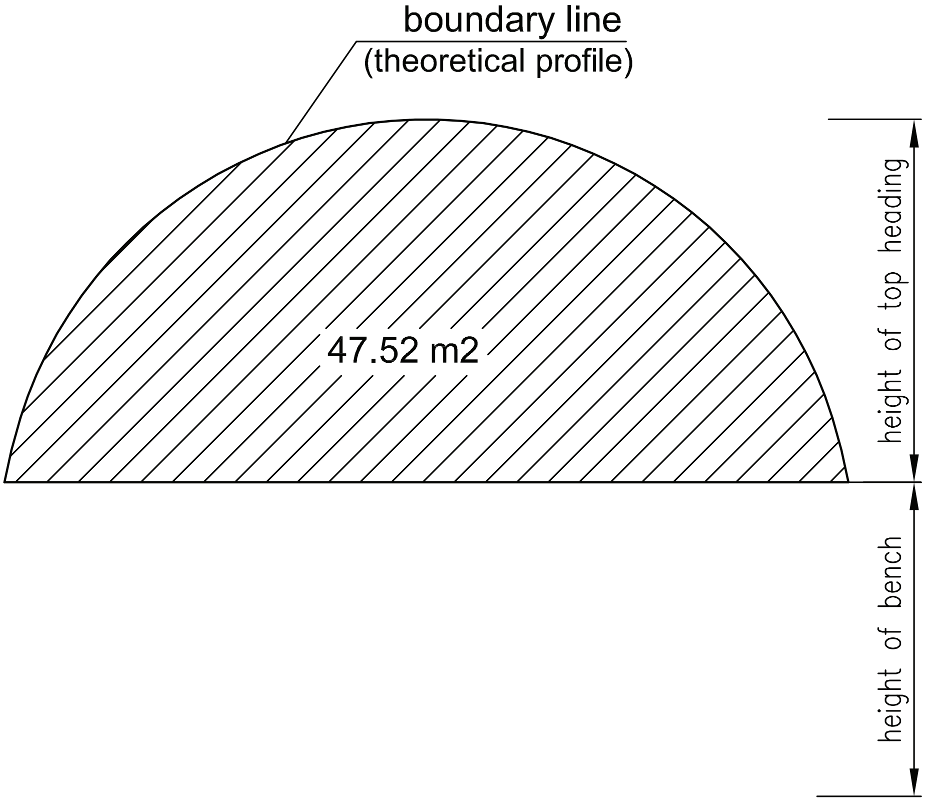


Tunneling Class Top Heading		Round Length up to / üm			
TC 6/6.45		Top Heading	1.3m / 0.1 m		
Installation site **Top heading**	**installation time**	**Support elements (for 1 m of Tunnel)**		**Volume/ round**	**Volume/ m of tunnel**
T	before excavation round	Grouted spiles	L= 3 m	90.00 m	69.23 m
T	immediately excavation round	Filling spandrels		1.57 m³	1.21 m³
F	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.05m (75%)	0.02 m³	0.02 m³
T	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.2m	4.64 m³	3.57 m³
T	immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 outer Layer	23.19 m²	17.84 m²
T	immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 inner Layer	23.19 m²	17.84 m²
T	immediately after excavation round	Lattice girder	YES	17.84 m	13.72 m
T	max. 2 excavation rounds behind top-heading face	Self-drilling bolts	Ultimate Load 250 kN, 0 m	21.00 m	16.15 m
T	max. 2 excavation rounds behind top-heading face	Grouted bolts	Ultimate Load 250 kN, 0 m	21.00 m	16.15 m
			Excavation volume	**69.93 m³**	**53.79 m³**

Tunnel "Example"
calculating Tunnelling Class 6/6.45
Top heading

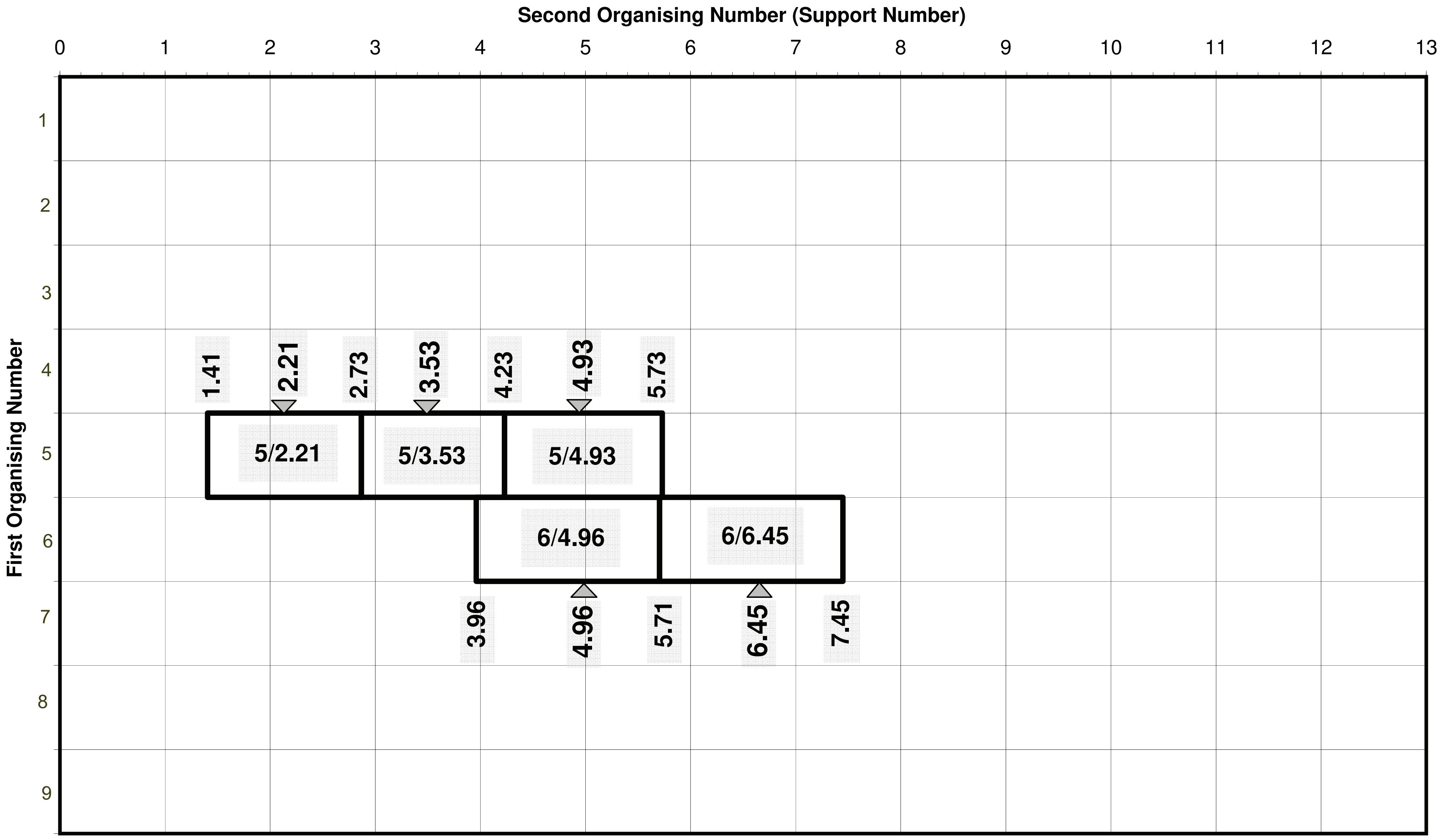
Top heading		üm=0.10 m	6/6.45		
Excavation profile	53.79 m²	Round length	up to 1.3 m		
Support elements (for 1 m of Tunnel)		Unit	quantily	Rating factor per unit of quantity	Ratio
Bolts	Friction bolts (Swellex or equivalent)	m		0.8	
	Grouted bolts	m	16.15	1.1	17.77
	Self-drilling bolts	m	16.15	1.7	27.46
	Tube bolts	m		2.0	
	Prestressed grouted bolts	m		2.5	
Face Bolts	Number of bolts in the face	ST		8.0	
	Installation of face plates	ST		1.7	
	Installation of face plates plus prestressing	ST		5.0	
Spiles	Driven spiles	m		0.5	
	Non-grouted spiles	m		0.6	
	Friction spiles	m		0.8	
	Grouted spiles	m	69.23	0.9	62.31
	Self drilling spiles	m		1.3	
	Grouted hollow bar spiles	m		1.6	
Grouting in excess of 10kg per m of bolt, spile, footing micropile		kg		0.1	
Wire mesh	Outside with steel arch	m²	17.84	1.0	17.84
	inside with steel arch	m²	17.84	1.5	26.76
	Outside without steel arch	m²		2.0	
	Top heading invert	m²		0.8	
	Additional reinforcement, face wire mesh	m²		2.0	
Arches and wall beams		m	13.72	2.0	27.45
Shotcrete	Top heading and bench headings	m³	3.57	20.0	71.36
	Top heading invert, top heading footing (elephant footing)	m³		12.0	
	Face	m³	1.55	14.0	21.72
	Filling spandrels and over excavation	m³	1.21	14.0	16.91
Deformation gaps	withoute ductile elements	m		3.5	
	with ductile elements	m		5.0	
Steel-Sheet forepoling		m²		5.5	
Footing micro piles	micropiles dia. ≤ 38mm	m		4.5	
	micropiles dia. > 38mm	m		5.0	
Partial face excavation		ST	0.77	22.0	16.92
Top heading footing (elephant's foot)		m		50.0	
Demolition of top-heading invert arch during bench excavation		m		50.0	
Summation					**306.50**
Rating area					**47.52 m²**
Support number					**6.45**

Rating Area
Top Heading

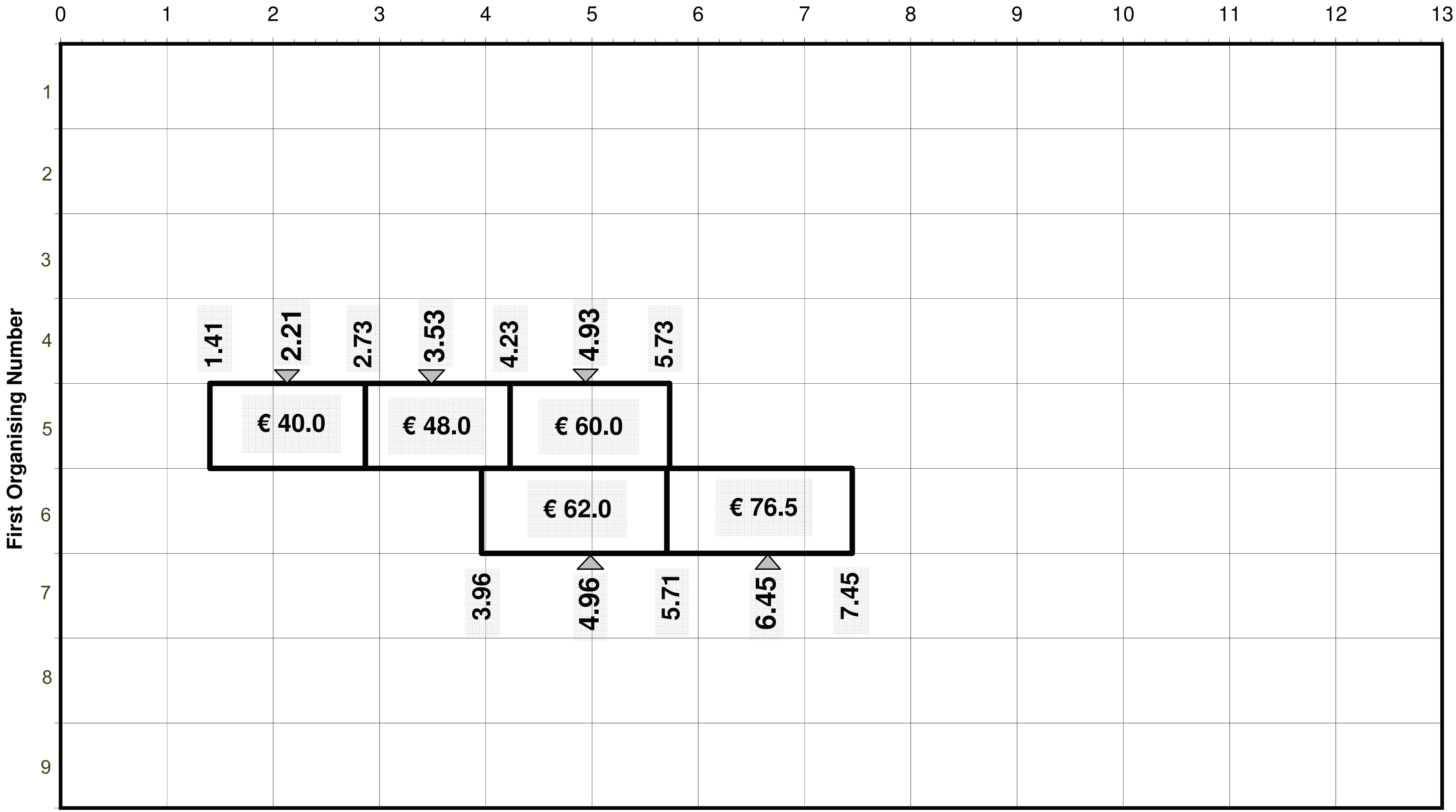


TOP HEADING						
	Excavation profile (m²)					**Line 1a**
ds (cm) / üm (cm)	**10**	**15**	**20**	**25**	**30**	
0	50.16	51.06	51.96			17.55
1	50.34	51.24	52.14	53.06		17.55
3	50.70	51.60	52.51	53.42		17.62
5		51.96	52.87	53.79	54.72	17.68
7			53.24	54.16	55.09	17.74
10			53.79	54.72	55.65	17.84
15						

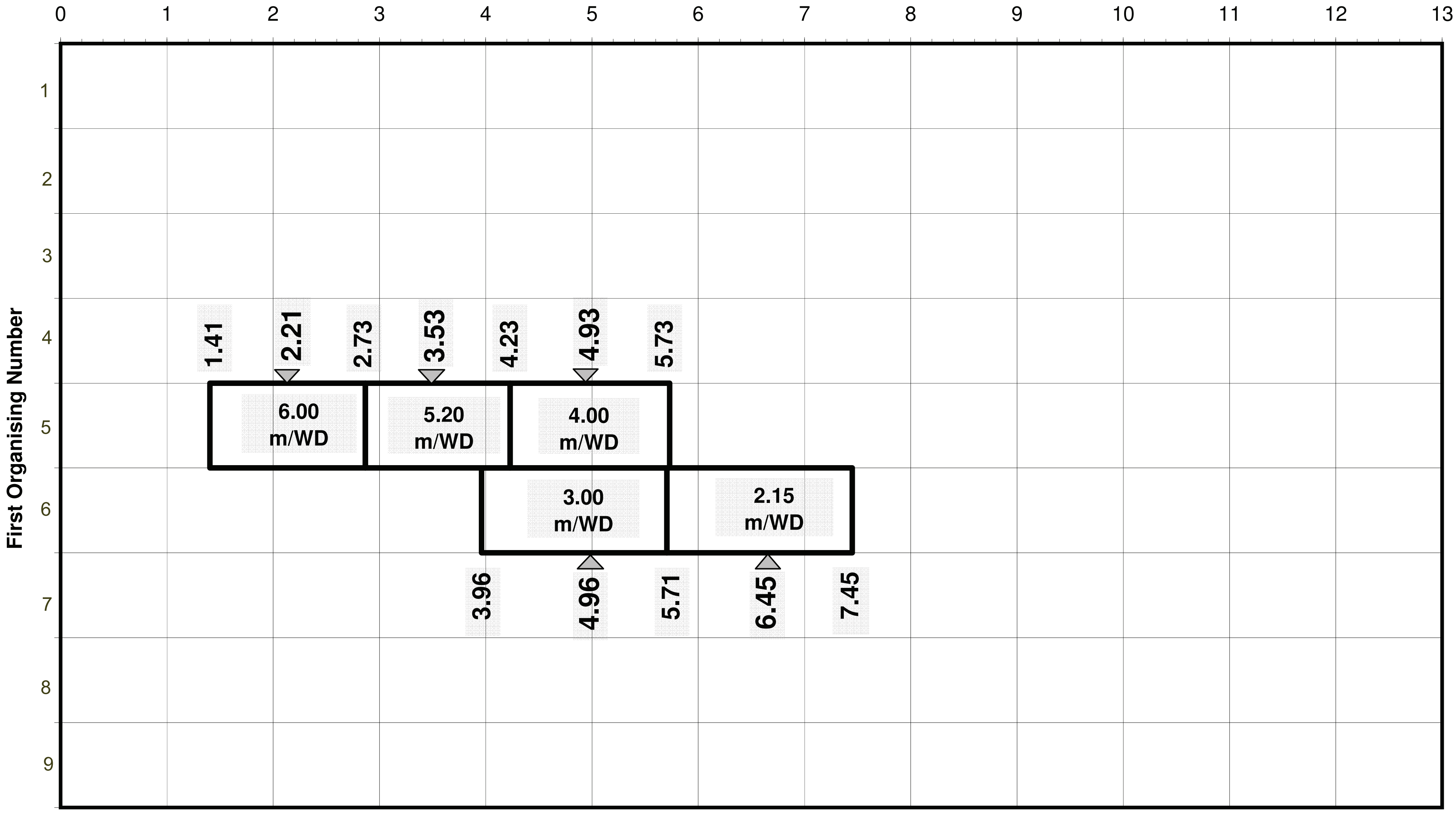
Tunnel "Example"
Tunnelling Class Matrix for projected support types
Top Heading TC 6/xx & 7/xx



Tunnel "Example"
Excavation cost € per m3
Tunnelling Classes 5/xx and 6/xx

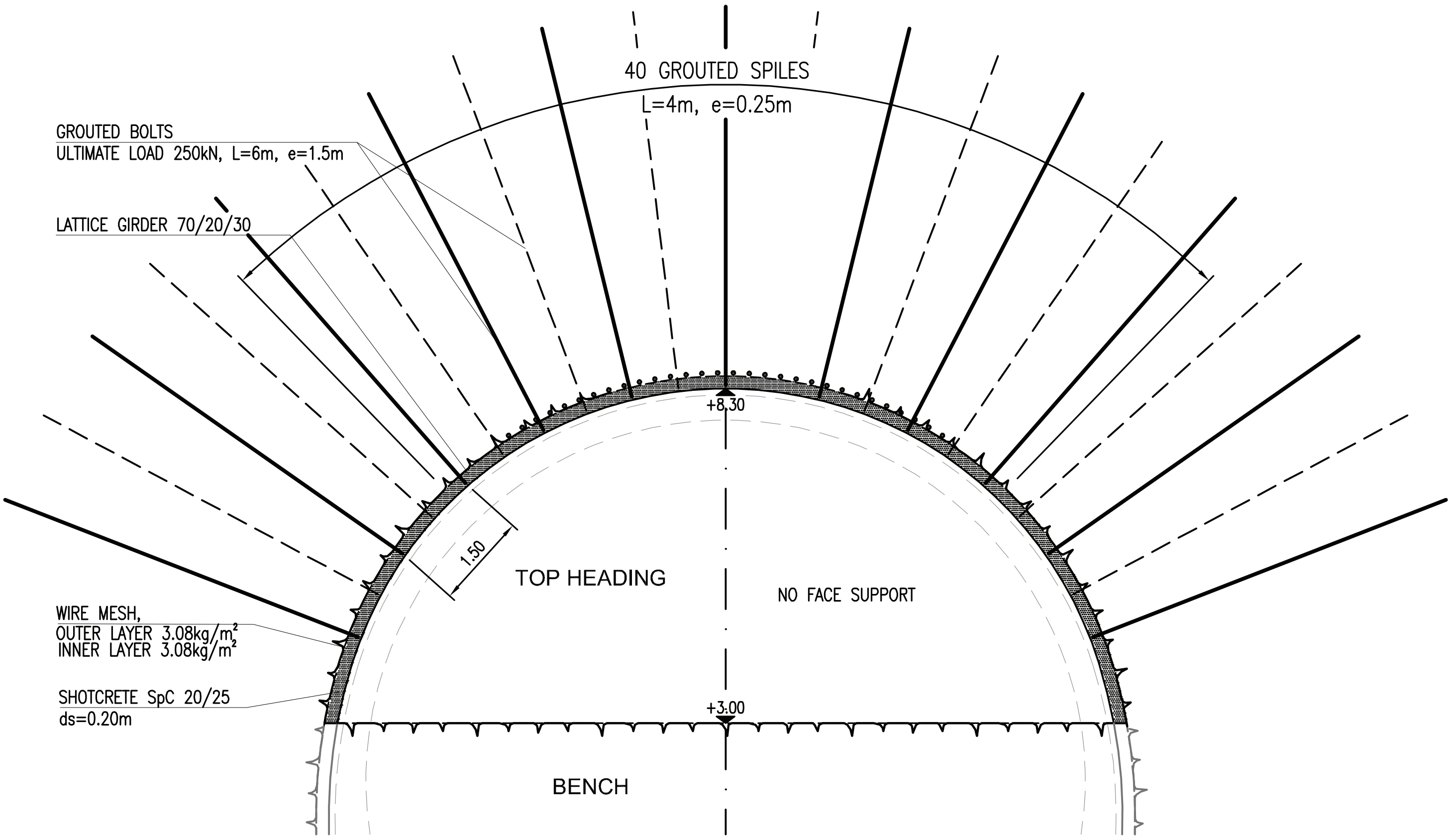


Tunnel "Example"
excavation advance rates m per workday
Tunnelling Classes 5/xx and 6/xx



Tunnel "Example"

Installed support elements No.12 (top heading)
Round length: 1.50m
üm = 0.05m



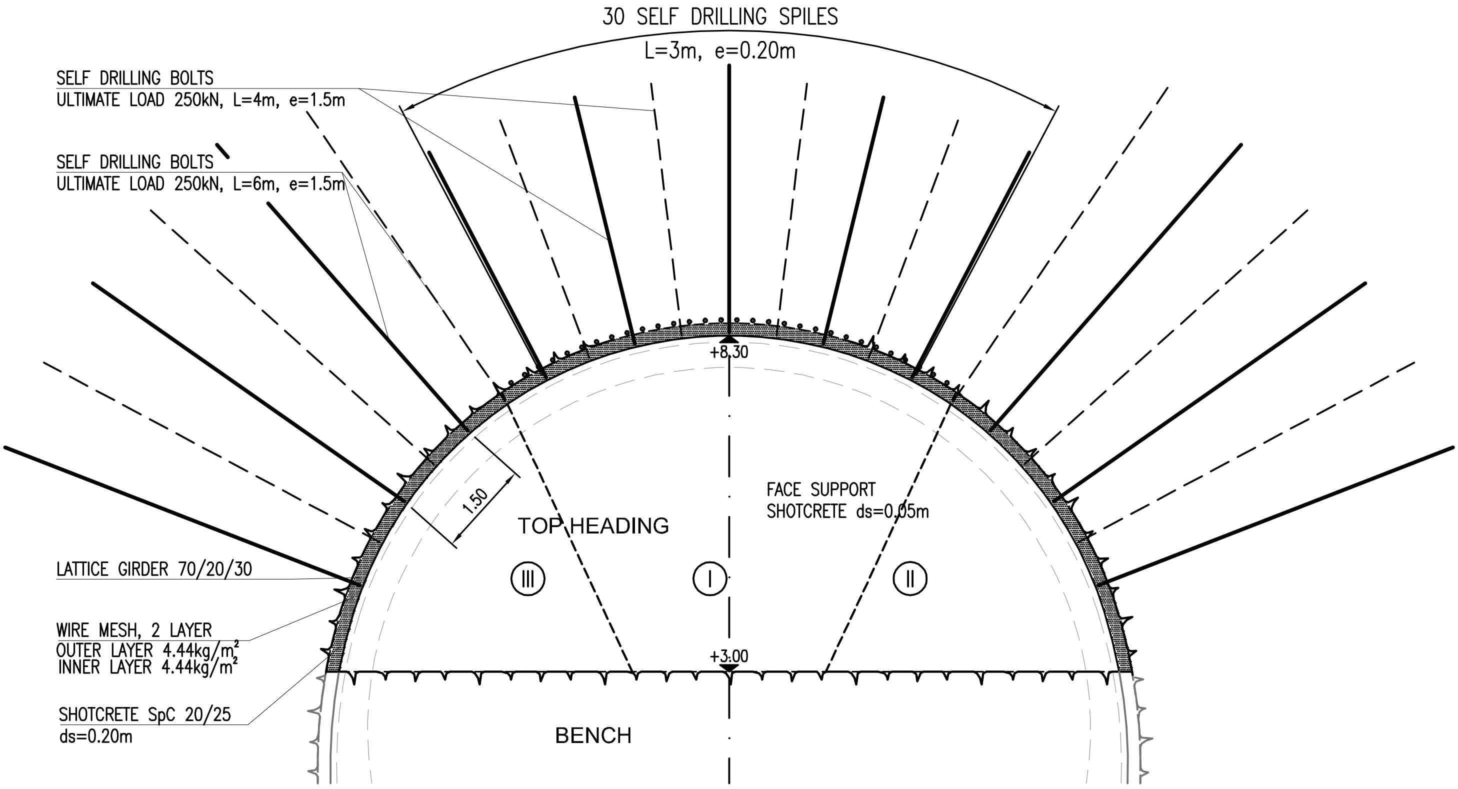
Tunneling Class Top Heading		Round Length up to / üm			
TC 5/6.14		Top Heading	1.5m / 0.05 m		
Installation site **Top heading**	**installation time**	**Support elements (for 1 m of Tunnel)**		**Volume/ round**	**Volume/ m of tunnel**
T	before excavation round	Grouted spiles	L= 4 m	160.00 m	106.67 m
T	immediately excavation round	Filling spandrels		1.20 m³	0.80 m³
T	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.2m	5.30 m³	3.54 m³
T	immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 outer Layer	26.52 m²	17.68 m²
T	immediately after excavation round	Wire mesh 1.96cm²/3.08kg/m²	1 inner Layer	26.52 m²	17.68 m²
T	immediately after excavation round	Lattice girder	YES	17.68 m	11.79 m
T	max. 2 excavation rounds behind top-heading face	Grouted bolts	Ultimate Load 250 kN, 0 m	63.00 m	42.00 m
			Excavation volume	**79.31 m³**	**52.87 m³**

Tunnel "Example"
installed support elements heading No 12
Top Heading

Top heading		ūm=0.05 m	**5/6.14**		
excavation profile	52.87 m²	Round length 1.5 m			
Support elements (for 1 m of Tunnel)		Unit	quantity	Rating factor per unit of quantity	Ratio
Bolts	Friction bolt (Swellex or equivalent)	m		0.8	
	Grouted bolt	m	42.00	1.1	46.20
	Self- drilling bolt	m		1.7	
	Tube bolt	m		2.0	
	Prestressed grouted bolt	m		2.5	
Face Bolts	Number of bolts in the face	ST		8.0	
	Installation of face plate	ST		1.7	
	Installation of face plate plus prestressing	ST		5.0	
Spiles	Driven spiles	m		0.5	
	Non-grouted spiles	m		0.6	
	Friction spile	m		0.8	
	Grouted spiles	m	106.67	0.9	96.00
	Self drilling spiles	m		1.3	
	Grouted hollow bar spiles	m		1.6	
Grouting in excess of 10kg per m of bolt, spile, footing micropile		kg		0.1	
Wire mesh	Outside with steel arch	m²	17.68	1.0	17.68
	inside with steel arch	m²	17.68	1.5	26.52
	Outside without steel arch	m²		2.0	
	Top heading invert	m²		0.8	
	Additional reinforcement, face wire mesh	m²		2.0	
Arches and wall beams		m	11.79	2.0	23.57
Shotcrete	Top heading and bench headings	m³	3.54	20.0	70.72
	Top heading invert, top heading footing (elephant footing)	m³		12.0	
	Filling spandrels and over excavation	m³		14.0	
	Filling spandrels and over excavation	m³	0.80	14.0	11.20
Deformation gaps	withoute ductile elements	m		3.5	
	with ductile elements	m		5.0	
Steel-Sheet forepoling		m²		5.5	
Footing micro piles	micropile dia. $\leq$ 38mm	m		4.5	
	micropile dia. > 38mm	m		5.0	
Partial face excavation		ST		22.0	
Top heading footing (elephant's foot)		m		50.0	
Demolition of top-heading invert arch during bench excavation		m		50.0	
Summation					**291.89**
Rating area					**47.52 m²**
Support number					**6.14**

Tunnel "Example"

Installed support elements No.17 (top heading)
Round length: 1.30m
üm = 0.10m

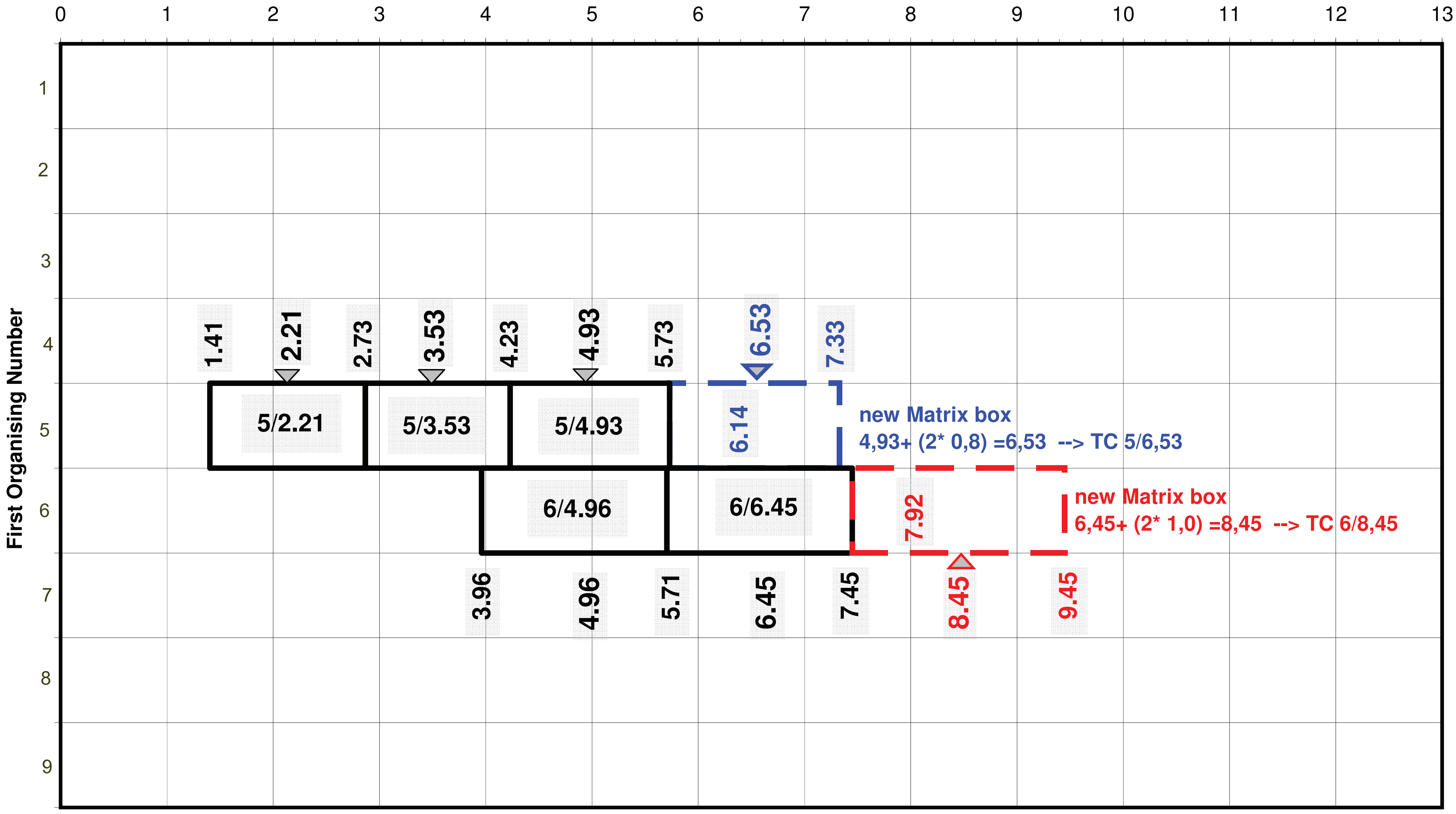


Tunneling Class Top Heading TC 6/7.92		Round Length up to / üm Top Heading 1.3m / 0.1 m			
Installation site **Top heading**	**installation time**	**Support elements (for 1 m of Tunnel)**		**Volume/ round**	**Volume/ m of tunnel**
T	before excavation round	Self drilling spiles	L= 3 m	90.00 m	69.23 m
T	immediately excavation round	Filling spandrels		0.90 m³	0.69 m³
F	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.05m (100%)	0.03 m³	0.02 m³
T	immediately after excavation round	Shotcrete SpC 20/25	ds= 0.2m	4.64 m³	3.57 m³
T	immediately after excavation round	Wire mesh 2.83cm²/4.44kg/m²	1 outer Layer	23.19 m²	17.84 m²
T	immediately after excavation round	Wire mesh 2.83cm²/4.44kg/m²	1 inner Layer	23.19 m²	17.84 m²
T	immediately after excavation round	Lattice girder	YES	17.84 m	13.72 m
T	max. 2 excavation rounds behind top-heading face	---	Ultimate Load 250 kN, 36 m	0.00 m	0.00 m
T	max. 2 excavation rounds behind top-heading face	Self-drilling bolts	Ultimate Load 250 kN, 36 m	54.00 m	41.54 m
			Excavation volume	**69.93 m³**	**53.79 m³**

Tunnel "Example"
installed support elements heading No 17
Top Heading

Top heading		üm=0.10 m	6/7.92		
excavation profile	53.79 m²	Round length	1.3 m		
Support elements (for 1 m of Tunnel)		Unit	quantity	Rating factor per unit of quantity	Ratio
Bolts	Friction bolt (Swellex or equivalent)	m		0.8	
	Grouted bolt	m		1.1	
	Self- drilling bolt	m	41.54	1.7	70.62
	Tube bolt	m		2.0	
	Prestressed grouted bolt	m		2.5	
Face Bolts	Number of bolts in the face	ST		8.0	
	Installation of face plate	ST		1.7	
	Installation of face plate plus prestressing	ST		5.0	
Spiles	Driven spiles	m		0.5	
	Non-grouted spiles	m		0.6	
	Friction spile	m		0.8	
	Grouted spiles	m		0.9	
	Self drilling spiles	m	69.23	1.3	90.00
	Grouted hollow bar spiles	m		1.6	
Grouting in excess of 10kg per m of bolt, spile, footing micropile		kg		0.1	
Wire mesh	Outside with steel arch	m²	17.84	1.0	17.84
	inside with steel arch	m²	17.84	1.5	26.76
	Outside without steel arch	m²		2.0	
	Top heading invert	m²		0.8	
	Additional reinforcement, face wire mesh	m²		2.0	
Arches and wall beams		m	13.72	2.0	27.45
Shotcrete	Top heading and bench headings	m³	3.57	20.0	71.36
	Top heading invert, top heading footing (elephant footing)	m³		12.0	
	Filling spandrels and over excavation	m³	2.07	14.0	28.96
	Filling spandrels and over excavation	m³	0.69	14.0	9.69
Deformation gaps	withoute ductile elements	m		3.5	
	with ductile elements	m		5.0	
Steel-Sheet forepoling		m²		5.5	
Footing micro piles	micropile dia. ≤ 38mm	m		4.5	
	micropile dia. > 38mm	m		5.0	
Partial face excavation		ST	1.54	22.0	33.85
Top heading footing (elephant's foot)		m		50.0	
Demolition of top-heading invert arch during bench excavation		m		50.0	
Summation					**376.52**
Rating area					**47.52 m²**
Support number					**7.92**

Tunnel "Example"
Extrapolating Tunnelling Class Matrix



Extrapolation with 2 existing tunnelling classes in one matrix line:e.g.: for TC 6/8.45

	TC 6/4.96	**TC 6/6.45**	**TC 6/8.45**
Excavation costs in €/m3	62.00	76.50	**91.00**
Advance Progress rates in m/wo	3.00	2.15	**1.30**

Extrapolation with 3 existing tunnelling classes in one matrix line: e.g.: for TC 5/6.53

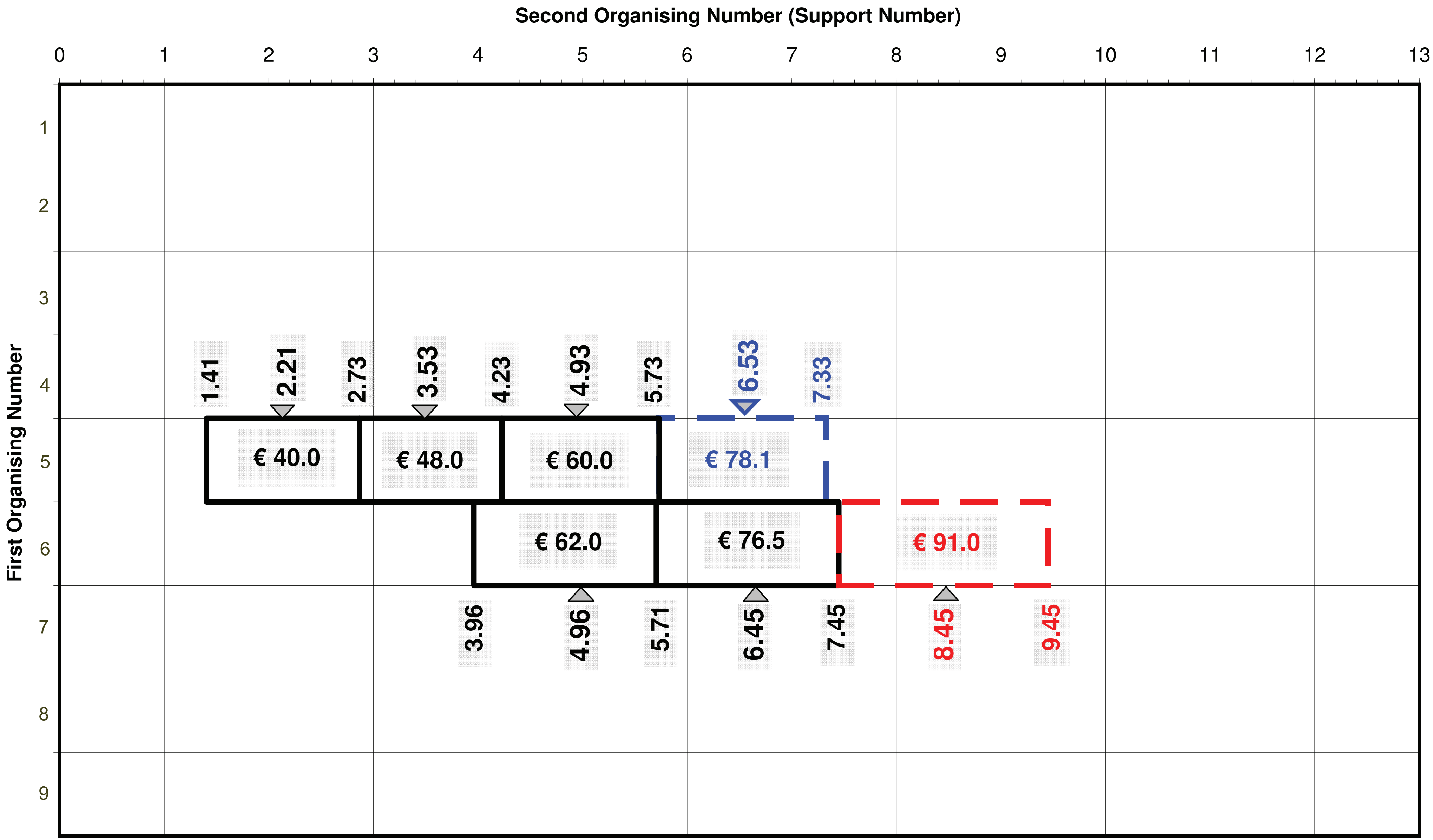
--> extrapolation by using a polynomial best-fit curve : $y=ax^2 + bx + c$

	TC 5/2.21	**TC 5/3.53**	**TC 5/4.93**	**TC 5/6.53**
Excavation costs in €/m3	40.00	48.00	60.00	**78.15**
Advance rates in m/working day	6.00	5.20	4.00	**2.19**

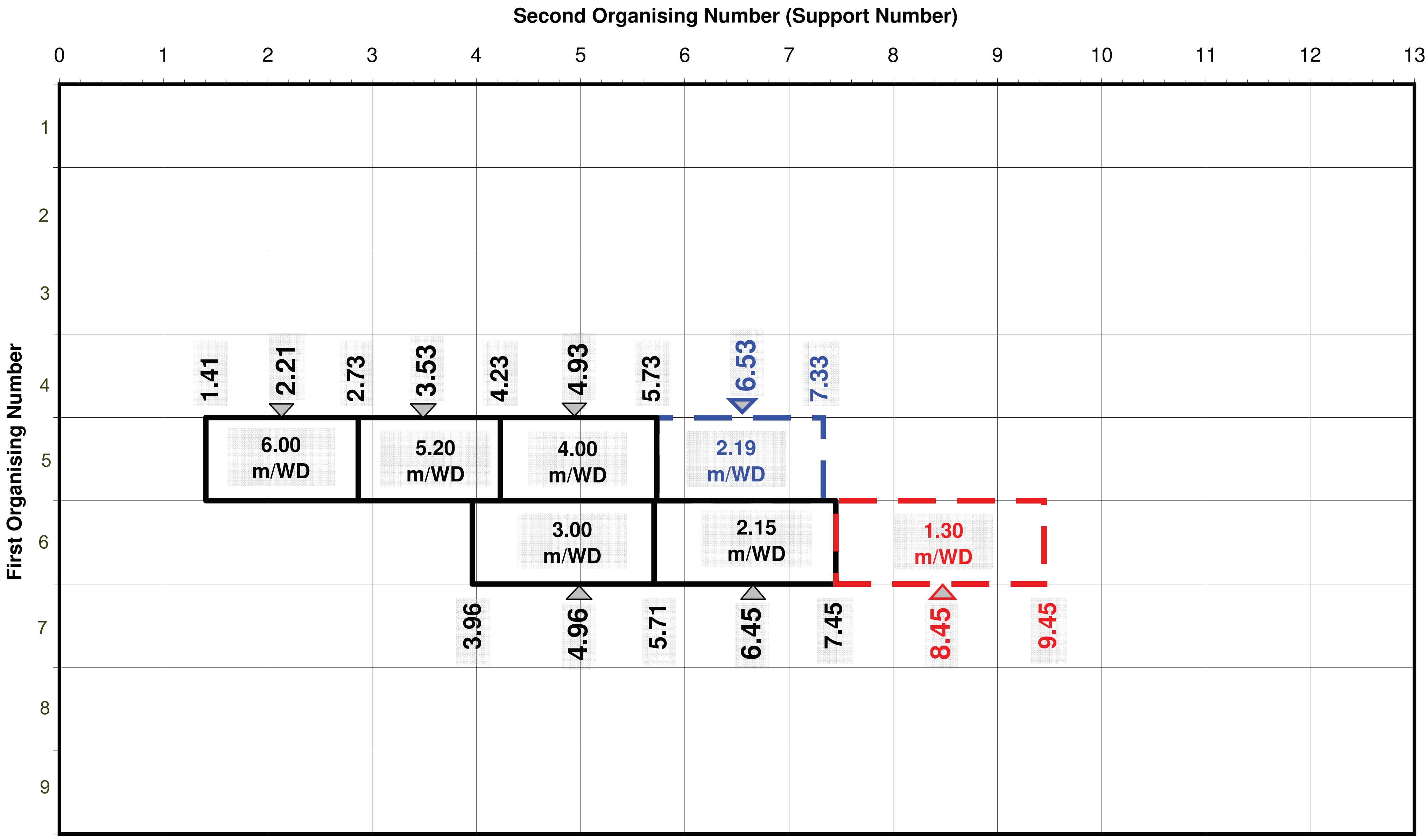
Extrapolation of excavation costs:	a=0,923, b=0,762, c=33,807 UP new = 6,53²x0,923+6,53x0,762+33,807=	**78.15 €/m3**
Extrapolation of Advance rates:	a=-0,092, b=-0,076, c=6,619 v new = -6,53²x0,092-6,53x0,076+6,619 =	**2.19**

where
TC…………… tunneling class
UP…………… unit price
v……………. advance rate m/working day

Tunnel "Example"
Excavation cost € per m3



Tunnel "Example"
excavation advance rates m per workday



Tunnel "EXAMPLE"
Calculation of construction time and time dependent costs

"WD" means work day

Calculation of offered excavation time (top heading)

Tunneling Classes (TC)	Estimated length of each TC in m	Offered advance Rates	Offered excavation time
TC 5/2.21	24.00	6.00 m/WD	4.00 WD
TC 5/3.53	95.00	5.20 m/WD	18.27 WD
TC 5/4.93	60.00	4.00 m/WD	15.00 WD
TC 6/4.96	124.00	3.00 m/WD	41.33 WD
TC 6/6.45	56.00	2.15 m/WD	26.05 WD
Total	**359.00**		**104.65 WD**

Calculation of Contractual Excavation Period (top heading)

Tunneling Classes (TC)	Actual Length of each TC in m	Contractual Progress Rates	Contractual Excavation Period
TC 5/2.21	68.00	6.00 m/WD	11.33 WD
TC 5/3.53	89.10	5.20 m/WD	17.13 WD
TC 5/4.93	76.50	4.00 m/WD	19.13 WD
TC 5/6.53	13.60	2.19 m/WD	6.22 WD
TC 6/4.96	71.50	3.00 m/WD	23.83 WD
TC 6/6 45	32.50	2.15 m/WD	15.12 WD
TC 6/8.45	7.80	1.30 m/WD	6.00 WD
Total	**359.00**		98.76 WD

Time dependent costs of top heading excavation

Offered lump sum for time dependent costs		**€ 996,265.00**
Change of lump sum into "costs per work day"	=996.265,00/104,65=	**€ 9,519.97**
Payment of time dependent costs for actual excavation time	=9519,97 x 98,76=	**€ 940,192.37**

Austrian Society for Geomechanics

Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation

Ground characterization
and coherent procedure for the determination
of excavation and support during design and construction

Translated from version 2.1

2010

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1 INTRODUCTION

One goal of the Austrian Society of Geomechanics is to improve the communication between clients, geologists, engineers, and contractors in the field of geotechnical engineering, as well as the improvement of design and design procedures for projects involving rock and soil.

The Guideline has first been established in conjunction with the new edition of the Austrian Standard ONORM B2203-1 [1] in 2001. This standard deals with contractual matters for underground construction with conventional excavation. All subjects related to ground characterization and behaviour evaluation have been summarized in the Guideline published by the OGG, which the Standard ONORM B2203-1 refers to. The Guideline cannot be used as a basis for contractual matters. The Guideline was revised in 2008 and replaces the edition from 2001.

The stability of underground structures is a key issue during design and construction. Depending on the geotechnical conditions and influencing factors, different failure modes can be expected. Depending on the potential failure modes, project specific requirements and boundary conditions, specific construction measures to ensure stability have to be chosen.

Due to the variation in the geotechnical conditions (the static system and the capacity of ground and supports) the design of an underground structure cannot be compared to a structural design of other buildings, where the loads, the system, and the characteristics of the materials used are known.

In underground construction the risks associated with construction cannot be precisely defined due to the uncertainties of the geotechnical model. This circumstance requires a continuous adaptation of the construction method to the actual ground conditions, and the implementation of a safety management system [2, 3].

The safety management system has to cover following topics:

- A design concept for the determination of excavation and support
- Criteria for the assessment of the stability based on the knowledge of the ground conditions during design
- A monitoring concept with all technical and organizational provisions to allow a continuous comparison between the expected and actual conditions
- A management concept for cases where the actual conditions deviate from the expected range, both in unfavourable and favourable direction

In underground engineering there are two major aspects that must be addressed during the design phase. The first and most important is developing a realistic estimate of the expected ground conditions and their potential behaviours as a result of the excavation. The second is to design an economic and safe excavation and support method for the determined ground behaviours. The design process begins with the feasibility study and continues through the preliminary design, the detail design, the tender design, and throughout the construction. The design is constantly updated during each stage, as more information is available. This requires the involvement of geological and geotechnical experts in all phases of a project.

A central issue for all geotechnical designs is the ground-structure interaction. This not only includes the final state, but also the transient effects of the construction processes, as well as time and stress dependent ground properties.

During the design phases the inherent complexity and variability in many geological settings prohibits a complete picture of the ground structure and quality to be excavated. The geotechnical design is targeted to a continuous refinement of the models and decision criteria. Besides a high professional standard, a systematic and consistent, well documented evaluation and decision process is of paramount importance. Uncertainties in the ground model shall be considered in the design.

Depending on the ground properties and the boundary conditions of a project, the importance of the geomechanical design and the structural design will vary. Most countries have regulations regarding the structural design of underground structures, especially in urban areas. The Austrian guideline RVS 09.01.42 may serve as an example.

The Guideline contains a description of the general procedure to be followed for the geotechnical design. It addresses everybody involved in an underground project, and assists in efficiently preparing and organizing the geotechnical design during all phases of a project. The Guideline does not contain distinct stipulations for engineering tasks.

Contractual matters, like sharing of geological risk, matters of responsibility or site organization are not addressed in this technical guideline, as the conditions will vary from project to project.

2 TARGETS

The main task of the geotechnical design is the economic optimization of the construction considering the ground conditions as well as safety, long term stability, and environmental requirements.

The variability of the geological architecture including the local ground structure, ground parameters, stress and ground water conditions requires that a consistent and specific procedure be used during the design process. The key influences governing the geotechnical design are the ground conditions and ground behaviour.

Existing schematic rating systems and their recommendations for excavation and support have been developed from experience under specific conditions. A generalization for other ground and boundary conditions frequently leads to inadequate design [4]. Consequently a technically sound and economical design and construction can be achieved only by applying a project and ground specific procedure.

In spite of all uncertainties in the description of the ground conditions, underground engineering needs a strategy, allowing a consistent and coherent design procedure that is traceable throughout the entire project, and an optimal adjustment of the construction to the actual ground conditions encountered on site.

Two main phases can be distinguished:

Phase 1: Design

This phase involves determining the expected ground properties, the classification into Ground Types (GT), the assessment of the Ground Behaviours, its categorization into Ground Behaviour Types (BT), as well as the determination of construction measures derived from the ground behaviour under consideration of the project specific boundary conditions. On this basis the expected System Behaviour is predicted. Tunnelling classes are then determined according to the rules stipulated in ONORM B2203-1.

The results of all phases of the geotechnical design are summarized in a geotechnical report. The geotechnical report clearly has to show, on which ground conditions, boundary conditions, and other assumptions the design is based. The framework plan is part of the geotechnical report. This plan has to contain clear application criteria, and shall indicate which measures shall not be modified during construction without consent of the designer, as well as the criteria for possible modifications and adjustments during construction.

Phase 2: Construction

During construction geotechnical relevant ground parameters have to be collected, recorded, and evaluated to determine the ground type. Under consideration of the influencing factors the actual System Behaviour in the excavation area is assessed according to the stipulations of the design. Excavation and support measures have to be chosen based on the criteria laid out in the framework plan and the safety management plan.

The geotechnical design and the framework plan have to be continuously updated based on the findings on site. The improved quality of the geotechnical model allows an optimization of the construction while observing all safety and environmental requirements.

The relevant data and assumptions made for all decisions during design and construction have to be recorded. Relevant information in connection with the ground properties, ground and system behaviour has to be collected, evaluated and analyzed in both phases.

The guideline shall help to follow a systematic procedure. All concepts, considerations and decisions shall be recorded in a way, that a review of the decision making process is possible.

3 DEFINITIONS

GROUND	Part of the earths crust, composed of rock and/or soil, frequently with anisoptopic properties, including discontinuities, and voids filled with liquids o gases.
ROCK	Aggregate, consisting of mineral components, developed from natural processes, characterized by the types and amount of the minerals and grain structure.
SOLID ROCK	Mineral aggregate, whose properties predominantly are determined by the physical/chemical bond.
SOIL	Accumulation of anorganic solid varigrained particels with occasional organic admixtures. The properties are predomonantely governed by the granulometric composition, the compaction, and the water content
DISCONTINUITY	General term for any mechanical discontinuity in a rock mass having zero or low tensile strength. Collective term for most types of joints, weak bedding planes, weak schistosity planes, weakness zones and faults.
ROCK TYPE	Soil or rock with similar properties
GROUND TYPE (GT)	Ground with similar properties.
GROUND BEHAVIOUR	Reaction of the ground to the excavation of the full profile without consideration of sequential excavation and support
BEHAVIOUR TYPE (BT)	General categories describing similar Ground Behaviours with respect to failure modes and displacement characteristics
SYSTEM BEHAVIOUR (SB)	Behaviour resulting from the interaction between ground, excavation, and support, separated in: system behaviour in the respective excavation section system behaviour in the supported section system behaviour in the final state
BOUNDARY CONDITIONS	Conditions, which influence construction process and methods due to other than geotechnical reasons
FRAMEWORK PLAN	Summary of the Geotechnical Design, including relevant parameters used in the design, and application criteria for the assignment of excavation and support methods
REQUIREMENTS	Definition of required parameters to safeguard serviceability, safety, and environmental issues

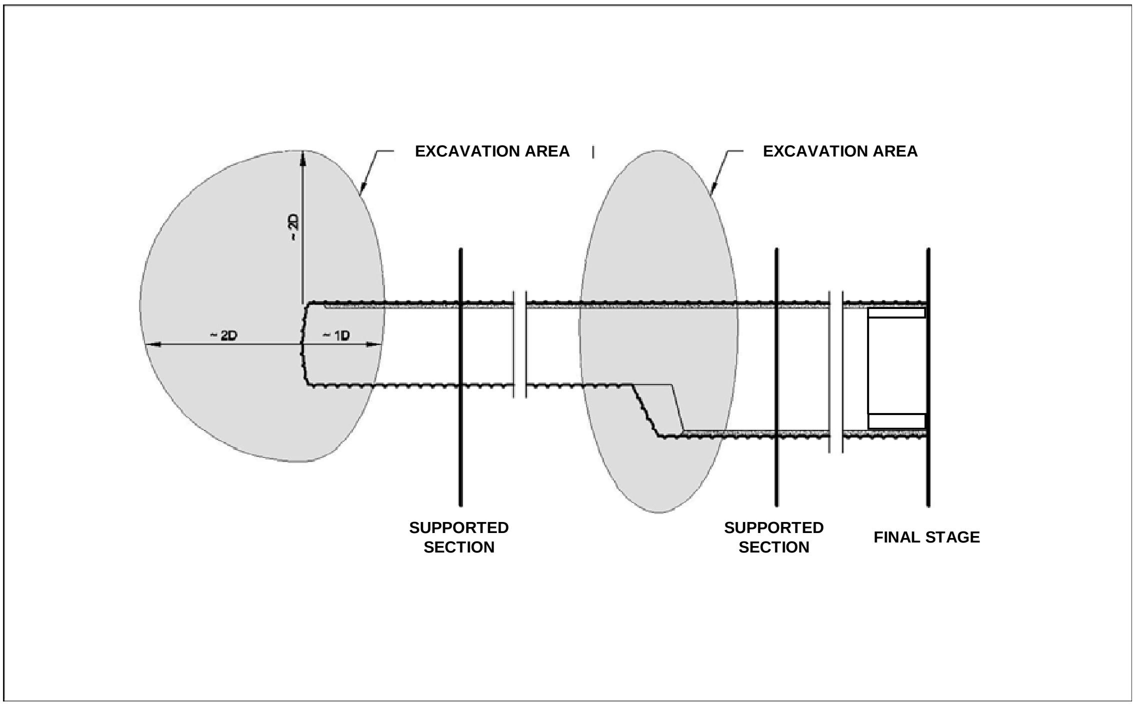

Figure 1: Allocation of system behaviour to different sections

4 PHASE 1 - DESIGN

4.1 Basic Procedure

The geotechnical design, as part of the tunnel design, serves as a basis for approval procedures, the tender documents (determination of excavation classes and their distribution), and the determination of the excavation and support methods used on site [5].

The flow chart (Figure 2) shows the basic procedure to develop the geotechnical design, beginning with the determination of the ground types and ending with the definition of excavation classes. Statistical and/or probabilistic analyses should be used to account for the variability and uncertainty in the parameter values and influencing factors, as well as their distribution along the projects route. The analyses may serve as a basis for a risk analysis.

The procedure incorporates following steps:

Step 1 – Determination of Ground Types

The first step starts with a description of the basic geologic model and proceeds by defining geotechnically relevant parameters for each ground type. The key parameters values and distributions are determined from available information and/or estimated with engineering and geological judgement. Ground with similar properties is classified into Ground Types (GT). The number of Ground Types elaborated depends on the project specific geological conditions.

Step 2 - Determination of Ground Behaviour and Assignment to Ground Behaviour Types

The second step involves evaluating the potential ground behaviours considering each ground type and local influencing factors, including the relative orientation of relevant discontinuities to the excavation, ground water conditions, stress situation, etc. For each section, which has similar ground properties and influencing factors, the Ground Behaviour is analyzed.

The ground behaviour has to be evaluated for the full cross sectional area without considering any modifications including the excavation method or sequence and support or other auxiliary measures.

The evaluated project specific ground behaviours shall be assigned to basic Ground Behaviour Types (table 2). Project specific conditions may require a further subdivision of the Ground Behaviour Types, as well as a detailed description of the single expected behaviours.

Step 3 – Selection of construction concept

Based of the ground characteristics and the determined ground behaviour for each characteristic situation a feasible construction concept is chosen, consisting of excavation method, sequence of excavation, support and auxiliary methods.

Step 4 – Assessment of system behaviour in the excavation area

Under consideration of the construction concept, including sequence of construction, stability of the face and perimeter, and the spatial stress distribution, the system behaviour in the excavation area is assessed.

Step 5 – Detailed determination of the excavation and support method and evaluation of system behaviour in the supported area

The excavation and support methods are fixed in quality and quantity, considering probable further excavation steps, and the system behaviour determined. The evaluated system behaviour is then compared to the requirements.

Step 6 - Geotechnical report-framework plan

Based on steps 1 through 5 the alignment is divided into sections with similar excavation and support requirements. The framework plan indicates the excavation and support methods available for each section, and contains limits and criteria for possible variations or modifications on site.

Step 7 - Determination of excavation classes

In the final step of the design process excavation classes are defined, based on the evaluation of the excavation and support measures. The excavation classes form a basis for compensation clauses in the tender documents. In Austria the definition of tunnelling classes is based on the regulations in ONORM B2203-1.

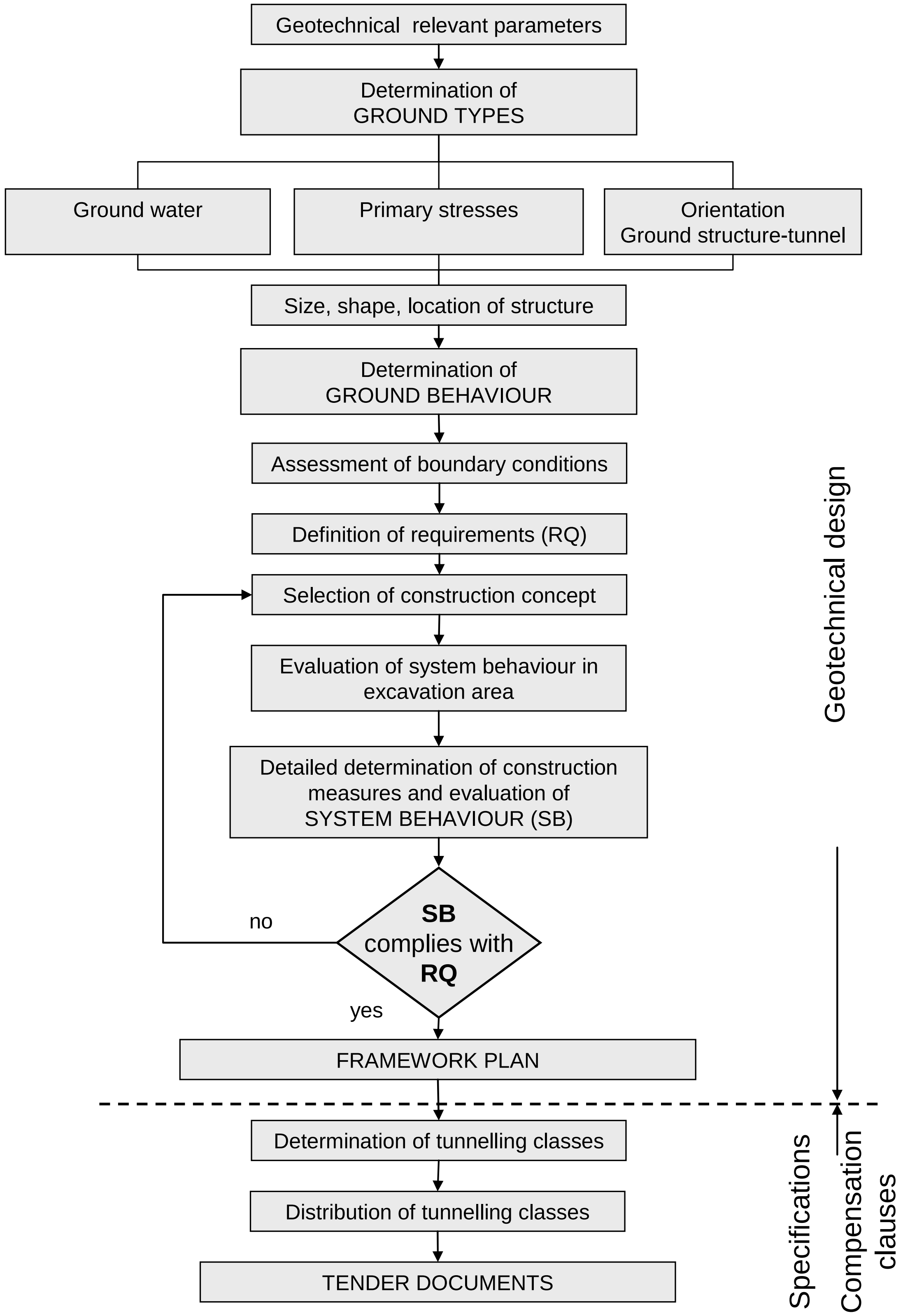

Figure 2: Schematic procedure of the geotechnical design

4.2 Determination of Ground Types

A Ground Type is defined as a geotechnical relevant ground volume, including matrix, discontinuities and tectonic structures, which is similar with respect to following properties

- in rock: mechanical properties (intact rock – rock mass), discontinuity characteristics and properties, rock type, rock- and rock mass conditions hydraulic properties
- in soil: mechanical properties, grain size distribution, density, mineral composition, parameters of the soil components, matrix parameters, water content and hydraulic properties

Different Ground Types have different characteristic parameters that influence their mechanical behaviour. To determine different ground types relevant key parameters have to be evaluated and defined. Different ground masses with similar combinations of relevant parameters are defined as one Ground Type.

The definition of the Ground Types has to be based on the current knowledge in each project stage, considering their importance for the successful completion of the project. The number of defined Ground Types is project specific and depends on the design phase, as well as on the complexity of the geological conditions in the project area. In general, in early design phases, a rough discrimination will be sufficient, with increased information in subsequent design phases the distinction of the single Ground Types will be, and has to be more precise.

The final task in this step is to assign the Ground Types to the alignment.

4.2.1 Method

Selected key parameters describe the geotechnical relevant properties of the ground [6]. Table 1 is intended to provide assistance for the selection of the relevant parameters for different rock types. Depending on project specific boundary conditions, other or additional parameters may have to be determined. In any case it has to be checked if the selected parameters are sufficient to adequately describe the ground properties [7, 8].

Appendix A contains a list of soil, rock, discontinuity, and ground parameters and relevant references.

The determination of the various parameters shall be based on local standards and regulations. The reasons for the use of other standards or procedures have to be clearly explained.

In all project stages the used data, the method of evaluation and the spread of the parameters have to be listed.

Different key parameters may be required depending on the type and use of the under-ground structure. The number of parameters used for the definition of the Ground Types and their mode of classification can change as the project progresses. For the determination of ground types the mechanical and hydraulic properties of the ground have to be determined.

Preferably the collection of the relevant geotechnical parameters and influencing factors is done during the preliminary design. Investigations during the tender design should concentrate on reducing the uncertainty or risk in geotechnical critical areas.

Simple rating methods ([9, 10]) can be used in early project phases (feasibility study, preliminary design). Frequently in these phases parameters from literature or previous experience have to be used due to lack of data from the project area. The origin of the used data has to be shown.

Empirical [11, 12, 13, 14] and numerical methods [15, 16]), as well as in situ tests may be used in later project phases (project approval, tender design) for the determination of the properties of the ground.

Ground strength, deformation characteristics, hydraulic properties, as well as specific properties (for example pronounced anisotropy [17], low friction of discontinuities, time dependent behaviour, intercalation of other rock types, etc.) have to be evaluated and shown in the documents.

BASIC ROCK TYPES		KEY PARAMETERS																		
		INTACT ROCK PROPERTIES													DISCONTINUITIES					
		Mineral Composition	Clay Mineral Composition (qualitative)	Clay Mineral Composition (quantitative)	Cementation	Grain Size	Texture	Ratio Matrix/Fraoments	Porosity	Alteration/Weatherino	Solution Phenomena	Swelling Properties	Strenoth Properties	Anisotropy	Block Shape	Block Size	Persistence	Aperture	Shear Strength/Roughness	Infilling
ROCKS	Plutonic Rocks	■				■	■			□			■		■	■	□	■	□	□
	Volcanic Rocks (massive)	□					□		■	■			■		■	■	□	■	□	■
	Volcano-Clastic Rocks	□	□		□	□		■	■	■		□	□							
	Coarse-grained Clastic Rocks (massive)	□		□	■	■	□	■	□	□			■		□	□	□	□		
	Fine-grained Clastic Rocks (massive)		■	■	■	■				□		■	□		□	□				
	Coarse-orained Clastic Rocks (bedded)	□		□	■	■		■	□	□			■	■					■	
	Fine-orained Clastic Rocks (bedded)		■	■	■	■				□		■		■					■	□
	Carbonatic Rocks (massive)	■									■		■		□	■	□	■		□
	Carbonatic Rocks (bedded)	■									■		■		■				□	□
	Sulfatic Rocks	■									■	■	□							
	Metamorphic Rocks (massive)	■				■	■			□			■		■	■	□	■		
	Metamorphic Rocks (bedded)	■				■	■			□			■	■	■	■	□		■	■
	Fault Rocks	□	■	■	■			■		□		■	■							
SOILS	Coarse-grained Soils (gravel)					■		■	□				■							
	Coarse-grained Soils (sand)					■		□	□				■							
	Coarse-grained Soil Mixtures	□		■		■		■	□			□	■							
	Fine-grained Soils (silt)					■			□				■							
	Fine-grained Soils (clay)	□		■		■			□			■	■							

Legend ■ Significant Parameter □ Less Important Parameter

Table 1. Example of selected key parameters for different general rock types. The selection of key parameters may vary depending on the project conditions and requirements.

4.2.2 Records

All parameters used for the determination of ground types have to be described and shown in the documents in the form of a table.

4.3 Determination of Ground Behaviour

The ground behaviour describes the response of the ground to full face excavation, considering ground type and influencing factors without the influence of supports, division of face or auxiliary measures.

First the orientation of relevant discontinuity sets relative to the axis of the underground structure must be determined; the appropriate stress conditions defined, as well as the local ground water conditions for each section along the alignment. After assigning all relevant properties and influencing factors to each section, the ground behaviour is evaluated for each section of the underground structure. The expected ground behaviour is then categorized into the general types listed in table 2, and the distribution along the alignment determined.

4.3.1 Method

When considering long underground structures (tunnels) an unsupported cavity without supporting influence of the face has to be assumed. Sequential excavation steps are not considered in this phase.

The following influencing factors are usually considered for the evaluation of the Ground Behaviour:

- Ground Type (GT)
- Virgin stress conditions
- Shape and size of the underground structure (final shape and size)
- Position of underground structure in relation to surface or existing structures
- Relative orientation of the underground structure and discontinuities as a basis for kinematical analyses, and the assessment of the stress redistribution
- Boundaries between different ground types
- Ground water, seepage force, hydraulic head

For the determination of the ground behaviour the following evaluations are recommended:

- Kinematics: Kinematical analyses for the determination of discontinuity controlled overbreak and sliding of wedges
  Methods: Key Block Theory [18], analyses using stereographic projection [19, 20]
- Ground utilization: evaluation of the ratio between the strength of the ground and the spatial stress situation in the vicinity of the underground opening. Methods: analytical and numerical methods [21, 22, 23], 24]
- Failure mechanisms: possible failure mechanisms of the ground have to be analyzed and described at least qualitatively (for example: spalling, shearing along discontinuities as result of stress release, shear failure, etc.)

Methods: model tests, analytical analyses, numerical analyses, which allow the modelling of discrete failure planes, case histories.

When influencing factors cannot be determined with sufficient accuracy, a parametric study considering the spread of parameters shall be made.

Analytical and/or numerical methods are to be used, which provide appropriate modelling methods for the characteristics of the ground types under the given boundary conditions.

The Ground Behaviours resulting from the analyses have to be assigned to one of the categories listed in Table 2. In case more than one Behaviour Type is identified in one of the general categories, sub types have to be assigned (for example 2/1, 2/2 for a ground with a different potential for overbreak with different combinations of joint sets or orientations). If combinations of behaviours are identified in the same section, all behaviours have to be shown. The assignment to the general categories is done according to the behaviour type considered dominating (for example: discontinuity controlled overbreak and swelling of invert BT 2+10). Ground with frequently changing strength and deformation characteristics, as can be found in fault zones are assigned to the general behaviour category 11. The characteristics and behaviours have to be described project specifically.

Basic categories of Behaviour Types (BT)		Description of potential failure modes/mechanisms during excavation of the unsupported ground
1	Stable	Stable ground with the potential of small local gravity induced falling or sliding of blocks
2	Potential of discontinuity controlled block fall	Voluminous discontinuity controlled, gravity induced falling and sliding of blocks, occasional local shear failure on discontinuities
3	Shallow failure	Shallow stress induced failure in combination with discontinuity and gravity controlled failure
4	Voluminous stress induced failure	Stress induced failure involving large ground volumes and large deformation
5	Rock burst	Sudden and violent failure of the rock mass, caused by highly stressed brittle rocks and the rapid release of accumulated strain energy
6	Buckling	Buckling of rocks with a narrowly spaced discontinuity set, frequently associated with shear failure
7	Crown failure	Voluminous overbreaks in the crown with progressive shear failure
8	Ravelling ground	Ravelling of dry or moist, intensely fractured, poorly interlocked rocks or soil with low cohesion
9	Flowing ground	Flow of intensely fractured, poorly interlocked rocks or soil with high water content
10	Swelling ground	Time dependent volume increase of the ground caused by physical-chemical reaction of ground and water in combination with stress relief
11	Ground with frequently changing deformation characteristics	Combination of several behaviours with strong local variations of stresses and deformations over longer sections due to heterogeneous ground (i.e. in heterogeneous fault zones; block-in-matrix rock, tectonic melanges)

Table 2: General categories of Ground Behaviours

4.3.2 Records

The description of each Ground Behaviour Type has to contain at least:

- Ground Type(s)
- Orientation of relevant discontinuities relative to the underground structure
- Utilization of ground strength at tunnel perimeter and in representative volume
- Ground water, limits of ground water quantity/pressure under which ground behaviour type applies
- Sketch of expected ground structure
- Description of ground behaviour (type of failure mechanism, long term behaviour, etc.)
- Displacements, estimate of magnitude, orientation, and development over time

4.4 Selection of construction concept and evaluation of System Behaviour in the excavation area

After the Ground Types and the Behaviour Types have been determined, an appropriate construction concept is chosen for each characteristic situation.

The tunnelling concept in general contains:

- Ground improvement methods
- Dewatering methods
- Excavation method
- Excavation and support sequence
- Pre-supports
- Support concept
- Possible round length

Based on the tunnelling concept the system behaviour under consideration of the influencing factors in the excavation area is determined.

Influencing factors are:

- The ground behaviour
- Shape and size of underground opening, considering intermediate construction steps
- Round length
- Excavation method
- Spatial stress condition
- Ground water
- Subdivision of excavation cross sesction
- Support elements, as far as they influence the system behaviour in the excavation area

The system behaviour in the excavation area has to be shown in a graphical representation with indication of potential failure modes.

4.5 Detailed determination of construction measures and evaluation of system behaviour in supported area

After evaluating the system behaviour in the excavation area the construction measures are designed in detail. The stability of the face and the perimeter, subsequent construction steps, and boundary conditions have to be considered.

The next step involves the evaluation of the system behaviour (interaction between ground, support, additional measures, and construction sequence) and its comparison to the requirements.

4.5.1 Influencing factors

In addition to the above mentioned influencing factors, following factors have to be considered for the evaluation of the system behaviour in the supported area:

- Time and position of installation of support, as well as their time dependent properties
- Time dependent properties of the ground
- Subsequent excavation steps

4.5.2 Method

The method of analysis depends on the specific boundary conditions of the underground structure. Following methods are applicable:

- Closed form solutions
- Numerical simulations
- Experience from similar structures under comparable conditions

4.5.3 Analyses and Proofs

The system behaviour shall be analyzed and compared to the requirements.

Following has to be proven:

- the stability in all construction stages and the servicability in the final stage
- the compliance with environmental requirements (surface settlements, vibrations, ground water disturbance, etc.)
- displacements are within acceptable limits (admissible displacements, serviceability; system compatibility, etc.)

All analyses have to be documented in a traceable and auditable form.

The spread of the influencing factors, as well as the influence of the construction on the environment has to be considered. In general influencing factors are not available as deterministic values, but rather as a range or distribution. The influence of the spread of critical parameters on the system behaviour shall be analysed by means of a parametric study.

As the chosen construction measures strongly influence the system behaviour, an optimal choice of construction sequence and support measures a priori is the exception. Generally construction sequence and support measures have to be varied until a safe and economical construction process is obtained.

In case the required parameters cannot be determined with sufficient accuracy in advance, a geotechnical safety management plan has to be developed. This plan shall prescribe methods and procedures for the verification of assumptions, for assessment of the stability, for compliance with the environmental requirements, and for the determination of the appropriate construction and support methods.

4.5.4 Records

For characteristic conditions (for example ground conditions, section of tunnel, different sequence, support method, etc.) the expected system behaviour has to be described in a way that it can be verified during construction.

Typically this includes, but is not limited to:

- Amount, orientation, and development of displacements with time/distance to the face in all construction stages
- Required face support
- Subsidence in case of shallow tunnels
- Behaviour of supports (utilization of lining, deformation of bolt plates and yielding elements, etc.)

Above information serves also as input in the safety management plan.

4.6 Determination of tunnelling classes

For characteristic combinations of support measures and construction sequences the tunnelling classes are determined according to the Austrian standard ÖNORM B2203-1.

To establish the bill of quantities a prediction of the distribution of excavation classes is required. This distribution has to be established for the most probable case, as well as the spread in the distribution resulting from the spread of ground parameters and influencing factors. When establishing the distribution of excavation classes along the alignment not only the geological and geotechnical conditions, but also the heterogeneity of the ground has to be considered. In very heterogeneous ground, frequently changing the excavation and support methods in many cases will be technically and economically unfeasible. If the distribution of excavation classes is “homogenized”, the reasons have to be explained.

4.7 Geotechnical report

The results of the geotechnical design have to be summarized in a geotechnical report. In this report the single steps described in this guideline have to be described in a comprehensible and auditable form.

The geotechnical report shall be compiled in joint co-operation between designer, geologist and geotechnical engineer.

4.7.1 Contents

- A summary of the results of geological and geotechnical investigations, and the interpretation of the results
- A description of the Ground Types and the associated key parameters

- A description of the predicted Ground Behaviour Types, the relevant influencing factors, the analyses performed, and the geotechnical models used for determination of the behaviours
- A report on the determination of excavation and support, relevant scenarios considered (for example stability of unsupported area and face), analyses conducted, and design results
- Definition of the criteria for assignment of excavation and support method to the system behaviour in the excavation area
- Description of system behaviours in all construction stages
- The framework plan
- Distribution of tunnelling classes along the alignment

4.7.2 Contents of the Framework Plan

The framework plan shall contain following information:

- Geological model with expected distribution of Ground Types in a longitudinal section
- Expected system behaviour in the excavation area for the respective ground types and influencing factors (e.g. overburden, orientation between discontinuities and structure)
- Criteria for the determination of construction measures on site with respect to system behaviour in the excavation area
- Fixed excavation and support types (round length, excavation sequence, over-excavation, invert closure distance, support quality and quantity, etc.)
- Measures to be determined on site (support ahead of the face, face support, ground improvement, drainage, etc.)
- Description of expected System Behaviour in supported section (deformation characteristics, utilization of supports, etc.)
- Warning criteria and levels, as well as remedial measures according to the safety management plan

5 PHASE 2 - CONSTRUCTION

5.1 Basic procedure

Due to the fact, that in many cases the ground conditions cannot be defined with the required accuracy prior to construction, a continuous updating of the geotechnical model and an adjustment of excavation and support to the actual ground conditions during construction is required.

The detailed analyses of the system behaviour during construction serve as a basis for refining the geotechnical model. Conclusions shall be used for the determination of the construction measures. For geotechnical difficult projects a geotechnical engineer shall be employed on site.

The final determination of excavation methods, as well as support type and quantity in most cases is possible only on site. In order to guarantee the required safety, a safety management plan needs to be established.

Figure 3 shows the basic procedure to be followed for each section

Step 1 – Determination of the encountered Ground Type and prediction of ground characteristics

To be able to determine the encountered Ground Type, the geological documentation during construction has to be targeted to collect and record the relevant parameters specified in the design. Additional observations, like indications of overstressing, deformation and failure mechanisms, as well as results from probing ahead and the evaluation of the geotechnical monitoring are used to update the ground model and predict the conditions ahead of the face.

Step 2 – Assessment of system behaviour in excavation area

Based on the predicted ground conditions the system behaviour in the section ahead has to be assessed under consideration of the influencing factors, and compared to the framework plan. Particular attention has to be paid on potential failure modes.

Step 3 – Determination of excavation and support measures and prediction of System Behaviour in supported section

To determine the appropriate excavation and support the criteria laid out in the framework plan have to be followed. Consequently, it has to be checked if the actual ground conditions (ground type, system behaviour) comply with the prediction. The additional data obtained during construction form the basis for the determination of the applied excavation and support methods. The goal is to achieve an economical and safe tunnel construction.

The system behaviour has to be predicted for the next excavation section, considering ground conditions, and the chosen construction measures. Records have to be kept on this process.

Note: Both, excavation and support, to a major extent, have to be determined prior to the excavation. After the initial excavation only minor modifications, like additional bolts, are possible. This fact stresses the importance of a continuous short-term prediction.

Step 4 – Verification of System Behaviour

By monitoring the system behaviour (visually and by measurements) the compliance with the requirements and criteria defined in the geotechnical safety management plan is checked. When differences between the observed and predicted behaviour occur, the parameters and criteria used during excavation for the determination of the ground type and the excavation and support have to be reviewed. When the displacements or support utilization are higher than predicted, a detailed investigation into the reasons for the different system behaviour has to be conducted, and if required mitigation measures (like increase of support) ordered. In case the system behaviour is more favourable than expected, the reasons have to be analyzed as well, and the used parameters modified if appropriate. This allows for a continuous improvement and refinement of the method for assignment of excavation and support methods.

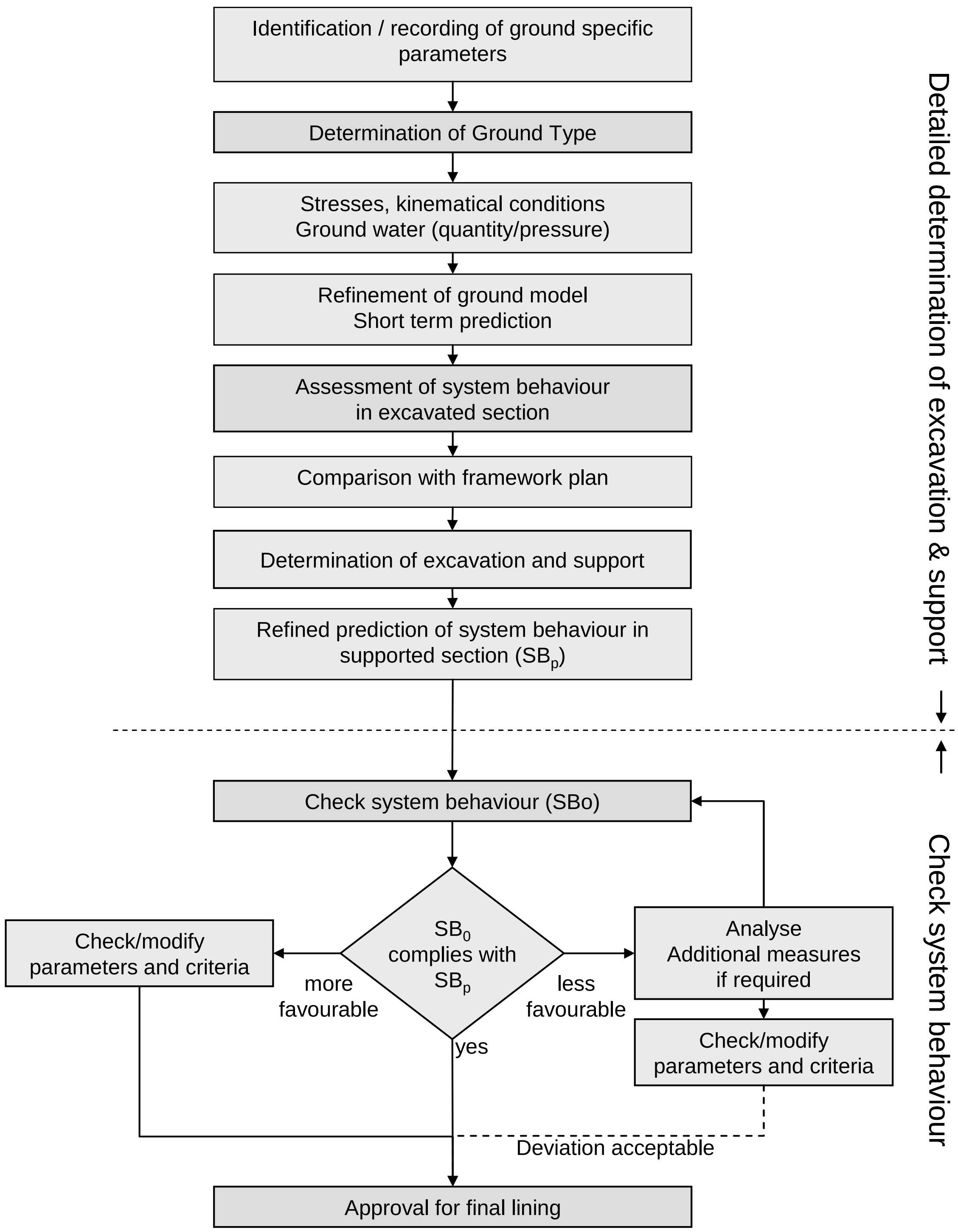

Figure 3: Basic procedure of determination of construction measures and check of system behaviour during construction (SB_p = predicted system behaviour, SB_o = observed system behaviour)

5.2 Determination of actual ground type

5.2.1 Preparation and method

During design key parameters had been defined for the identification of each ground type, considering that those can be recorded during construction. If required the recording of additional parameters, relevant for the system behaviour can be required during construction. The use of additional parameters has to be justified and agreed upon by all parties involved. Appropriate documentation is required.

Each of the key parameters is categorized. Whenever feasible, numerical values shall be used rather than descriptive data, like spacing, joint opening, strength, etc. Due to practical reasons some of the required parameters can only be described qualitatively.

Using predefined criteria the parameters are weighted and combined, allowing the appropriate Ground Types to be identified. A correlation matrix shall be used.

5.2.2 Collection of parameters on site and determination of ground type

Data collection on site has to concentrate on collecting relevant geological and geotechnical data and on observing and recording the ground structure. The data collected are recorded in prepared forms. With the criteria defined during the design, the Ground Type is determined. In heterogeneous ground conditions, the ground has to be divided into several sections, and the appropriate key parameters have to be collected for each section separately.

The geological and geotechnical data collected and evaluated on site are the basis for the extrapolation and prediction of the ground conditions into a representative volume. The geological work thus is not limited to recording the face conditions, but also has to involve predicting the conditions in the volume of rock that controls the ground response.

5.3 Assessment of system behaviour in the excavation area

5.3.1 Method

In addition to the parameters required to determine the Ground Type(s), influencing factors, like ground water conditions, ground structure, estimated stress situation, and kinematical conditions, as well as observations of the system behaviour in the excavation area shall be recorded.

The reaction of the ground to the excavation and support are observed by using an appropriate monitoring system.

Continuous evaluation of the mechanical processes in the excavated sections allows assessing the ground conditions outside the visible volume. Besides the geological prediction, an extended evaluation of monitoring data can help in modelling the ground conditions in a representative ground volume.

Applicable methods of analyses using the results of displacement measurements are:

- Analysis of the spatial stress redistribution by using deflection curves [25, 26]

- Extrapolation of displacement trends [27]
- Analysis of the displacement vector orientations and/or ratios of displacements of different monitoring points [28, 29, 30, 31, 32]
- Analysis of additional monitoring results (extensometers, inclinometers, etc.) [33]

The predicted ground structure in combination with the on site observations and monitoring results is used to predict the ground behaviour for the sections to be excavated next.

5.4 Determination of excavation and support and prediction of System Behaviour

5.4.1 Comparison with the Framework plan

For the final determination of the excavation and support method, it must be checked if the ground conditions and system behaviour observed on site conform to the design assumptions (according to the framework plan). When the observed conditions conform to the predicted ones, stipulations in the framework plan have to be followed when determining the construction measures. Additional locally required measures have to be set, even if those are not required explicitly in the framework plan.

In case of a deviation exceeding the specified tolerance in the framework plan, the designer has to be informed to allow for an adaptation of the prediction, based on new findings. The designer shall agree with the required additional measures in due time, and update the framework plan accordingly.

5.4.2 Decisions on site

The final decisions on the construction measures applied are based on the design and additional information gained during construction. The goal is a safe and economical construction. The decisions have to be coherently explained and documented, for example in an appendix to the excavation and support sheet.

5.4.3 Refinement of correlation criteria

During the design construction measures are assigned to each Ground Behaviour Type. The increase in information during the construction allows refining the criteria. In order to allow more accurate decisions on site, the categories for each parameter can be increased, or additional parameters defined. Changes in the criteria or parameter categories have to be supported with site data and evaluations. Changes in the parameter categories or criteria require an update of the framework plan.

5.4.4 Refinement of the prediction of the System Behaviour

With the increase in available information the actual ground behaviour and system behaviour can be predicted more precisely. The prediction generally is done for a section 10 to 20 m ahead of the actual face position.

The prediction of the system behaviour should contain (minimum requirements):

- Expected magnitude and orientation of the tunnel displacements, and the surface (if applicable), including the displacements spatial and time dependent development [32, 34, 35]
- Expected utilization factor of the support

5.5 Check of System Behaviour

Using observations of the system behaviour during excavation and evaluation and analysis of the measurement results, the actual system behaviour in the supported area and in the final stage is compared to the predicted, and checked, whether the behaviour is within the specified limits of the warning criteria. Additional measurements or evaluations may be required to determine for example the utilization of the lining [36, 37].

Deviations between the expected and the observed behaviours have to be analyzed and documented. The result of the analysis is basis for further decisions.

Observed system behaviour deviates from predicted

A discrepancy between observed and predicted system behaviours can have following reasons:

- Different geological or geotechnical conditions
- Actual ground behaviour different from the predicted
- Inappropriate parameter selection
- Wrong assumptions of the influencing parameters

The reasons for the deviation in behaviour have to be analyzed. In case the assumptions regarding the influencing factors are inappropriate, the parameters have to be modified. The modifications have to be supported by appropriate data and analyses and documented in an updated framework plan.

In case the ground quality is **better** than predicted, the geotechnical model has to be revised. In case of a significant deviation, the criteria for the determination of excavation and support have to be modified.

In case the ground quality is **worse** than predicted and warning levels exceeded, contingency measures according to the safety management plan have to be implemented, and excavation and support adjusted accordingly. This can be done for example by additional bolting, installation of a temporary invert, etc. In some cases the installation of a stronger support in the following rounds may be sufficient to achieve the target.

In case of significant deviations, the geotechnical model has to be revised. In case of a significant deviation, the criteria for the determination of excavation and support have to be modified. This generally requires that the framework plan is updated.

5.6 Updating of design

Due to limited information available during design, a number of assumptions and simplified models have to be used to arrive at a design, which is the basis for the framework plan and the tender documents.

To achieve the goal of a safe and economical construction it is required to continuously update the geotechnical design with the increasing level of information.

This applies to the determination of the ground types, the assignment and calibration of key parameters and criteria, as well as for the determination of the system behaviour. The refinement of parameter categories, the introduction of additional criteria, etc. help in improving the geotechnical model.

The geotechnical engineer on site has to report to the designer in case of significant deviations of the actual geological/geotechnical situation or system behaviour from the predicted ones, as outlined in the framework plan. A detailed report, containing all relevant information and coordinated with the site geologist and the representatives of the owner and contractor has to be prepared and submitted. After consideration of the facts, the designer has to update the framework plan. This has to be documented in a supplement to the geotechnical report.

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Appendix

Soil, rock, and ground parameters

Table of Contents

The following listing of parameters and references does not claim to be complete or exclusive. Actually decisive parameters of ground types have to be selected and evaluated according to the specific requirements of a geotechnical project.

1 INTACT ROCK

1.1 Description

- Rock name
  Applied classification system: [1, 2, 3, 4, 5, ÖNORM B 4401/3]
- Geotechnically relevant components, intercalations and variations should be given in percent per volume (vol.-%) and frequency.
- Mineral assemblage
  main and minor constituents (vol.-%), accessory minerals; cement, composition of components and matrix, contents/distribution of clay minerals qualitatively/quantitatively; (EN 12407, EN 12470, EN 12440, EN ISO 14689, [1, 2, 6, 7, 8, 9]
- Potential for swelling or aggressive behaviour: [9,10, 11]

1.2 Micro-Fabric

- Texture, micro-structure
- grain size, interlocking
- Micro-fractures [12, 13]
- Ratio of components to matrix, porosity, quantitative indices on grain fabrics ([2, 4, 5, 14, 15, 16, 17]

1.3 Condition of Rock and Rock Mass

- Tectonic or hydro-thermal alteration, disintegration
  cataclasis: [18, 19]
- Type of weathering
  applied classification system; discoloration, influence on material stregth, grain bonding, effect on discontinuity properties. [1, 2, 6, 20] 21, 22, 23, 24, 25, 26]
- Dissolution – transformation – neoformation of constituents or parts of rock mass (subrosion, karst formation)

1.4 Discontinuities, Macro-Fabric

- Macro structure
  (folding, bedding. Layering, schistosity, cleavage), type of discontinuity, age relationships, genensis
- Number and geometrical pattern of dominant discontinuity sets, size and shape of discontinuity-bounded blocks. [1, 2, 6, 17, 22, 26, 27])

1.5 Discontinuity properties

- Size measures (trace length – persistence, area)
  set-related distance, aperture, termination; [26, 28, 29]
- Alteration on discontinuities, filling, coating [22]
- Waviness - roughness, dilation angle, parameters of shear strength and stiffness of discontinuities [22, 28, 30, 31, 32]
- Characteristic measures of discontinuity intensity – density, rock mass permeability [6, 17, 29, 33, 34, 35] 36]

1.6 Strength Characteristics of Rock, Rock Mass

- Rock strength in shear, compression, tension, [37, 38]
- Elastic constants (e.g.: E, ν, G, V)
- Coulomb/Hoek-Brown parameters (e.g.: c, φ, mi, s, GSI): [32, 35, 39, 40, 41, 42, 43, 44]
- Point load-, Brazilian-, elastic rebound index values, [26, 45 46, 47, 48, 49, 50]
- Anisotropy with respect to rock or rock mass strength and deformability [22, 31, 51, 52, 53]
- Abrasivity, cuttability, ease of excavation, [15, 26, 54, 55, 56, 57, 58, 59, 60]
- Stability against wear, temperature changes, weathering and immersion. [11, 61, 62, 63], EN 1367/1, ÖNORM B3126/1-2, B 3128

2 SOIL

2.1 Soil Classification

- Definition of grain size classes
- Grain size distribution
- Properties of plasticity
- Constituents of organic origin [64, [65]

2.2 Parameters of the composite

- Specific weight, unit weight, density (ÖNORM B 4413, B 4414/1/2, DIN 18124, DIN 18125 T1/T2, DIN 18126, ASTM D 854)
- Grain size distribution (ÖNORM B 4412/1/2, B4401/3, B 3120, DIN 8196, DIN18123, DIN 4021 T1, ASTM D 2487, ASTM D 3282, ASTM D 422, EN 932/3/4, EN 933/1-6, [2], [5], EN ISO 14688)
- Porosity, structure - texture
- (ratio of components to matrix, kind and arrangement of the component framework (EN 1097/3-4, [5])
- Properties (and potential direction-dependence) of strength and deformability (ÖNORM B 4420, B 4416, B 4415, B 4411, DIN 18122 T1/T2, DIN 18127, ASTM 4318, ASTM 2435, ASTM D 2166, ASTM D 2850, ASTM D 3080)

2.3 Parameter of components

- Mineralogical composition of the main constituents, grain shape, see 1.1, 1.2, ÖNORM B4401/3, ASTM 2488, [5, 66]
- • State of components (e.g. weathering, alteration): see section 1.3, EN 1097/1-2, [6], ÖNORM B 3128
- Mineralogical composition of the main constituents, grain shape, see 1.1, 1.2, ÖNORM B4401/3, ASTM 2488, [5]
- State of components (e.g. weathering, alteration): see section 1.3, EN 1097/1-2, [6], ÖNORM B 3128

2.4 Parameters of matrix

- Mineralogical composition, contents of clay minerals and organic material, cementation [5], [9], EN 933/8-10

2.5 Permeability

ÖNORM B 4410, B4422/1/2, DIN18130 T1, ASTM: D 4643, D 4944, D 2434

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Guideline for the Cost Determination for Transportation Infrastructure Projects

Taking relevant project risk and uncertainty into consideration

2016

GUIDELINE

Cost Determination for Transportation Infrastructure Projects

Taking relevant project risk and uncertainty into consideration

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Review

This guideline was made available for review to all members of the Austrian Society for Geomechanics. All contributions were considered and the results were made available to the reviewers.

CONTENTS

1 Preface

1.1 Objectives

Transportation infrastructure projects are distinguished by long timeframes and project phases and a high number of participants and stakeholders. They are influenced by factors that are difficult to predict – such as the availability of financing, the legal environment, the political context, public pressures, and the unique character of the project itself.

Project costs must be determined based on these “framework” conditions and a sufficient knowledge of the project environment – which can change during the implementation of the project.

Project costs are dependent on many factors, such as the status of authorizations, environmental requirements, the level of planning contracting procedures, and the rate of progress of the project’s implementation. Dealing with unknowns and risks requires an expert determination during the planning and implementation phases of potential risk costs as well as consideration of cost-impacting factors that, while not yet specifically identified or quantified, have historical precedents. Allowance for these factors should be included, based on experience and historical data.

This guideline provides the basis for an appropriate project cost determination, which is necessary for cost stability and achievement of project objectives. Under these guidelines, an individual cost evaluation of each specific project is required and a proactive approach to cost determination by planners and contracting authorities is extremely important. The successful management of a project depends on a sufficiently precise description of the project’s scope and context (which also establishes the basis for the cost estimate).

The aim of this guideline is to describe a process that can provide a sufficiently complete and clear representation of the expected costs of a project, or elements of a project, based on the state of knowledge as the project evolves from initiation through planning, development, preliminary design, tendering, and awarding of contracts.

The graphics presented in this guideline are intended for easier understanding of the concepts and processes presented. They are conceptual in nature and need to be modified to be specific for each project application.

1.2 Scope and Limits

This guideline can be used for tunnel construction (cut and cover and mined tunnelling), infrastructure projects (airports, railway stations, bridges), and individual project elements (e.g., trenches, access roads, etc.).

The systematic approach used in this guideline is also appropriate for other major projects such as power plants and similar projects, including corrective maintenance work.

This guideline governs cost determination in the planning and design phases. Cost monitoring in the construction phase, and actual costs as the project is executed, are not within the scope of this guideline.

This guideline only addresses those costs and risks that are part of the contracting authority's (owner’s) sphere of influence or responsibility, including potential effects (impacts) caused by risks that are part of the contractor's sphere of influence but that need to be included in cost estimates by anticipating them in the planning and design phases. In addressing risk, it is normal to assign some risks to specific "risk owners" who are part of the contracting authority's sphere of influence and to assign responsibility for other risks to the contractor, through the contract documents, or to insurers or other third-parties, if and as appropriate.

The determination of the following costs and associated risks are not part of this guideline and, where necessary, should be considered separately: subsequent costs such as operating costs, maintenance costs, and, where pertinent, any dismantling or remediation costs at the end of the structure's life cycle time; financing costs; income tax; cost contributions from third parties; grants by the European Union (EU); or subsidies.

2 Principles of Cost Determination

2.1 Project Content and Delimitation

The project content describes the measures to be implemented and the facilities to be constructed to achieve the project's quality, functional, cost, and schedule objectives.

The project content must be defined physically and time-wise. As work is done and the project develops, the project content will become more precisely defined – resulting in more detailed project element definition and more detailed cost estimates.

2.2 Project Phases

The project should be divided into phases such as those listed in Table 1.

For each project phase, milestones should be defined for completing project elements and for cost de-termination. Methods for cost and risk assessment should be defined that are appropriate for that phase.

Table 1: Example Project Phases

	Project Initiation Phase	**Project Development Phase**	**Preliminary Project Planning and Design Phase**	**Project Approval Phase**	**Tendering / Contracting Phase**	**Construction / Execution Phase**	**Final Project Phase / Contract Closeout**
Activity	Conceptual Planning	Basic Planning	Preliminary Design	Project Documents advanced to secure "Approval to Construct"	Contract Documents Published for Bidding / Tender	Project Execution and Construction	Close out Contracts, Final Payments, Formal Acceptance
Project Milestones	Project objectives, Project start / Project Completion	Product Requirements, Document Purpose and Need	Basic Project Characteristics Defined	Submission to Authorities for Approval to Contract	Transition from Design to Construction	Award / Notice-to-Proceed	Project Completion
Cost Calculation Milestones		Cost Framework Defined, Preliminary Estimate	Update and Advance Cost Estimates	Update, Cost Estimate for Approval	Owner's Tender Cost Estimate	*Not subject of this guideline*	
Costing Methods		Benchmark Method	Benchmark and Element Method	Method according to the planning status: Element Method	Item Method		

Project Initiation Phase

Based on the defined purpose and need, project objectives, general characteristics, and an initial cost estimate are defined using conceptual planning.

Project Development Phase

In the project development phase, the product requirement documents are drawn up, including detailed performance, quality, cost, and schedule objectives. This phase includes, for example, requirements and location analyses, cost-benefit analyses, feasibility studies, and project conceptualizations. The benchmark method is normally used for cost determination and to define the cost framework.

Preliminary Project Planning and Design Phase

During preliminary planning and design, various routes and project alternatives are evaluated with the aim of deciding on one possible solution or to narrow the alternatives for approval. The method used for cost determination may be the benchmark or element method (these methods are defined later in this document).

In general, there is a significant increase in information in this phase, which may lead to a significant reduction in the "mark-up" or contingency for unknown risk costs in this and the subsequent phase (see Figure 6).

Project Approval Phase

The project approval or authorization phase may be divided into two steps. The first includes the draft and authorization planning documents that are to be presented to the authorities for approval. These documents may be required by environmental, roadway, railway, and water related laws.

In some cases, the contracting authority may require design to be completed to a high level in this phase for evaluation by the contracting authority.

The second step includes verification and acceptance of the documents by the authorities.

The approval phase ends with granting of authorization to proceed by the authorities. Cost determination is updated based on the accepted approval documentation. Should cost-related conditions of approval be imposed (e.g., a lower probable cost is required), it may be necessary to revise the scope of the project and re-work the cost estimate.

Tendering/Contracting Phase

The tendering/contracting phase includes finalization of the tender documents, which are structured based on the type of contract to be awarded (e.g., fixed price, contract with functional tender specifications, use of shared contingencies or allowances, etc.). Conditions resulting from previous authorization procedures and requirements are included in the tender documents. Bids are submitted by contractors and these offers are evaluated on specified acceptance criteria (e.g., best-value, alternate technical concepts, compliance with contractual performance requirements related to incentives and penalties). The tendering phase may begin during the project approval phase and ends with the signing of the contract.

Construction Phase

The construction phase begins with the signing of the contract and notice-to-proceed to the successful contractor. This phase includes mobilization, final design of elements, drafting of pertinent construction documentation, and construction of structures on the basis of the con-tract documents. In this phase, costs are regularly monitored, with changes and adjustments to account for local conditions and scope or site condition changes during the implementation of the contract. This phase ends when the contracting authority accepts and takes over the completed work.

Final Project Phase/Contract Closeout

The final phase of the project includes closing-out of all contracts, final invoicing, analysis and reconciliation of accounts, final payments, formal acceptance, benchmarking, and “as-built” documentation of the project.

2.3 Cost Structuring Options

The cost structure to be used is based on the project’s structure, configuration, and phases.

A Work Breakdown Structure (WBS) is recommended that separates the project into definable elements and units used for cost estimating and controlling (tasks, partial tasks) or work packets that can be used as a basis for further project planning and management of such tasks. The work breakdown structure should show all essential relations between project elements.

The work breakdown structure can be organized using different approaches:

- By construction phases: Construction phases are finite, time-related, or logical segments of a project. They are not necessarily ordered in sequence and can be parallel or overlapping (for example, modules such as partial and complete construction, construction lots).
- By objects: A function-oriented organization of the elements in the work breakdown structure shows the individual parts and construction groups based on the similarity of the pertinent objects (such as at-grade areas, bridges, tunnels, auxiliary systems, or structures).
- By organisational function: A function-oriented organization of the elements in the work breakdown structure may be based on participants (e.g., building trades, specialized subcontractors) or technical categories of the project (e.g., land acquisition, systems, new construction, expansion, operations).

To integrate these in the work breakdown structure and cost structuring, cost groups can be assigned to such elements. These cost groups may, for example, include the following:

- Project Management
- Land Acquisition
- Design
- Monitoring
- Service Providers in the Construction Phase
- Construction
- Equipment and Systems
- Environmentally Relevant Measures
- Commissioning
- In-House Services
- Public Relations

For a further subdivision of these cost groups see Appendix 10.1.

The work breakdown structure must be clear, sufficiently precise, and comprehensible in order to be updated on an on-going basis.

2.4 Dealing with Uncertainty

If costs are predicted using a deterministic approach (by single numbers for project elements or in total), there is no allowance for, or quantification of, uncertainty. It is almost certain, however, that so-called "exact values," predicted deterministically, will not materialize exactly during construction. For a variety of reasons, there will always be differences between results and predictions. To take these differences into account, a range of values (using distributions) should be considered.

In such a distribution (e.g., a range of costs), the deterministic value will correspond to the modal value (see Figure 1). To represent such ranges, Figure 1 shows, for example, a triangular distribution, which takes into account the lower probability of occurrence of marginal (upper and lower) values, as compared to the deterministic value.

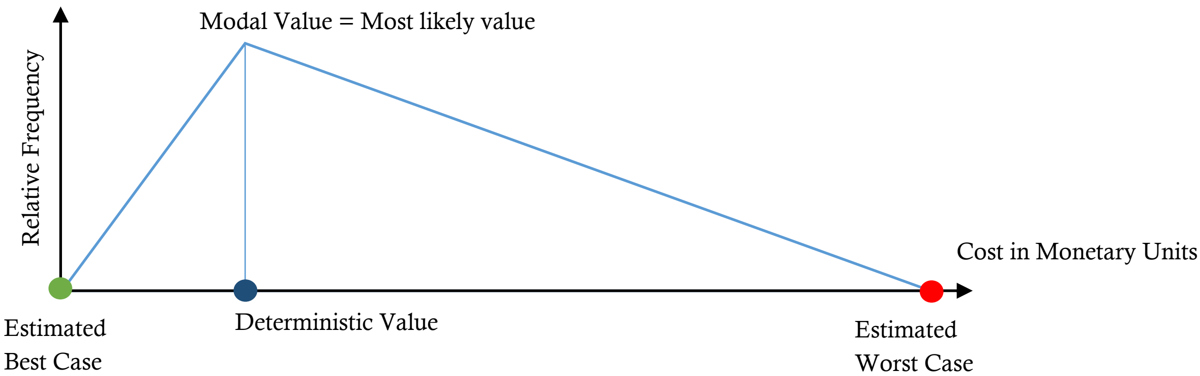

Figure 1: Adding range to a deterministic value

Figure 2 – Calculation of overall probability distribution by aggregation of cost elements shows the use of a probabilistic method. The individual cost elements are represented by appropriate distributions, in order to take uncertainty into account. The result is an aggregated probability distribution of costs that takes prediction-based deviations into account.

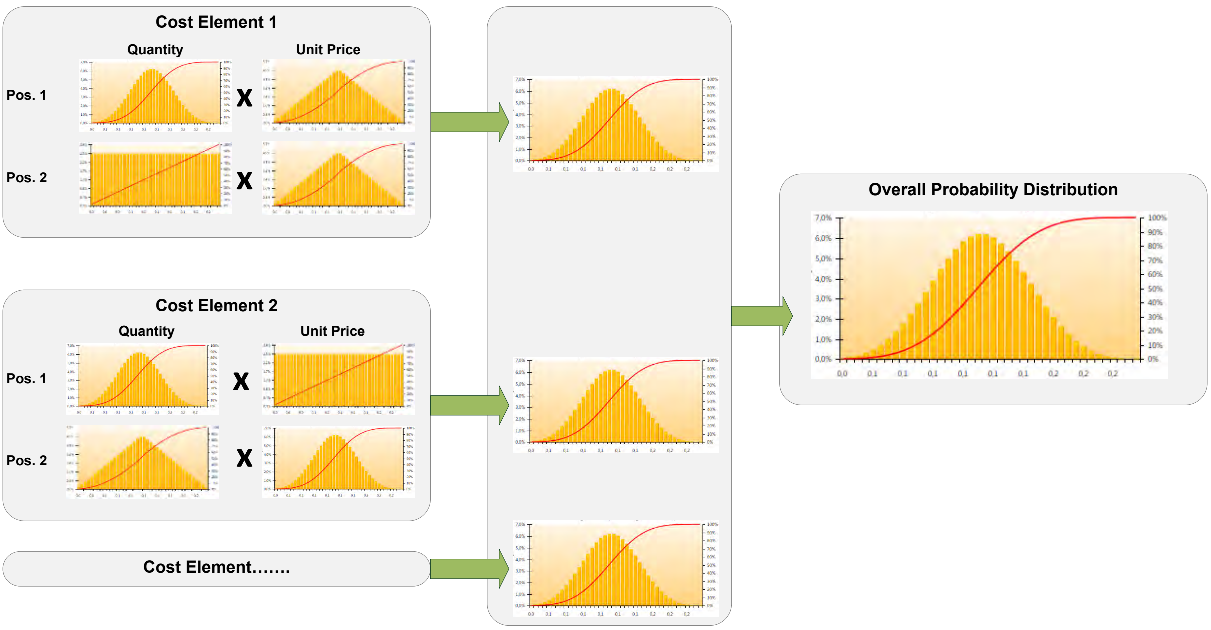

Figure 2: Calculation of overall probability distribution by aggregation of cost elements

3 Cost Components

The total project cost estimate includes the following elements:

- Base Cost (B)
- Indexation and Value Adjustment (I)
- Risk (R)
- Escalation (E)

These costs are predicated on the assumption that the project will progress in a certain (defined) manner and with a certain development of market prices as the project develops. Allowance is made for possible deviations from the expected development by adding or subtracting costs probabilistically to account for risk and uncertainty.

The build-up (summation) of project costs (B+I+R+E) over project milestone dates can be represented by the following graph, where individual cost components may be zero at specific points in time.

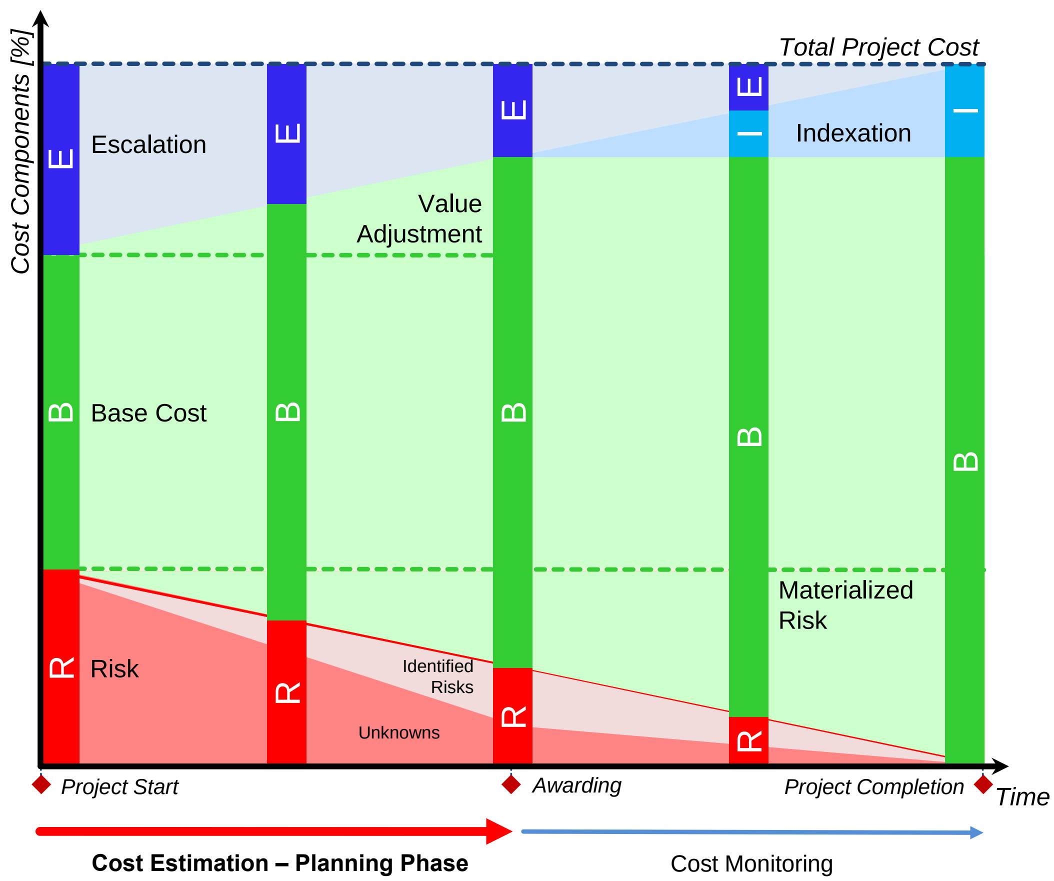

Figure 3: Schematic graph of project cost components over time/phase

3.1 Base Cost (B)

The base cost is that cost which can reasonably be expected if the project materializes as planned, with a defined content, schedule, and market situation. The base cost estimate is to be neither optimistic nor conservative and does not include price and/or quantity variability. The base cost estimate does not include contingency or the cost of potential risk events or escalation. The base cost is determined in accordance with a specific, defined base price and base date.

3.1.1 Basic Principles

The base cost generally includes all costs necessary for the design, construction, and functioning of the project, including land acquisition and development, services and works, systems, and commissioning. They include in-house and consultant services provided by the contracting authority (for possible sub-division into cost groups, see Section 3.3).

The choice of method for the determination of base cost depends on the project phase (see Table 1). The following methods can be used, depending on the level of detail required:

- Benchmark method
- Element method
- Line item method

Depending on the project structure and the progress of the project, the degree of detail for elements of the project may vary at any specific date – that is, one part of the project may already be in the construction phase, whereas the status of another part may still be in the planning, design, or tendering phase. This means that the method(s) used to determine base cost for elements at a certain reference date can vary within the same project, based on the progress of the respective parts of the project.

All three methods may not be able to take into full account certain parts of the project, based on the state of project knowledge at a particular time. In this case, contingencies must be added to allow for these unknowns (see Section 3.1.2.4).

3.1.2 Determination of Base Cost

Estimated quantities and unit costs form the basis for the determination of base cost. The following procedures are available for this determination:

- Deterministic procedure
- Probabilistic procedure

The choice of the specific procedure is to be determined by the project team and approved by the contracting authority.

In both procedures, base cost is determined from a summation of the product of estimated quantities times unit costs. In the deterministic method quantities and unit costs are single values, whereas in the probabilistic method both quantities and unit costs are defined by distributions in order to provide for uncertainties (see Section 2.4).

Unit costs are usually based on historical values, taken from comparable completed projects or from a price database. For parts of a project for which reference values are not available, reasonable estimates must be used to determine costs.

3.1.2.1 The Benchmark Method

This method considers higher-level components of a project to which reference values can be assigned (for example, costs related to linear meters for tunnels, square meters for bridges, lump sums for demolition work) based on unit costs. Values are determined by historical experience from historical projects or cost databases.

The method can be used to determine the cost framework at the beginning of the project or for the cost estimate in the preliminary project phase. For lower level cost groups such as land acquisition, costs can be assumed as a lump sum or as a percentage.

3.1.2.2 Element method

This method considers typical elements of a project, to which reference values can be assigned (for example, square meters for final lining, linear meters for tunnel excavation classes) and is based on unit cost.

For the smallest unit, there is differentiation between generic elements in the preliminary project phase and detailed elements in the authorization and subsequent phases. The distinction between generic and detailed elements is context-dependent.

3.1.2.3 The Line Item Method

This method considers line items from a bill of quantities (such as cubic meters for final lining concrete, each for rock bolts). It is based on unit costs from comparable projects or experiential values and can be used for cost quotes in the tender phase.

In drafting the bill of quantities, provision for risks for items such as force-account works, downtime days, and excavation disruptions should be considered and categorized as risk costs when determining overall costs.

3.1.2.4 Contingencies (For Undefined Elements)

Additional amounts for contingencies are included for those components of a project that are expected to be realized, based on current knowledge of the project, but have not yet been described in detail and whose costs cannot be specifically determined.

Adding contingencies allows for a sufficiently complete base cost to be determined even though there are unknown elements due to an incomplete project definition at a particular time. The amount of contingency to be added is dependent on the level of project definition and the type of project. As the project advances and more details are available, contingency costs may be replaced by known estimated values plus provision for risk costs.

3.2 Value Adjustment and Indexation (I)

3.2.1 Basic Principles

Value Adjustment is used to take into account a real market price development from, or related to, a certain reference date, which was previously included in Escalation. The Value Adjustment is a component of the initial escalation (E) (see Figure 3).

Two components should be distinguished:

- Before an active contract award, in which case a value adjustment is applied, and
- After a contract becomes active, in which case indexation is applied.

If costs are determined before a contract is signed, changes in price caused, among other factors, by inflation plus market factors (the interaction between demand and supply) will be considered in value adjustment.

With signed (active) contracts, price adjustments are generally planned for and made based on contractually stipulated cost indexes or agreed-upon inflation related to project-specific commodities. In contracts with fixed pricing, the cost component for indexation is zero.

3.2.2 Determination Value Adjustment

Value adjustment covers price fluctuation for contract services that have not yet been awarded, which occurs between the reference date for the related base cost and the current reference date ("cut-off date"). Value adjustment for the base cost is calculated from the reference date to the base cost per the current reference date ("cut-off date") (see Figure 3).

Costs may vary in proportion to market price fluctuations (price indices).

3.3 Risks (R)

3.3.1 Basic Principles

Predicted project costs must include provisions for risks that may occur, appropriate to the status and character of the project.

Risks are the combination of probability and consequence and may be either threats (negative consequence) or opportunities (positive consequence). The ability to characterize risk (quantification of probability and consequence) improves with increasing knowledge of the project as well as the experience of the project team and involved experts.

If risks actually occur during project development and/or construction, in principle the associated cost components can be added to the base cost and removed from the estimated risk cost (since the risk has occurred). The same approach applies also to opportunities.

Since risks are treated on a probabilistic basis, normally a one-to-one correspondence of actual (realized) risk costs to the estimated risk costs will not exist. This means that, while a specific risk that has occurred can be "retired" from the risk register, the overall risk profile (the sum of future estimated risk costs) should be reduced conservatively.

3.3.2 Structure of Risk Evaluation

A structured risk evaluation is a basic process for estimating potential risk costs. Risk costs are divided into identified risks and mark-up for unknowns[1]:

Identified Risks + <u>Mark-up for Unknowns</u> = Risk Costs (R)

Identified risks include, based on the phase of the project, all characterized individual risks. The completeness of the identified risks depends on the level of knowledge of the project and the scope and quality of the risk analysis.

Unknowns can be divided into:

Unidentified Risks + <u>Unidentifiable Risks</u> = Unknowns

The completeness of **unidentified risks** depends on the knowledge of the project and the scope and quality of the risk analysis. **Unidentifiable risks** cannot be identified using risk analysis and therefore only become known when such risks actually occur.

Three methods are used to determine risk costs:

- Benchmark method
- Risk identification and characterization
- A combination of the two

The choice of method is up to the project team and contracting authority and can be made on the basis of the following aspects and considerations (these are listed as examples – other factors are also possible):

- Size of the project (quantified by predicted project costs)
- Complexity of the project and its environment
- Uniqueness, lack of precedent or comparative projects
- Public perception of the project (opposition or support)
- Available data (knowns vs. unknowns)

If using the benchmark method, the total risk costs are determined as a lump sum without distinguishing between identified risks and unknowns.

If using an individual risk evaluation, risk costs are determined from the sum of all identified risks plus a certain amount (allowance, contingency) for unknowns that is added to the risk costs. The resulting amount is then added to the base cost to give the total estimated project cost. More information and an example of the methods are included below.

[1] Please note the possibility of considering separate cost mark-ups by the contracting authority according to Section 0.

3.3.3 Process Sequence

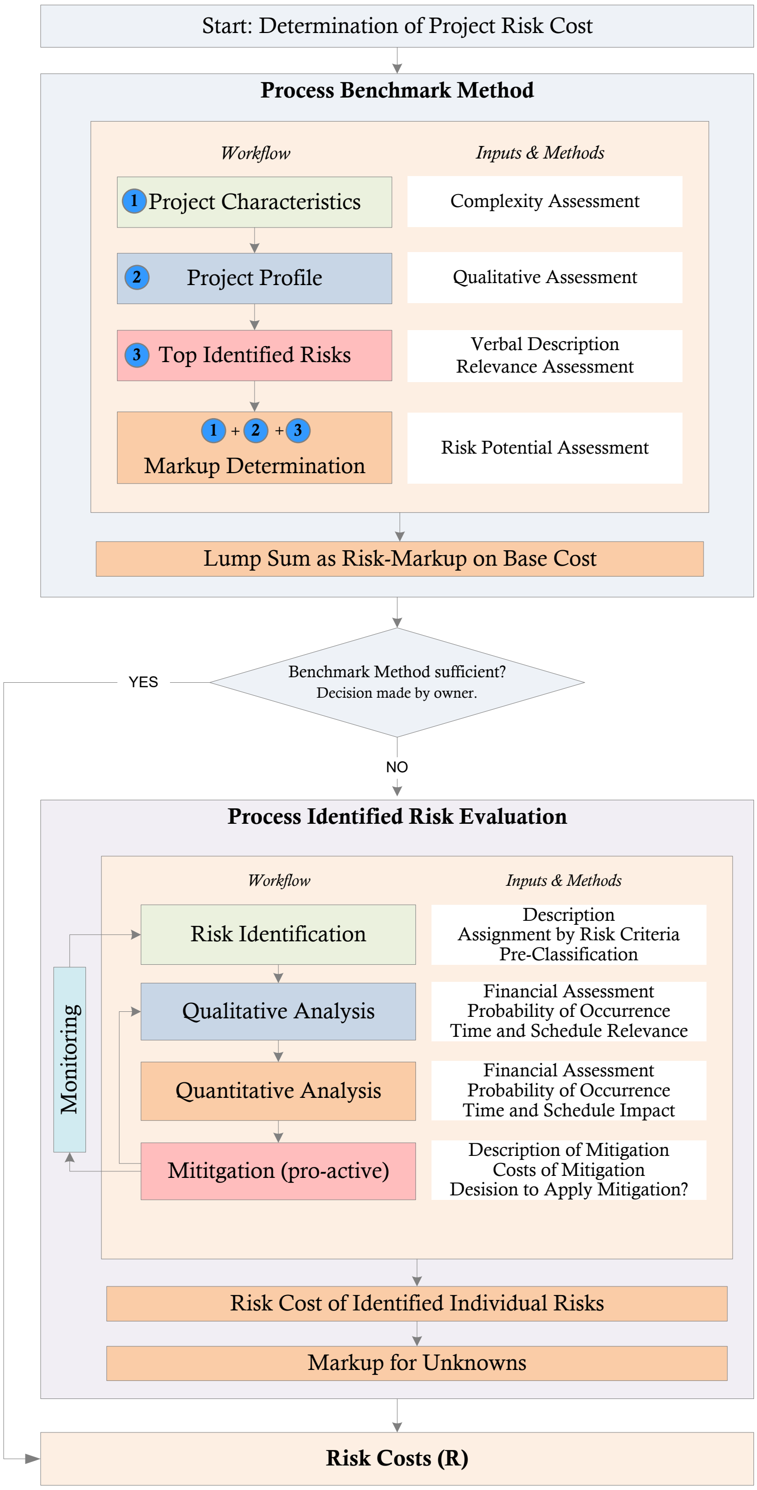

Figure 4: Sequence of steps in determining risk costs for the project

It is recommended that this process be organized in a structured manner with an expert cost/risk moderator and that the process be executed as follows:

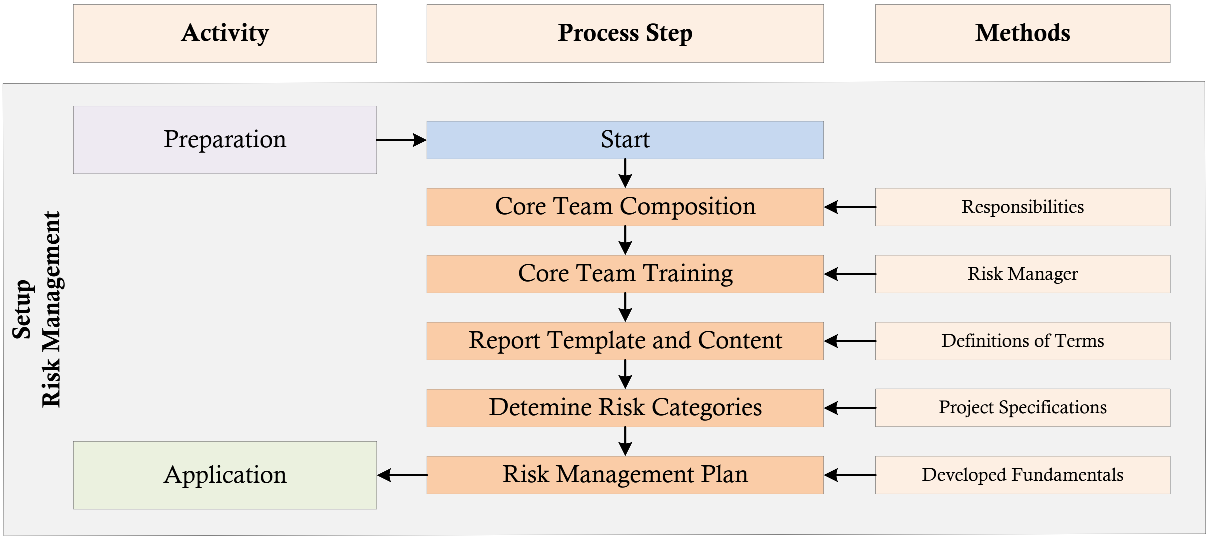

Figure 5: Preparation of the Risk Identification and Characterization process

3.3.4 Risk Breakdown Structure

The following list of risks is divided into categories in order to support administration of the risk identification and characterization process. The following structure follows from an evaluation of risk causes (triggers) to ensure that duplicate risks are not included.

Table 2: Classification and Structuring of Risks

Abbr.	Category	Typical Description	Examples
PD	**Planning Development**	The development of project detail in the planning stage with no change of project scope.	Advancing design of project elements with increased understanding and definition.
CO	**Cost**	Updated estimation of cost with unchanged project scope.	Obtain cost quotes for the E+M cost of a power plant.
RE	**Real Estate**	Cost and/or schedule changes caused by changes or updates in real estate acquisition.	Delays as a result of prolonged processes or required authorizations for real estate acquisition, which is necessary for the project. New considerations of official real estate acquisition requirements.
AU	**Authorizations**	Changes in the requirements for, or processing of, authorization procedures.	Delays in obtaining approvals. Consideration of new official requirements.
CT	**Contract**	Contract modifications	Deviations (changes) in the contract, that are necessary, in order to achieve authorized project
01	***Contract modifications***	Additional specifications or requirements, which do not appear in the contract, but are necessary to complete the project.	Missing work in bill of quantity.
02	***Quantity deviation***	Quantity deviations from the initial contract with no changes to project scope.	Amount of excavation is more than planned
03	***Contract disputes***	Different interpretations of contract by client and contractor.	Type of ground is different that planner by owner and/or anticipated by contractor.
04	***Process optimization***	Changes required for optimization of contracted services with no change of project scope.	Alternative excavation support system, value engineering required changes.
05	***Changes in design***	Changes to design requirements with no change of project scope.	Mistakes or errors in planning or design services.
06	***Compliance with requirements or agreements***	Contract compliance.	Compliance with official requirements and agreements, that were known at the stage of planning/design but were not implemented in the
CH	**Change Order**	New or changed requirements for the project ordered by the client.	Changes in project scope or schedule or conditions, compliance with third-party needs.

Table 2: Classification and Structuring of Risks (Continuation)

GC	**Ground Conditions**	Changed requirements, originating from unknown or insufficiently known underground conditions.	For example: -changes of soil classifications -ingress of water, additional flows -cave-ins
01	***Changed conditions***	Conditions are different than planned or assumed.	Differences between predicted and actual underground conditions, soil types, quantity of water
02	***Design assumptions***	Differences between planned and actually occurring ground or support system behavior.	Changes to shotcrete or reinforcing required in construction under the observational method.
03	***Unforeseen events, circumstances***	Occurrence of unforeseen underground conditions.	Gases, ingress of water, collapse, running sands, high abrasivity.
MF	**Market Forces**	Changes in prices and/or costs, that originate from market forces such as limited availability of labor or materials.	Inflation + escalation, general market conditions, economic conditions, changes in costs or fees, tracking errors, limitations on competition, difficulties in awarding contracts.
FU	**Funding**	Risks due to difficulties in funding or obtaining authorizations, deviations from planned financing models.	Rising interest costs due to short-term financing (supplementary financing) or due to amended foreign currency loans, reduced revenues.
PE	**Project Environment**	Environmental or project context changes, which affect the progress of the project or project costs.	Differences between contractual partners, contractor deficiencies, owner issues, internal/management risks.
01	***Third party costs***	Expenses or requirements relating to local residents or municipalities.	Additional measures (protection against dust, noise, etc. - not required by regulations), public events, citizens' initiatives, demonstrations, educational events, information material.
02	***Basic infrastructure***	Changes in basic infrastructure elements.	Road closures, restrictions of transit at local areas, power and water supply.
03	***External interfaces***	Changes of contract and/or project interfaces, which may not be in the client's sphere of influence.	Changes in authority, responsibilities, deferrals to other projects, changes in laws or regulations, new interpretations of regulations.
04	***Law, regulations, requirements***	Changes in laws, regulations, requirements.	Laws/guidelines/standards/provisions/official requirements.
05	***Adjacent Structures***	Deviations in extent, quantity and/or quality, between assumed and discovered conditions, of buildings or adjacent structures.	Neighboring houses that are in danger of damage or collapse
06	***Safety, Security***	Additional measures required to avoid incidents that endanger the public or construction site safety.	Thievery, vandalism, security services, health and safety requirements on the construction site
IN	**Internal**	Changes as a result of internal changes to project (e.g. management).	
01	***Staff***	Personnel resources and management.	Staff turnover, staff reduction, changes in staff deployment; issues with staff qualifications, staff availability.
02	***Organization***	Organizational management.	Clarity of organization, definition of roles and responsibilities, issues with internal and external communication, management of scope and schedule.
CN	**Contractual**	Contract Changes	Changes in costs or schedule or requirements, associated with project participants and new requirements, not necessarily arising from changes to
01	***Interface***	Interface requirements that are in the client's sphere of influence.	Organizational interfaces with contractor or third parties which impact cost or schedule.
02	***Contractor***	Suitability, capability	Qualifications, quality of execution, potential insolvency, technical, economical and financial performance issues, reliability and authority.
FM	**Higher forces, Force Majure**	Effects of higher level forces or Force Majure to an extent that is more than usually expected in planning or design.	Earthquakes, flood, avalanches, war, extraordinary weather conditions, storms, environmental disasters, strikes, labor disputes.

3.3.5 Benchmark Method

The benchmark method is a fast way to determine risk-related contingency costs, in terms of a lump sum amount added to the base cost. It is a function of the impact of construction and other conditions and is related to the project phase. There is no breakout or assessment of individual risks.

It is advisable to use the benchmark method with an expert moderator and to develop a spreadsheet – for an example, see Appendix 10.2.

From a qualitative point of view, the following aspects should be considered:

1. Project Complexity

   Note: The complexity of a project depends on the quantity of interacting components. Other relevant factors are the number of contractors, the number of the project participants, the previous experience of project participants, the project context, and timing. Complexity should, ideally, be defined jointly by the planner or engineer and the contracting authority.

2. Project Profile

   - Project base conditions
   - Project context
   - Maturity of planning
   - Approvals required
   - Construction sites
   - Contractual partner(s)

3. Definition level for identification and characterization of risks without quantitative evaluation

These aspects are used and considered for a qualitative assessment of potential risks for the project or parts of the project, often stated as a percentage of the base cost.

The ranges for added contingency (lump sum cost increase over base cost) for risks, including identified, quantified risks and unknowns, are shown in Figure 6.

In Figure 6 the approval phase is differentiated into two phases (also see Table 1) in order to determine the benchmarks. This differentiation can be used in a two-step authorization procedure.

3.3.6 Risk Identification and Characterization of Individual Risks

In the single risk assessment method, multiple phases are evaluated, focusing on the identification, characterization, and management of individual risks specific to each phase. This method is based on the principles of ISO 31000.

The following sequence is recommended:

- Identification of individual risks using a risk fact sheet.
- Classification of the identified risks according to Table 2.
- Pre-classification of risk scenarios according to section 11.3.
  This classification will help to decide whether each risk should undergo further analysis.
- Qualitative evaluation of risks without taking mitigation measures into account (as an example, see Figure 15).
- Based on the results of the evaluation, mitigation measures can be defined and risks are then re-evaluated for a revised probability of occurrence and impact. The cost of such mitigation measures, if implemented, will be taken into account in the base cost.
- Once the qualitative risk analysis is complete, a decision can be made as to whether a quantitative risk evaluation is required. The option of analysing and defining risks using a range approach (as described in Section 3.3) provides the basis for the probabilistic approach. It is up to the contracting authority whether to use a deterministic or probabilistic method for quantitative risk assessment. If at a given point in time a quantitative analysis is not feasible, the process stops with the qualitative documentation of the risk. Risks can then be quantified at a later date.
- Even with this method, not all individual risks can be identified. Therefore, an additional mark-up for "unidentifiable risks" should be added.
- Results from the individual risk fact sheets should be aggregated.

In quantitative analyses, the probability of occurrence is given as a percentage and the financial impact is expressed in monetary units (costs). In general, deterministic and probabilistic methods differ as follows:

With deterministic analyses, risk is the product of the estimated probability of occurrence [p] and the impact [I]. The product is the predicted value for risk costs. With multiple risks, the total risk is the sum of the single predicted values of the risk costs. The predicted value of the risk costs is calculated using the following formula:

$$R_{Ges} = \sum p_i * A_i$$

When using probabilistic methods, the financial impact of risks is more realistically assessed using probability distributions. Computer simulations to model the probable outcome, such as the Monte-Carlo Simulation, are needed for this method.

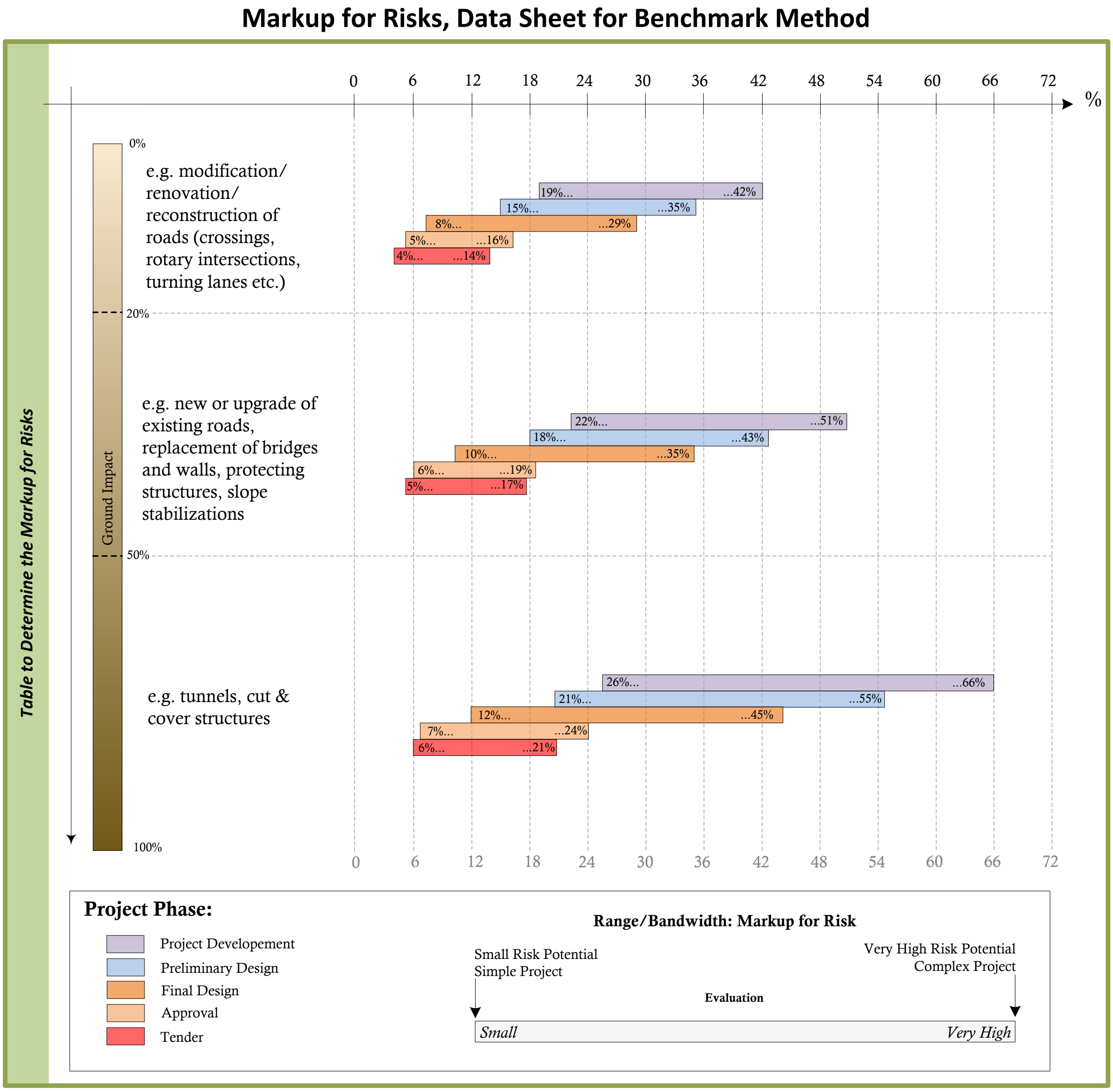

Figure 6: General Ranges for added Contingency by Project Phase

Table 3: Comparison of deterministic and probabilistic methods

	Deterministic Method	Probabilistic Method
Input	Indication of a single value for probability of occurrence and for impact of each risk.	Risk analysis requires an input value for the **probability of occurrence** and, for example, **three values for the impact** (minimal, expected, and maximum). This takes into account an "uncertain" prediction in the risk evaluation.
Result	A simple sum of the predicted values of the single risks (impact times probability of occurrence) gives the predicted value for the total risk, but not the most probable risk cost.	Simulation methods deliver the range of the total project risk as a probability distribution.
Statement	The result is a single number that gives no information regarding cost certainty.	The resulting probability distribution delivers a prediction for a certain risk. By using the probability of not exceeding a certain value within the given distribution, defined by the contracting authority, a predicted level of cost certainty can be determined.

3.3.7 Risk Mark-ups by Contracting Authority

Based on specific benchmarks, considerations, and experience of the contracting authority, it may be necessary to define certain separate contractor-specific cost increases to be added to the risk cost.

3.4 Escalation (E)

3.4.1 Basic Principles

Since transportation infrastructure projects generally take a long time to be realized, the cost increase due to escalation is of significant importance.

Cost indices for escalation are a methodical approach that takes into account assumed future market fluctuations from a specific cut-off date until the end of the project. Unlike value adjustment (I), these costs consider market price developments as of a certain cut-off date as cost indices for escalation (E).

Consideration of escalation is meant to give the best possible estimate of future price fluctuations on the construction market (such as construction or producer price indices) for not yet awarded services and, on the other hand, for the future development of contractors' internal costs (such as construction cost indices), while taking into account the various cost groups (land acquisition, tunnel construction, etc.).

If projects or parts of project are delayed, escalation will vary. If indices are increasing, delays will lead to higher estimated total BIRE project costs.

3.4.2 Determination Escalation

Determining escalation (E) requires a schedule of deliverables for services to be provided, broken down into project phases, and a market assessment for each phase.

In long-term projects, escalation (E) can be determined by using a constant percentage for all cost groups for the annual variation, to be applied to both value adjustment and indexation. This is because over the long term it can be assumed that costs and prices, which differ only by the profit margin plus risk mark-ups and by productivity, will neither converge nor spread. The percentages are to be applied to the planned future costs using a compound interest calculation. The appropriate percentages should be added to the predicted project costs (BIR).

The definition of the percentage is up to the contracting authority, which can define the percentage on the basis of the escalation (inflation/deflation) rates of the last years.

4 Aggregation of Cost Components

The determination of total estimated project costs (BIRE) requires the aggregation of the cost components of Base Cost (B), Escalation (E), Risk (R), and Prospective Value Adjustment (I). The type of aggregation to be used is dependent on the methods used to determine the individual cost components.

$$\mathbf{BIRE = B + I + R + E}$$

If all cost components have been calculated in a deterministic manner, they are added together arithmetically. The result (BIRE) is then a deterministic value whose probability of occurrence cannot be predicted. Therefore, no quantitative statement can be made as to the degree of cost certainty.

If at least one cost component – for example, risk costs – has been determined using the probabilistic method, the aggregation should be carried out according to the rules of the probabilistic method. Estimated project costs and cost certainty can then both be assessed, based on the resulting probability distribution of the aggregated cost components (BIRE). The cost certainty mentioned in this context (Value at Risk or VaR) refers only to those cost components that were determined probabilistically.

For a probabilistic estimation of cost components, the contracting authority can choose a specific probability for budgeting, considering the likelihood of cost over or under runs.

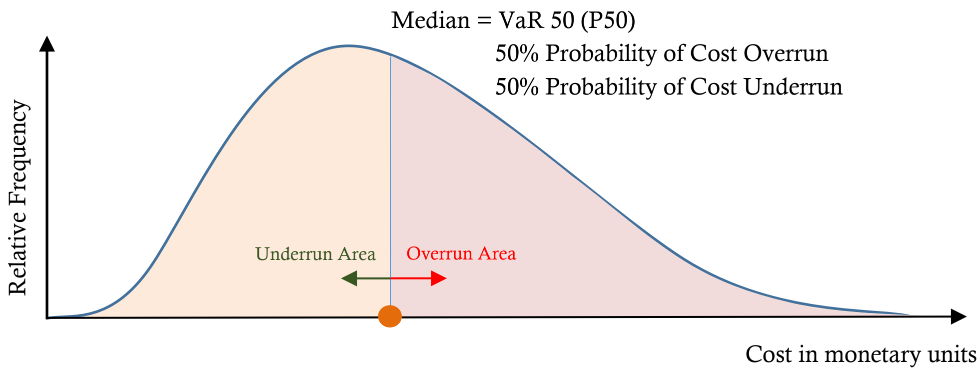

Figure 7: Representation of median value (50% probability of underrun, 50% of overrun)

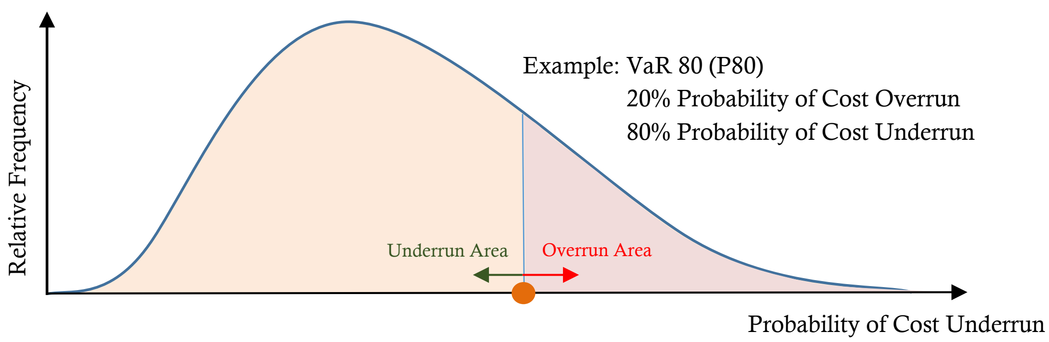

Figure 8: Representation with an 80% probability of underrun and 20% of overrun

5 Cost Management

During the construction phase, cost management requires periodic checks of the estimated project costs. Cost prediction as a whole must be updated taking into consideration the results of the tender procedures and the changes in the services required during execution. Project costs, then, consist of the actual costs for services that have already been delivered and predicted costs for services yet to be performed, an appropriate risk provision, and the costs pursuant to the prospective value adjustment for escalation until the end of the construction phase.

Cost monitoring in the construction phase, and the actual costs as part of project costs, are not the object of this guideline.

6 Final Accounting

Once the project has been completed and after all final invoices have been accepted, the total project costs (actual, out-turn costs) will be determined and defined.

The result is the basis for the subsequent management and amortisation of the infrastructure and is used to assign a value to the infrastructure in order to obtain cost benchmarks.

7 Bibliography

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8 List of Tables

9 List of Figures

10 Annex

10.1 Checklists for Further Breakdown of Cost Groups

1 Project Management

- Project auditing
- Project direction
- Project guidance

2 Land Acquisition

- Assessment property acquisition, land acquisition, servitudes
- Expropriations
- Reimbursement for spoil
- Drawing up of agreements
- Drawing up of partition plans
- Use of land in the prospection phase
- Land acquisition
- Expert opinions concerning hunting, forestry, fishing, impacts on wildlife
- Expert opinions and authentications
- Expert opinion on pecuniary damages e.g. water rights
- Notary's fees
- Property acquisition
- Attorneys' fees
- Servitudes
- Costs for trustee services
- Agreements with infrastructure owners (companies)
- Agreements with fire fighters
- Agreements with municipalities
- Agreements with private companies
- Agreements with transport carriers
- Registration in land registry after final topographic measurements

3 Planning Services

- Planning of construction works
- Basic planning of construction works
- Preliminary planning of construction works
- Draft and approval planning of construction works
- Tender planning of construction works
- Executive planning of construction works
- Survey and assessment of construction works once built
- Documents for subsequent work concerning construction works
- Conceptual planning of equipment and outfitting systems
- Basic planning of equipment and outfitting systems
- Preliminary planning of equipment and outfitting systems
- Draft and approval planning of equipment and outfitting systems
- Tender planning of equipment and outfitting systems
- Executive planning of equipment and outfitting systems
- Survey and assessment of equipment and outfitting systems once built
- Documents for subsequent work concerning equipment and outfitting systems
- Conceptual planning of environmentally relevant measures
- Basic planning of environmentally relevant measures
- Expertise for tender procedures
- Altitude model data
- Preliminary planning of environmentally relevant measures
- Draft and approval planning of environmentally relevant measures
- Tendering planning of environmentally relevant measures
- Executive planning of environmentally relevant measures
- Survey and assessment of environmentally relevant measures once built
- Documents for subsequent work concerning environmentally relevant measures
- Expert opinions as prescribed by §31a
- Construction management as prescribed by §40
- Runoff calculation
- Acceptance tests
- Aerodynamics and tunnel climate
- Airborne Laser scanning
- Accompanying architectural planning of structures
- Tender preparation and offer evaluation
- Geological documentation, consulting, planning and elaboration
- Calculations in construction physics
- Preliminary construction planning
- Requirement analyses
- Calculation of power consumption in the operational phase
- Calculations for operational management
- Calculations of capacity utilisation rate
- Database for requirements of notifications
- Consulting services in cement technology
- Work regulations for technical systems
- Economic assessment
- Evaluation archaeological artefacts
- Evaluation of war relics
- Geomechanical expertise (soil mechanics)
- Geomechanical laboratory tests (soil mechanics)
- Database for hydrogeological, geological, ventilation measurement values etc.
- Detailed analyses for subsoil modelling
- Documentation requirements of notifications
- Simulations of breakthrough errors
- Obtaining basic data
- Analysis of earthquake intensity
- Local enquiries (e.g., fish, macrozoobenthos, phythobenthos, flora, fauna)
- Elaboration of design principles
- Elaboration and adaptation emergency folder
- Geomechanical expertise (rock mechanics)
- Geomechanical laboratory tests (rock mechanics)
- Geomechanical special procedures on fault rocks
- Forest ecology planning
- Geodetic basic data
- Geo-information systems
- Geophysical prospection of fault zones
- Geotechnical experts
- Elaboration of an overall time schedule
- Total economic evaluation
- GPS reference network test

- Hydrogeological documentation, consultancy services, planning and elaboration
- IOP-tests
- Cadastre data
- Acceptance documents
- Cost for tender procedure or public order publication
- Cost calculations
- Cost verifications
- Prescribed costs due to authorization procedures
- Laboratory tests
- Life-Cycle-Cost calculations
- Analysis of aerial photos
- Disposal plan for spoil
- Nature conservation planning
- Ecological planning
- Orthophotographs
- Planning management
- Planning and construction coordination
- Swelling test
- Regional economic assessment
- Reproduction of planning documents
- Risk analyses for the construction and operational phases
- Risk analyses cost determination
- Safety plans
- Simulated calculations (e.g., ventilation, smoke extraction, electrical fire, evacuation)
- Software developments
- Static calculations and construction planning
- Morale analyses
- Tunnel and surface seismology
- Route planning
- Tectonic and structural geology analysis
- Structure design services
- TSI evaluation per phase
- Experts on tunnel construction
- Tunnel safety concept
- Analysis of the influence of alternating current on gas pipelines
- Analyses concerning water resources
- EIA expert fees
- Variant analyses
- Transportation analyses
- Expertise on Transportation safety
- Transportation assessment
- Economic assessment
- Water balance management
- Central project folders

*Note: Evaluation must be done per phase and system and/or measure

4 Monitoring

- Waste analysis
- Waste chemical analyses
- Asphalt testing
- Accompanying surveys during construction
- Preparatory construction work surveys
- Accompanying geotechnical testing during construction
- Concrete testing
- Monitoring of streets, real estate, installations
- Borehole tests
- Borehole topography
- Chemical analysis
- Detailed survey and inventory of pre-existing structures
- Fish stock saving and fish stock survey
- Extraction of frozen ground core samples
- Geophysical measurements
- Bedload analysis
- Basic principles of spoil classification
- Hydrochemical and isotopic-hydrological analyses
- Inclinometer measurements and anchoring force measurements
- Clearance of explosive ordnance
- Climate measuring stations
- Control surveys
- Perpendicular deviation surveys
- Material testing and quality controls
- Measurement and calculation of electromagnetic fields
- Monitoring for soil management, agriculture and forestry
- Monitoring of discharge points into waters
- Monitoring of vibrations
- Monitoring of river ecology
- Monitoring of hydrogeology
- Monitoring of noise protection barriers
- Monitoring of air/dust emissions
- Monitoring of springs, wells, etc.
- Monitoring of ecology
- Level measurements
- Soil mechanics testing
- Retention samples of concrete and test structures
- Gravel testing
- Vibroscan analysis
- Concrete testing, asphalt testing

*Note: Evaluation must be done per phase and system and/or measure

5 Construction Supervision or Service Providers in the Construction Phase

- Acceptance testing of concrete, asphalt, waterproofing, etc.
- Construction management
- Construction site coordination in accordance with the Bau KG (Austrian Construction Work Coordination Act)
- Official acceptances
- Official construction supervision (water legislation, disposal site, hydrogeology, etc.)
- External accompanying inspection
- External cost management
- Geotechnical experts for in situ underground work
- Ordnance technical safety during construction
- Environmental construction supervision
- Local construction supervision for equipment and outfitting systems
- Local construction supervision for construction works
- Local construction supervision for prospection drilling
- Local construction supervision for environmentally relevant measures
- Inspecting engineer activities
- Survey services in the construction phase
- Supervisions in accordance with the water laws
- Disposal sites

*Note: Evaluation for all systems and measures

6 Construction

- Demolition work
- Waterproofing measures
- Waste disposal to external disposal sites
- Sedimentation pools
- Equipment for rest areas
- Platform equipment and outfitting
- Railway transport
- Construction site offices
- Land clearing
- Ground improvements
- Construction site communication
- Construction site set-up areas
- Construction site clearing
- Construction site security
- Construction electricity supply
- Construction electricity supply
- Structures for substitute water supply
- Plantings
- Coatings
- Signage
- Visitor centre
- Operations and ventilation building
- Operations building
- Ground markings
- Piling walls
- Bridge structures
- Roofing works
- Dam structures
- Construction for disposal sites
- Jet grouting with experimental tests
- Disposal of excavated material and concrete
- Prospection work
- Substitute water supply
- Vibration protection measures for the construction phase
- Vibration protection measures for the operational phase
- Fiber optical measuring systems
- Channel regulations
- Water treatment facilities
- Water treatment facilities
- Digging activities and laying work
- Basic cleaning
- Foundations
- Aboveground structures
- Info centre
- Info points
- Injection measures
- Injection testing fields
- Landscaping projects
- Noise and vibration protection
- Noise protection structures for the construction phase
- Noise protection structures for the operational phase
- Ventilation systems for the construction phase
- Ventilation buildings
- Construction site safety measures
- Auxiliary facilities
- Auxiliary buildings
- Emergency stop, floors, walls, doors, interior outfitting
- Superstructure
- Pilot tunnels
- Portal cuts
- Cross passages floors, walls, doors
- Tire washing facilities
- Recultivation
- Dismantling of construction works
- Holding basins
- Forestry works
- Barrier systems
- Steel structures
- Road and path network for the construction phase and the operational phase
- Road equipment
- Supporting structures
- Transformer building
- Tunnel constructions
- Tunnel coating
- Substructure
- Transportation signs
- Surveying pillars and ground points
- Preliminary works
- Preliminary works for ground-breaking
- Trench construction
- Water and brook control, avalanche barrier construction
- Access control for the construction phase

*Note: project specific

7 Equipment and Systems

- 50 Hz Energy systems
- Dismantling, upgrading and conversion of existing systems
- Axis control measurements
- Adjustment of existing software
- Lifts
- Fire Brigade Equipment
- Equipment for the surveillance centre
- Equipment logistics
- Railway equipment and outfitting
- Electrical traction systems
- Electrical systems
- Power supply systems
- Electrical grounding works
- Telecommunications
- Remote control engineering
- Ballastless track
- Radio equipment
- Building services
- Heating, air conditioning, ventilation, sanitary systems
- Communication devices
- Cooling
- Control engineering
- 20KV, 30KV, 110KV, 220KV cables
- Lighting systems
- Light mass-spring system
- fire extinguishing water supply pipes
- Ventilation systems for the construction part of the equipment and outfitting phase
- Ventilation systems for the operational phase

- Fitting and wiring works
- Network provision and network access current
- Low-voltage installation circuits
- Contact wire
- Rescue equipment
- Dismantling equipment and outfitting systems
- Switchgears
- Rails
- Cabinets for technical systems
- Security systems
- Safety installations
- Signaling and systems technology
- Signal box
- Road outfitting
- Technical equipment systems for roads
- Telecommunication systems
- Tunnel painting
- Doors
- Switch system
- Switch heating
- Train running checkpoint
- Train pre-heating systems

*Note: project specific

8 Environmentally-Relevant Measures

- Amphibian protection
- Accompanying measures
- Humid biotopes
- Ecological measures over large areas
- Ecologically functional measures
- Ecological rebalancing measures
- Protective measures for historical monuments

* Note: project specific

9 Start of Operations *

- Fire tests
- Obtainment of decree for the start of operations
- Start of operations of the entire system
- Ventilation tests
- Planning for the start of operations
- Planning of single system and whole system control procedures
- RAMS evidence
- Exercises for intervention units

* Note: project specific

10 In-house Services

- Supply of locomotive(s)
- Supply of road equipment
- Company in-house services
- Material supply
- Planning services in-house
- Look-outs
- Transportation safety measures by the highway maintenance agencies

11 Public Relations Services

- 3D-Videos
- Agency services
- Arrival plans
- Construction documentation with Webcam and orthophotography
- Construction signage
- Surveying flights
- Population polls
- Accompanying public relation services during the construction phase
- Accompanying public relation services during the construction phase -activity plan
- Supply of project information, brochures, DVDs, etc.
- Catering
- Photographic documentation
- Give-aways
- Info- and visitor management
- Information films
- Information events
- Print media insertions
- Conferences
- Fair stands
- Models
- Modelling activities
- Ombudsman
- Visitor safety equipment
- Ground breaking ceremony
- Visual aids

12 Other Items

- Construction - technical expert activities
- Hearing members
- Legal assistance during construction work
- Legal assistance for authorization procedures
- Legal assistance for tender procedures
- Legal opinions
- Expert services
- Sureties or coverage for disposal sites

10.2 Appendix to the Section "Benchmark Method"

The following two templates may be used:

- Risk Fact Sheet Project
- Diagram to determine the additional lump sum mark-up for risks

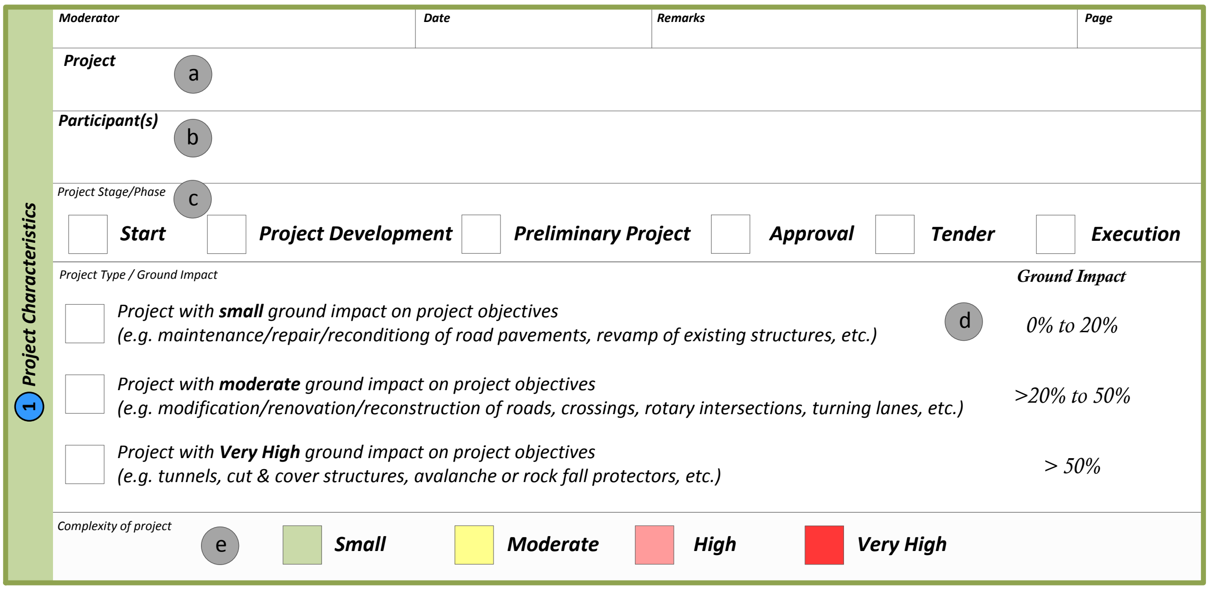

Figure 9: Data Sheet for the Benchmark Method

a **Project Name & Description**

b **Risk Team Participants**

c **Project Phase according to Section 3.2**

d **Impact of Ground Conditions**

e **Estimate of Project Complexity**

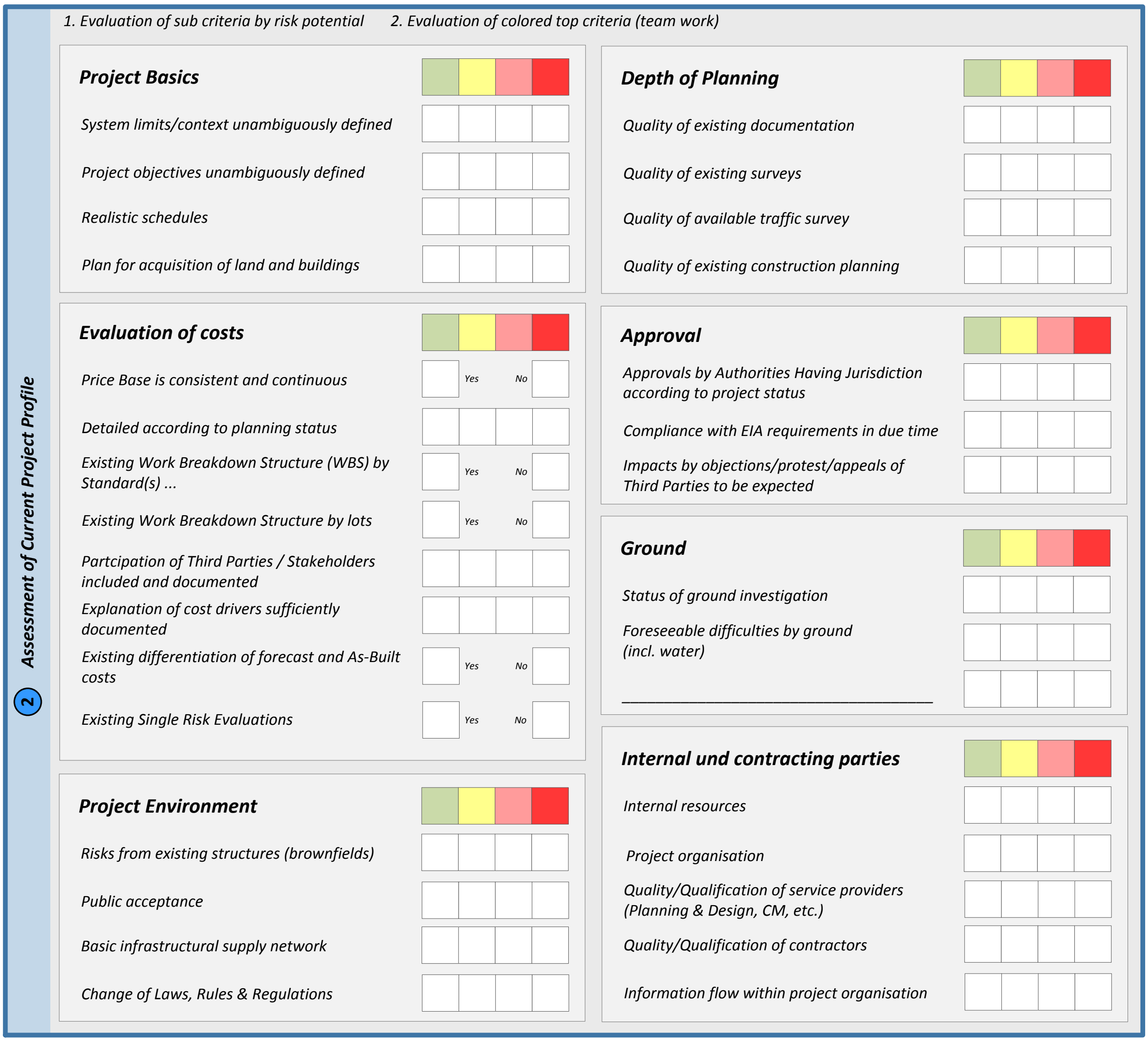

Figure 10: Data Sheet for the Evaluation of the current Project Profile

Procedure to evaluate the current project profile following certain evaluation criteria:

- 1. Step: Evaluation of the subcategories (white fields)
- 2. Step: Evaluation of the main categories following a summary evaluation of the sub-categories by the team (coloured fields)

Data Sheet for Benchmark Method

Figure 11: Data Sheet to identify Single Risks

Procedure to identify single risks:

- Brief verbal description
- Assessment of risk relevance

Note: In case of subsequent single risk analysis, single risks will be analysed and assessed with a greater degree of detail using the data sheet for single risks (10.3).

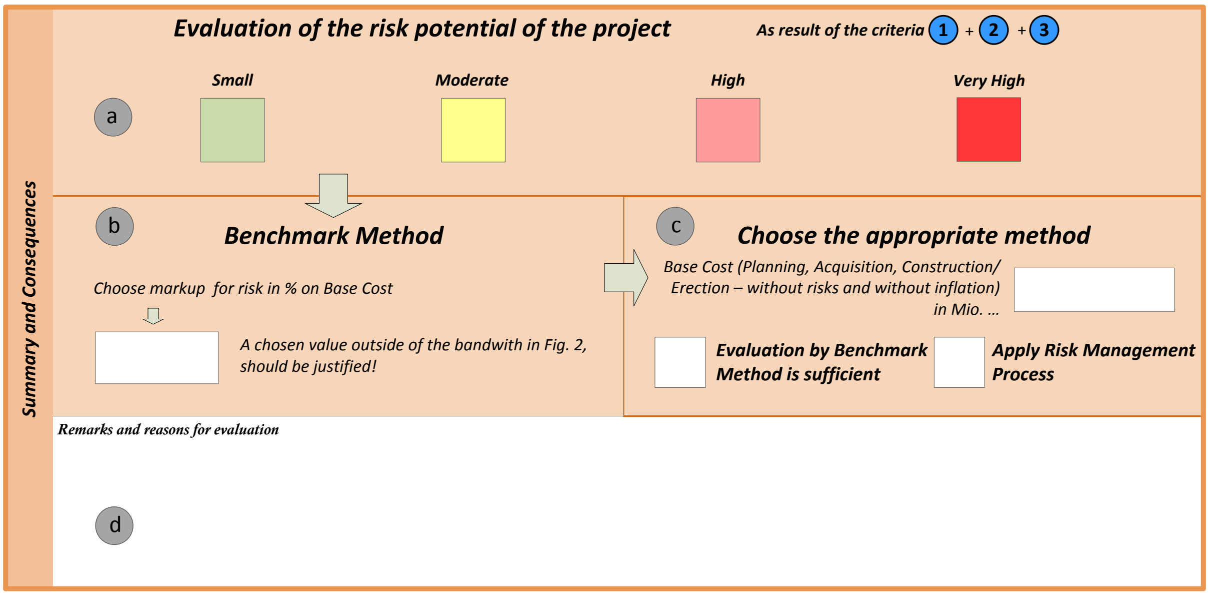

Figure 12: Data Sheet to assess the Project Risk Potential

a **Assessment of the project's risk potential**

together with the evaluated aspects

- Project Characteristics

- Project Profile

- Single Risks

b **Application of the Benchmark Method**

c **Decision as to whether the benchmark method is sufficient or if a method using single risk evaluation should be subsequently applied**

d **Reasons for the decision**

10.3 Appendices to the Section "Risk Identification and Characterization of Individual Risks"

10.3.1 Risk Identification

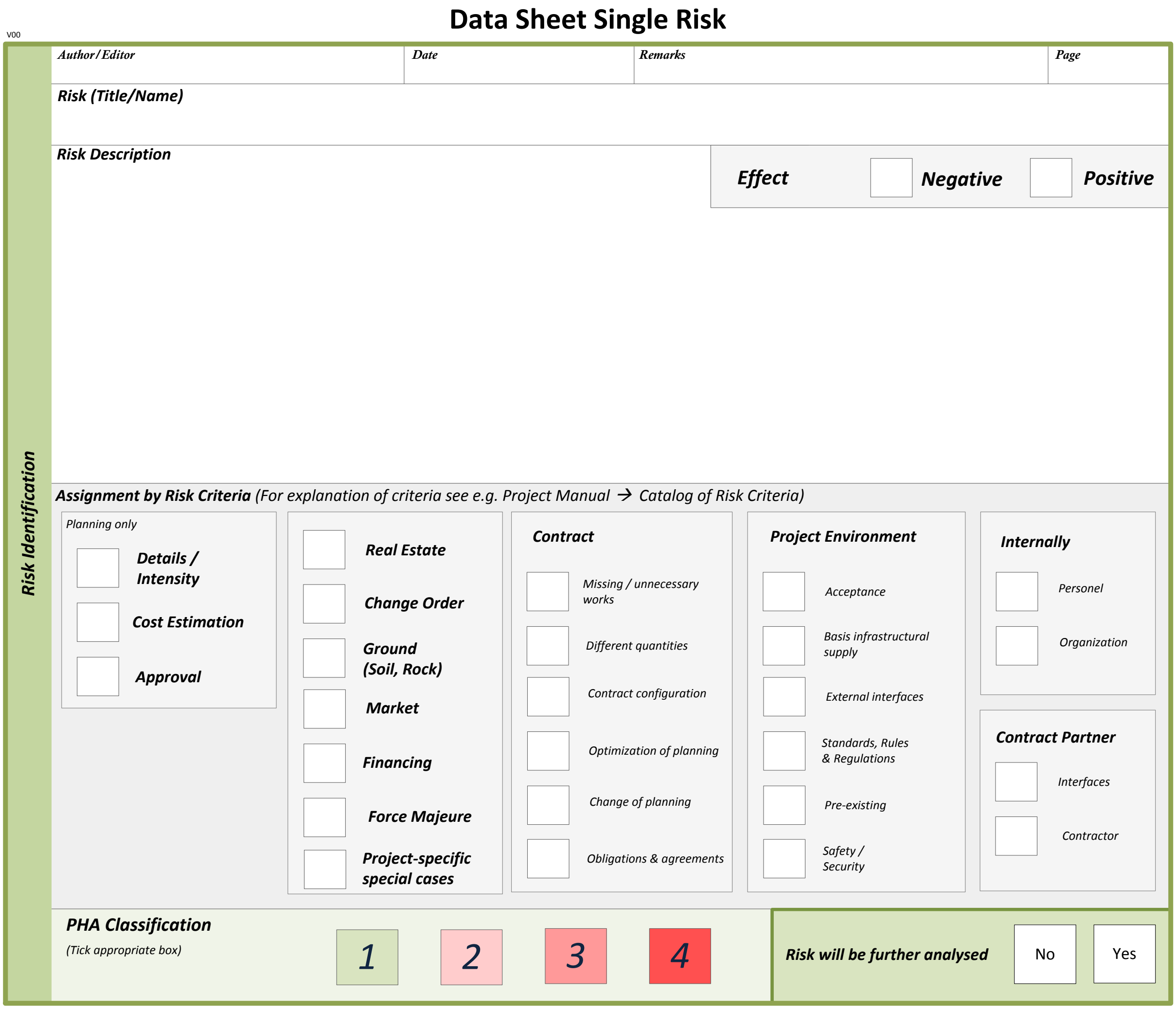

Figure 13: Pre-Classification of Single Risk

Workflow:

1. Several methods can be used for risk identification. Some recognized methods are brainstorming, 6-3-5 brainwriting method, and brainwriting pool.
2. Basic data registration: Administrators, Recorders (one or more), data and notes.
3. The identified single risks will be described verbally. Thereby, one has to refer specifically to the scenario and its causes. General descriptions have to be avoided.
4. Risk Categories will be assigned according to the table "Risk Categories."
5. Pre-Classification

The Preliminary Hazard Analysis (PHA) is a certified method (see IEC/ISO 31010) adopted specially for the classification of risks in early project phases. The aim is to identify the relevant risks. On the basis of the results, resources and further analysis methods can be applied to the relevant risks in a focused manner. The procedure can be summarized as follows:

- Listing of risk scenarios
- Classification of risk scenarios
- Decision as to which threats will be analysed in-depth as risks
- Documentation of the results

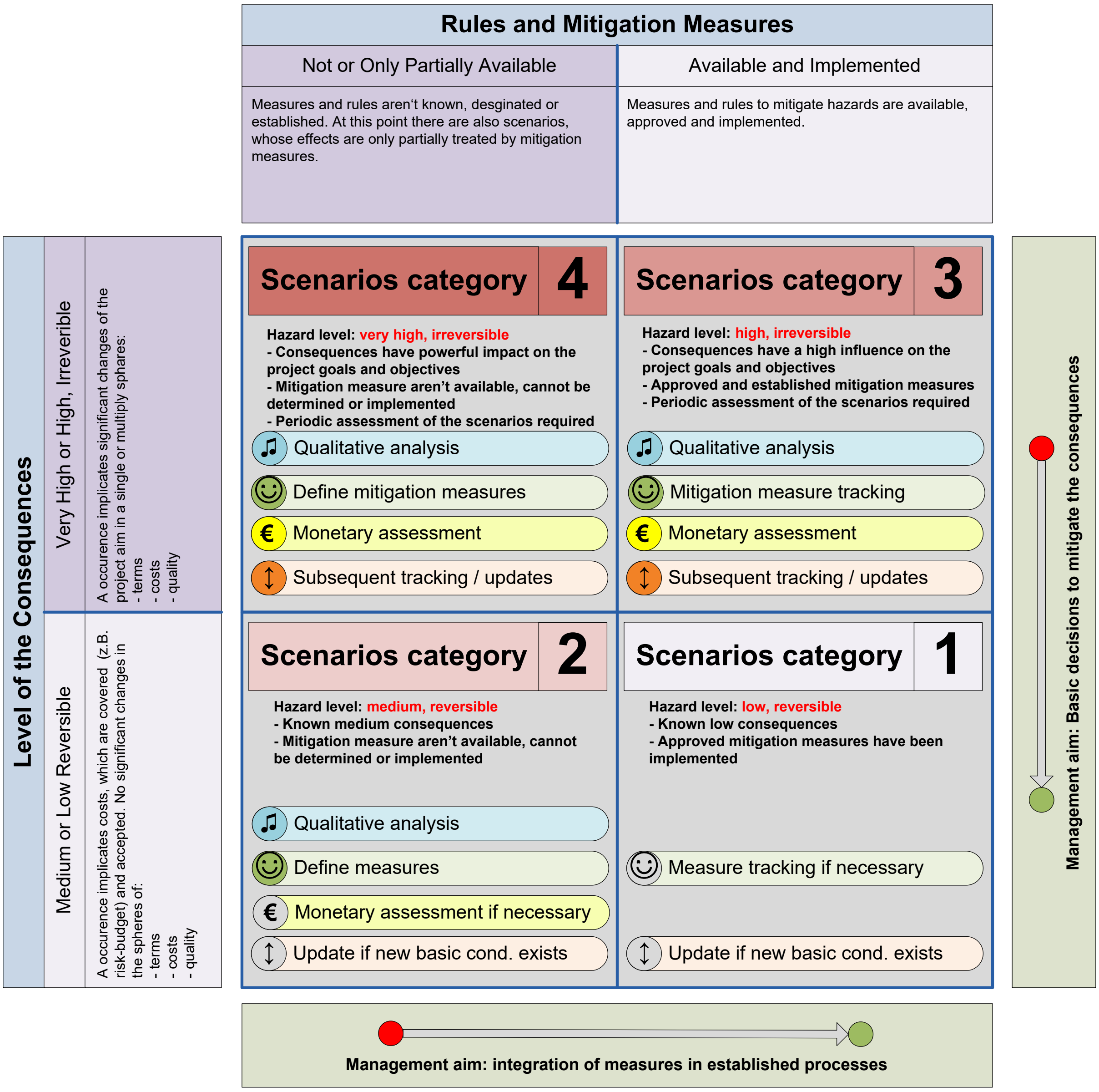

Figure 14: Classification of Risk Scenarios (Preliminary Hazard Analysis Matrix)

Based on the result of the PHA, a decision will be made whether to evaluate the risk in greater detail.

10.3.2 Qualitative Risk Analysis

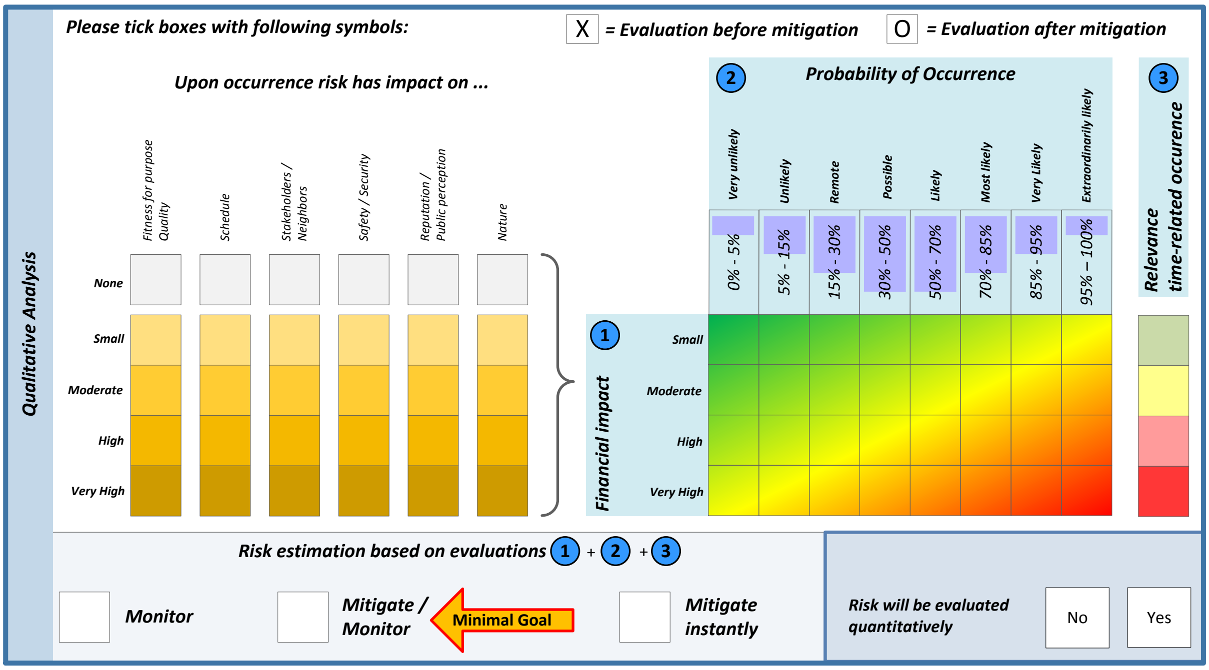

Figure 15: Data Sheet for Qualitative Analysis of Single Risks

Workflow:

1. Qualitative analysis should be done before measures are implemented. Therefore, an "X" is used to select evaluation before mitigation.
2. First of all, the implications of risk occurrence on the six categories of Fit for Purpose, Schedule, Involved Parties/Neighbouring Communities, Safety/Security, Reputation/Public Relations and Environment should be evaluated.
3. Together for all these six categories, the
   - Monetary impacts have to be evaluated and
   - Probability of occurrence has to be assessed and
   - Urgency should be evaluated.
4. From an overview of the above mentioned three evaluations, risk should be assessed as a whole as:
   - Act immediately
   - Act/Monitor
   - Monitor only
5. Once measures have been implemented (in following steps), the evaluation should be performed again in a similar way in a second walk-through. There, an "O" will be used to select evaluation after mitigation.
6. Once measures have been defined, all risks categorized as "to be handled immediately" should be lowered at least by one level.

10.3.3 Quantitative Risk Analysis

Data Sheet Single Risk

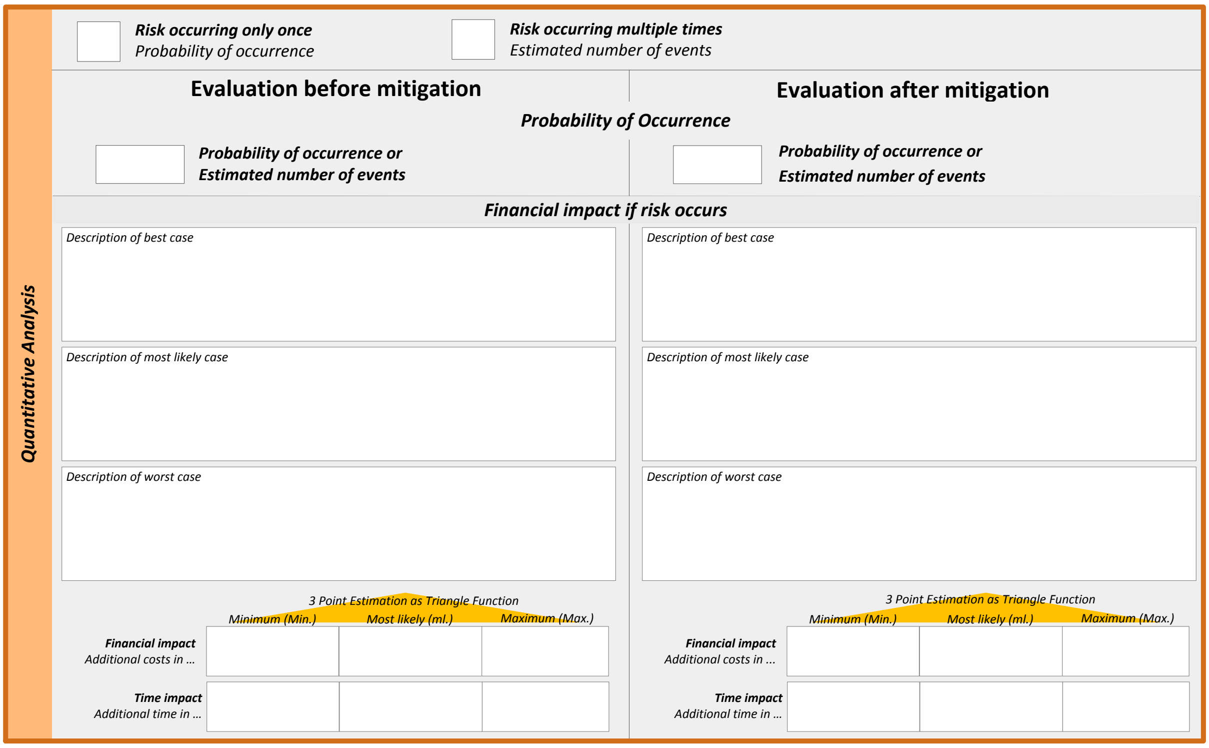

Figure 16: Risk Fact Sheet for Single Risks for Quantitative Analysis

Workflow:

1. Indicate whether a risk occurs just once or multiple times.
2. Fill in the left column: Evaluation before mitigation.
3. Probability of occurrence should be assessed. For single risks, the percentage of the qualitative analysis can be used. In case of risks occurring multiple times, the number of events should be estimated.
4. With regard to monetary impacts – in case of risk occurrence – each risk case should be described verbally (best case, expected case, and worst case).
5. After the verbal description, monetary and time impacts should be indicated using a 3-Point-Estimate (best case, expected case, and worst case):
6. Using the probabilistic method, impacts will be determined indicating three values (in currency units), for example, by a triangular distribution (minimal impact, expected or most probable impact, maximum impact).
7. Once measures have been implemented, the right-hand column, for evaluation after mitigation, should be filled in in a similar way in a second walk through.

10.3.4 Proactive Measures

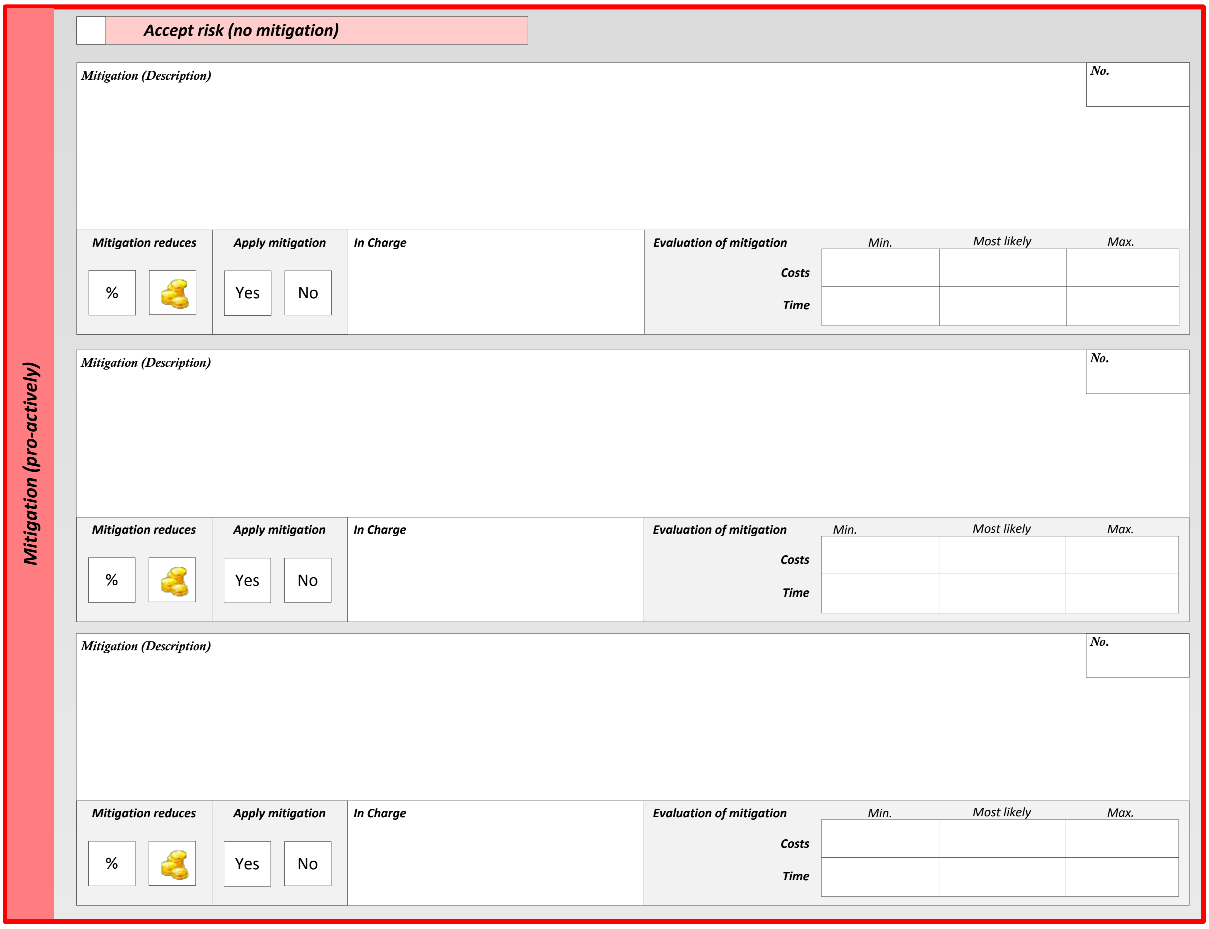

Figure 17: Risk Fact Sheet for Single Risks for Planning of Measures

Workflow:

1. After qualitative and quantitative evaluation before measures, appropriate measures have to be defined in order to minimize or completely eliminate the risk. The Risk Fact Sheet for Single Risks provides space for up to three measures.
2. The measure should be described exactly.
3. Indicate whether a successful implementation of the measure influences the probability of occurrence or the effects on timing and costs – or both.
4. Indicate whether the measure(s) should be implemented or not. In most cases this decision can only be taken at the end of the completed analysis.
5. A responsible person for each measure should be nominated. Measure updates should be documented periodically within the risk-management-process.

10.4 Definitions

The definitions used below have largely been taken out of the literature referenced in Section 7.

Allowances on Base Cost	An additional amount added to a cost estimate to cover those components of a project that are expected, based on the knowledge of the project, but have not yet been described or estimated in detail.
Base Cost (B)	The base cost is that cost which can reasonably be expected if the project materializes as planned, with a defined content, schedule and market situation. The base cost estimate is to be neither optimistic nor conservative and does not normally include price and quantity variability. The base cost estimate does not include contingency or the cost of potential risk events or escalation. Prices normally used are current values but can be stated at a specific price and date basis.
Contracting Authority	A person or legal entity who contracts, or intends to contract, with another party (the contractor) to deliver services for reimbursement and is authorized to enter into such a contract.
Contractor	Any person or legal entity with which a contracting authority signs a contract to deliver services for which they will be compensated.
Cost	Expenses that the Owner or Contractor will incur in the delivery of a project. From a general economic point of view, the evaluated and quantified use of resources to obtain goods and or services. In project development, costs are defined (as opposed to a macroeconomic cost-benefit analysis) as a monetary use of services, supplies, and goods required to implement the project. Depending on the type of entity, taxes and other fees may be included in costs.
Cost Actual	Costs recorded up to a certain date, under a cost centre or cost unit.
Cost Coefficient	The ratio of applicable cost(s) to a measurable unit of reference (such as length, base area of land, capacity, cost areas, elements, services).
Cost Components	Elements that make up a cost. These can include base cost, cost for value adjustment and indexation, cost for risk, and escalation.

Cost Estimation	The process of aggregating all relevant cost, including base cost, allowances, escalation, consequences of potential risk events, and other expected costs of a project.
Cost of Financing	Cost involved in obtaining the necessary funding for a project, but not the funds themselves.
Cost Project (Predicted)	A quantitative assessment of a likely amount or outcome in monetary terms required to reach defined project goals. Such costs can include project management, auditing, bookkeeping, project information management, planning, project-related procedural costs, expertise, construction, construction management, land management, land acquisition – whether in-house or outsourced – and cost factors for risks and escalation.
Cost, Planning	Costs estimated or incurred in the planning phase.
Cost, Preliminary	A number which defines estimated project costs determined in the project development phase.
Escalation (E)	The total annual rate of increase in the cost of work elements or sub-elements. Escalation includes the effects of inflation plus market conditions and other similar factors.
Estimated Cost	A quantitative assessment of a likely amount or outcome in monetary terms (PMI def).
Inflation	A persistent tendency for prices to increase, measured by proportional changes over time relative to an appropriate price index.
Invitation to Tender	A document, published by a contracting authority to a selected, invited, or solicited number of companies, in which the contracting authority defines services to be provided under a contract with conditions for the provision of such services.
Maintenance	Those activities to maintain or restore systems to a proper state (performance, safety, etc.). Maintenance does not imply an improvement as compared to the system when new.
Owners estimate of Project Cost	The owner's estimate of project cost defines the project cost estimated before publication for the tender phase.
Price Basis/Base	Reference point in time for the price level on which costs are based.

Project Scope	The elements of a project that are to be produced or secured to reach defined quality, cost, and time objectives.
Risk	The combination of the probability and consequences of a potential event, should it occur. Risk consequences can be positive (opportunities) or negative (threats).
Risk Cost (R)	The cost component that covers the monetary aspect of a risk. Costs can be positive (opportunities) or negative (threats).
Risks Identified	Identified risks include potential events, which have a probability and consequence (positive or negative), that are not part of the base, and which may eventuate during the project or a specific phase of the project. Risks are usually identified by experts in a risk workshop.
Unknown Risk Costs	All risk costs that are not identifiable or were not identified in the respective project phase.
Value Adjustment and Indexation (I)	A methodical approach to take into account a variation in market prices that has already occurred by a certain reference date. Value adjustment governs the pre-contract phase and indexation is used in the contract phase.
Value at Risk (VaR)	Probability of not exceeding a certain value within a distribution. That value (for example, € or $) corresponding to a specific probability within a probability distribution.
Work Breakdown Structure (Project Structure)	A framework of project elements defining important relationships between such elements that can be set up with multiple hierarchical levels (for example, based on construction steps, on structures, or on organizational functions).

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